Ranking Teams*

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Abstract

A principal wishes to rank and reward teams in an organization, modeled by cliques in a graph. Agents in the organizational network perfectly observe the local ranking of their teams, and strictly prefer being on higher-ranking teams. I show that the only organizations in which the principal can always extract a complete ranking of teams are those where every pair of teams shares an agent in common. Unless the organizational network is a star, there is no ex-post incentive compatible and efficient mechanism that ranks every team. By considering a subset of teams, the set of admissible organizations can expand.

Keywords: peer mechanisms, social networks, teams, organization design.

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1 Introduction

Collaboration and teamwork are at the heart of organizational structures. Team-based rewards, which can take the form of project-specific compensation, profit-sharing, and one-time team bonuses,[1] have become widespread in corporate incentive schemes.[2] In addition to this, it is increasingly common for individuals to work on multiple teams within the same organization.[3] Beyond corporate settings, there are numerous situations where individuals can belong to different teams that compete against each other for a prize: a manager wants to identify the hardest-working teams in her department; a teacher wishes to reward the most collaborative groups of students in the classroom; a conference aims to recognize the most prolific co-authors in a field. Succinctly, these situations all share the following characteristics: (i) A principal is interested in ranking and rewarding teams, rather than individuals, (ii) Agents can be in many teams at once, and (iii) Agents benefit from being on higher-ranking teams.

When can the principal obtain a complete and honest ranking of the teams in her organization? And how does the structure of the organization affect the principal's ability to design a desirable ranking mechanism? The existing literature on peer mechanisms has exclusively considered comparing individuals.[4] In the standard setting, agents may be asked to evaluate, nominate, or rank their peers in order to determine the allocation of a prize. For instance, if agents are asked to rank their neighbors in a social network, Bloch and Olckers (2022) show that a principal can design an incentive compatible peer ranking mechanism for a fairly large class of networks. A natural question, therefore, is whether similar results can be obtained when the focus is shifted from individual rankings to team rankings.

In this paper, I consider the problem of a principal who wants to rank every group of co-workers in an organization, represented by cliques (complete subgraphs) in an organizational network. More specifically, she wishes to get a complete ranking of these teams based on a single unobservable characteristic, such as work ethic, potential, productivity, or financial need. To do so, she asks each agent to report a ranking of his teams. Agents in the organizational network perfectly observe the local ranking of the teams they are in, and strictly prefer being on higher-ranking teams in order to receive

[1] For several decades, a vast body of empirical research in management science and organizational psychology has advocated for the use of adequately designed team-based rewards (DeMatteo et al., 1998; Lawler and Cohen, 1992). In settings where production is highly interdependent, team-based rewards can enhance performance (Boning et al., 2007; Friebel et al., 2017; Englmaier et al., 2024), promote motivation (Garbers and Konradt, 2014), and increase pro-social behavior between team members (Bamberger and Levi, 2009).

[2] "The University of Southern California's Center for Effective Organizations indicates that 85% of Fortune 1000 companies used team-based pay to some degree in 2005, up from 59% in 1990" (Merriman, 2008)

[3] "Research estimates that between 81% and 95% of employees around the world actively serve on multiple teams simultaneously." (Smith et al., 2018)

[4] See Olckers and Walsh (2024) for a comprehensive survey on peer mechanisms spanning economics and computer science.

a greater reward.[5] If aggregating reports fails to yield a complete ordering of teams, the mechanism completes the partial order by arbitrarily ranking the remaining teams.

To simplify the analysis, I begin by identifying all network structures in which aggregating local comparisons results in a complete ranking of teams for any realization of team characteristics, and refer to such graphs as *clique informative.* My first result states that this condition is satisfied if and only if every pair of teams in the organization shares an agent in common. An equivalent characterization shows that clique informativeness is only satisfied by two networks: the triangle and the star graph.

The main result, Theorem 1, states that unless the organizational network is shaped like a star, there is no ex-post incentive compatible and efficient mechanism that ranks every group of co-workers. The key insight is that if agents are indifferent to permutations of their teams' ranks, they may be willing to decrease one of their teams' ranks if it leads to a more-than-proportional increase in another of their teams' ranks. Concretely, agents can manipulate the ranking either by completing an incomplete order, or by creating an incompletion and causing an arbitrary ranking of teams in the agent's favor. Notably, this type of misreporting differs from manipulation in individual peer evaluation problems, where agents typically have a direct incentive to exaggerate their ranking relative to their neighbors', as well as an indirect incentive to under-evaluate agents who are likely to win the prize.

Two extensions are considered. First, I ask what would happen if instead of assigning better prizes to higher-ranking teams, the principal gave identical prizes to the k highest-ranking teams. Faced with this type of mechanism, an agent now attempts to maximize the number of winning teams he is on. Despite this change in incentives, I show that adopting a coarser ranking leaves Theorem 1 essentially unchanged. Next, I relax the principal's objective by considering mechanisms that rank an arbitrary subset of teams in the organization. One advantage of this approach is the potential increase in overlapping team comparisons, which aids the principal in the construction of truthtelling incentives. On the flip side, the same organizational network can now be associated with multiple configurations of teams, making the analysis considerably less tractable. Nevertheless, I identify two simple sufficient conditions for the existence of a team ranking mechanism that are likely to be met by many real-world organizations: either there exists an agent who is a member of every team (a supervisor, or manager condition), or, whenever two teams share an agent in common they share at least two agents in common (a collaboration condition). The latter of these conditions ensures that every comparison is made by multiple agents. Intuitively, this allows the principal to verify that an agent's report matches his colleague's and to punish him otherwise.

Related Literature. This paper directly contributes to an emerging literature at the intersection of peer evaluations and social networks, in which agents can only evaluate those they share a connection with (Baumann, 2023; Baumann and Dutta, 2022; Babichenko et al., 2020; Bloch and Olckers, 2021, 2022). Within this literature,

[5]Even in the absence of monetary rewards, the disclosure of team rankings in an organization can have a significant effect on the behavior of teams and individuals (Bandiera et al., 2013).

I largely follow the approach in Bloch and Olckers (2022), where a principal wishes to extract a complete and ordinal ranking of agents in a social network. Their main result states that a mechanism exists if and only if every pair of friends has a friend in common. By contrast, I exclusively consider the problem of ranking *teams* of agents. By treating cliques rather than nodes as the main object of interest, I obtain considerably fewer informative networks than those found in Bloch and Olckers (2022). More surprisingly, I show that the star graph is the unique network that admits a desirable team ranking mechanism, a strong negative result when contrasted with friend-based rankings.

More broadly, this paper is conceptually related to the literature on impartial peer mechanisms initiated by Amorós et al. (2002), De Clippel et al. (2008) and Holzman and Moulin (2013) in economics, and Alon et al. (2011) in computer science. Thematically, this literature encompasses a wide range of design issues, including the analysis of peer nomination rules (Fischer and Klimm, 2014; Tamura and Ohseto, 2014; Mackenzie, 2015; Edelman and Por, 2021), peer grading systems (De Alfaro and Shavlovsky, 2014; Kurokawa et al., 2015; Aziz et al., 2016, 2019; Dhull et al., 2022), and most pertinent to us, peer ranking mechanisms (Kahng et al., 2018; Xu et al., 2019; Stelmakh et al., 2021; Alcalde-Unzu et al., 2022; Lev et al., 2023; Amorós, 2023; Cembrano et al., 2023). While the majority of these works consider strategy-proof mechanisms, I find that even ex-post incentive compatibility cannot be sustained in most networks, suggesting large differences in the incentive environment. To the best of my knowledge, this is the first paper to consider situations where agents evaluate their teams rather than their peers.

2 Model

A finite set of agents $N = \{1, 2, ..., n\}$ with $n \geq 3$ is organized in a connected and undirected graph g whose structure is common knowledge, and we write $g_{ij} = 1$ if agents i and j are linked. Denote by $N_i = \{j \in N \mid g_{ij} = 1\}$ the set of agent i's neighbors, or colleagues, and let $d_i = |N_i|$ be the degree of agent i. Next, let $\mathcal{C} = \{C_1, ..., C_m\}$ be the set of all cliques (complete subgraphs) in g with two or more nodes. For the remainder of the paper, I will refer to each element of $\mathcal{C}$ as a team of co-workers. Abusing notation, we can write $i \in C_j$ if agent i is a node in team C_j, and define $\mathcal{C}^i = \{C_j \in \mathcal{C} \mid i \in C_j\}$ as the set of teams that agent i belongs to. By connectedness of g we have $d_i \geq 1$ for every $i \in N$, and since connected pairs make up the smallest teams this implies that every agent is part of at least one team.

Each team C_j possesses a single characteristic of interest, $\delta_j \in \mathbb{R}$, and I assume that there are no ties: $\delta_l \neq \delta_m$ for any distinct teams (C_l, C_m). Concretely, δ_j could represent a team's synergy, work-ethic, or financial need. Conceptually, a team's characteristic can be entirely distinct from the characteristics of the agents in the team. For instance, a team may surpass another in its share of skilled agents while being less productive due to a lack of chemistry.

The analysis is completely ordinal. Each agent does *not* directly observe the characteristics of his teams, but perfectly observes the *local ranking* of his teams. For any agent i and any pair of teams (C_l, C_m), let $t^i_{lm} = 1$ if agent i observes $\delta_l > \delta_m$, $t^i_{lm} = -1$

if he observes $\delta_l < \delta_m$, and $t^i_{lm} = 0$ if he cannot compare teams C_l and C_m. The last scenario can arise if agent i is part of team C_m but not C_l, C_l but not C_m, or neither C_m nor C_l. Agent i's type is summarized by the matrix $T^i = [t^i_{lm}]$. Aggregating these matrices across agents, the vector $\mathbf{T} = (T^1, ..., T^n)$ contains all the information available on team rankings in the organization. Based on $\mathbf{T}$, one can define a partial order as follows: $C_l \succ_{\mathbf{T}} C_m$ if $t^i_{lm} \neq -1$ for all agents i, there is no sequence of comparisons indicating $\delta_m > \delta_l$ by transitivity, and there exists either an agent i reporting $t^i_{lm} = 1$ or a sequence of comparisons indicating $\delta_l > \delta_m$ by transitivity.

A deterministic *team ranking mechanism* is a pair $(\mathbf{T}, \sigma)$ that assigns a complete ranking $\sigma \in \mathcal{S}$ to any vector of reported team rankings $\mathbf{T} \in \mathcal{T}^n$, where $\mathcal{S}$ is the set of all complete orders on $\mathcal{C}$. Mechanically, this procedure assigns a rank σ_j to each team C_j, where the worst rank is $\sigma_j = 1$ and the best rank is $\sigma_j = |\mathcal{C}|$. In a similar fashion, I define the rank of an agent i who is part of k teams as the ordered vector $\sigma^i = (\sigma_1, \sigma_2, ..., \sigma_k)$, where $\sigma_1, \sigma_2, ..., \sigma_k$ are ordered from highest ranked to lowest ranked. Given two possible ranks $\sigma^i, \tilde{\sigma}^i$, agents have strongly monotonic preferences:[6]

$$\text{if } \sigma^i \geq \tilde{\sigma}^i, \text{ and } \sigma^i \neq \tilde{\sigma}^i, \text{ then } \sigma^i \succ_i \tilde{\sigma}^i$$

Thus, an agent i prefers σ^i over $\tilde{\sigma}^i$ if the highest ranked team in σ^i is at least as highly ranked as the highest ranked team in $\tilde{\sigma}^i$, the second-highest ranked team in σ^i is at least as highly ranked as the second-highest ranked team in $\tilde{\sigma}^i$, etc. with at least one of these comparisons holding strictly. Importantly, this assumes that agents are indifferent to substitutions across their teams' ranks.[7]

It is worth noting that strong monotonicity is not required for any of the results. Rather, it is the "weakest" condition on preferences with which I am still able derive the main impossibility result. In particular, the proofs remain valid if agents have lexicographic preferences, value the minimum of team ranks, the sum of team ranks (in case of monetary prizes), or the average team rank (in case of qualitative rewards).[8]

Throughout, I consider team ranking mechanisms that satisfy the following:

Definition 1. *A team ranking mechanism σ is ex-post efficient if for any pairs of teams (C_l, C_m) and any vector $\mathbf{T}$:*

$$\textit{if } C_l \succ_{\mathbf{T}} C_m, \textit{ then } \sigma_l(\mathbf{T}) > \sigma_m(\mathbf{T})$$

Definition 2. *A team ranking mechanism σ is ex-post incentive compatible if for any agent i, any vector $\mathbf{T} = (T^i, T^{-i})$, and any alternative report $\tilde{T}^i$:*

$$\sigma^i(T^i, T^{-i}) \succsim_i \sigma^i(\tilde{T}^i, T^{-i})$$

[6]Equivalently, i prefers the unordered vector σ^i to $\tilde{\sigma}^i$ if σ^i weakly majorizes $\tilde{\sigma}^i$.

[7]This is a reasonable assumption when prizes are not divided among team members, and do not depend on group size. For instance, a principal might distribute a bonus payment to every member of a winning team, assign winning teams to more desirable projects, or supply a public good that can be enjoyed by all team members.

[8]One exception is if agents have max preferences, in which case Theorem 1 would change slightly: both the triangle and the star admit a team ranking mechanism.

3 Organizational Networks

As a preliminary question, when can a principal be sure to extract a complete ranking of teams from the local information at each agent's disposal? In the current setting, even if the principal had access to every agent's observations, she may still be unable to compare certain teams in the organization. Borrowing terminology from Bloch and Olckers (2022), I refer to a network as *clique informative* if for any realization of characteristics δ, the information in $\mathbf{T}$ results in a complete ranking of cliques.[9] As the next example shows, connectedness and informativeness are unrelated in this setting.

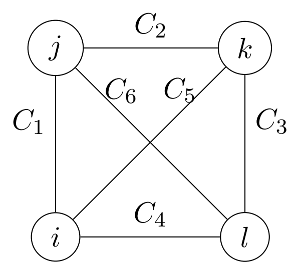

Figure 1: The complete graph K_4 is not clique informative

Example 1. A complete network need not be clique informative. Consider the complete graph in Figure 1, where $C_1, C_2, C_3, C_4, C_5, C_6$ respectively denote teams $(i,j),(j,k),(k,l),(i,l),(i,k),(j,l)$. Now consider the following realization of team characteristics: $\delta_1 > \delta_3 > \delta_6 > \delta_5 > \delta_2 > \delta_4$. Note that for clarity of exposition, we have restricted our attention to teams of pairs, omitting 3-cliques and 4-cliques. Based on each agent's information, agent i observes $C_1 \succ_{T^i} C_5 \succ_{T^i} C_4$, agent j observes $C_1 \succ_{T^j} C_6 \succ_{T^j} C_2$, agent k observes $C_3 \succ_{T^k} C_5 \succ_{T^k} C_2$ and agent l observes $C_3 \succ_{T^l} C_6 \succ_{T^l} C_4$. Overall, the information in $\mathbf{T}$ does not allow us to compare teams C_1 and C_3, teams C_2 and C_4, and teams C_5 and C_6.

The takeaway is there is no systematic relationship between connectedness and informativeness in this setting, simply because it is impossible to increase the number of edges (observations) in a graph without increasing its number of cliques (teams). The following lemma provides necessary and sufficient conditions for clique informativeness.

Lemma 1. *A network is clique informative if and only if every pair of cliques shares a node in common.*

This result is based on the fact that whenever two cliques do not share a common node, it is possible to find a vector of team characteristics for which the two cliques

[9] A similar question is discussed in Bloch and Olckers (2022), in the context of constructing a complete ranking of individuals in a social network. To ensure that aggregating local comparisons always results in a complete ordering of individuals—a property they term *completely informative*—they show that every pair of individuals in the network must either be connected or have a mutual connection.

cannot be compared.[10] As a consequence of this lemma, note that every clique informative network is completely informative (in the sense of Bloch and Olckers (2022)). An immediate and useful corollary states that every clique informative network is either a triangle or a star.

Corollary 1. *A network is clique informative if and only if it is a triangle or a star.*

The intuition for this is straightforward. First, observe that any connected graph with three nodes is either a triangle or a star. For graphs with four or more nodes, one can use the fact that any connected graph that is not a star must have an open path of length three. For any such graph, the first and last edge on this path make up two cliques that do not share a node in common, which violates clique informativeness by the previous lemma. Hence, any connected and clique informative graph of size four or greater must be a star.

4 Ranking All Teams

We are now ready to analyze the mechanism design problem faced by the principal. Specifically, when can the principal design an ex-post incentive compatible and efficient mechanism that assigns a rank to *every* team in the organizational network? Here we have in mind situations where it is useful to view each clique as a team in its own right. For example, when assessing the chemistry of co-author groups, one accounts for the possibility that a pair of researchers only works well together when joined by a third colleague. The general problem of ranking any subset of cliques is tackled in Section 5.

To start, recall that agents can manipulate the ranking in one of two ways: either by completing a partial order, or, by making two teams that were originally comparable, uncomparable. I provide some intuition for the former of these situations in Figure 2, in the case of a simple line graph with four nodes.

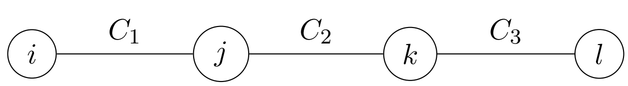

Figure 2: Three teams of pairs

Example 2. Let $(\delta_1, \delta_2, \delta_3)$ denote the characteristics of teams $(i, j), (j, k)$ and (k, l) respectively, and suppose we have: $\delta_2 > \delta_3 > \delta_1$. As was alluded to after Corollary 1, the presence of an open path of length three or greater allows for the possibility of an incomplete ranking to arise. In this particular case, it is impossible to compare teams C_1 and C_3. Since the mechanism must map any vector $\mathbf{T}$ to a *complete* order, the principal has to assign an arbitrary ranking between C_1 and C_3 while respecting C_2's relative ranking in $\succ_{\mathbf{T}}$. Without loss of generality, suppose that if the principal is unable to compare two teams, she assigns a higher rank to the team with the highest

[10] The same argument appears in Bloch and Olckers (2022) to characterize completely informative networks.

index.[11] Under truthful reporting, agent j will be on the first team (team C_2) and the third team (team C_1). Notice, however, that agent j stands to gain from switching his report, assuming that k's report is truthful. By switching his report from $C_2 \succ_{T^j} C_1$ to $C_1 \succ_{\tilde{T}^j} C_2$, agent j now guarantees that he will be on the first team (team C_1) and the second team (team C_2). Crucially, some realizations of δ will prevent the principal from detecting agent j if he chooses to lie.

A formalization of this argument is enough to rule out the construction of an ex-post incentive compatible and efficient mechanism in all but one network architecture. To see this, recall that every non clique informative graph must include an open path of length three like the one in Figure 2, which renders it prone to manipulation. By Corollary 1, the only remaining networks to consider are the triangle and star graphs. For the triangle graph, the proof in the Appendix shows that certain agents can create a cycle and obtain a higher rank by doing so. If the graph is a star, the only agent capable of making comparisons is the central node. But since a central agent belongs to every team, he is indifferent to all rankings and thus has no incentive to misreport. These insights are captured by the main result, which characterizes the star network as the unique organizational structure that admits a team ranking mechanism.

Theorem 1. *An organizational network g admits an ex-post incentive compatible and efficient team ranking mechanism if and only if g is a star.*

The sufficiency portion of this theorem relies on identifying realizations of δ for which an agent can profitably misreport without getting caught.[12] Critically, this procedure is made possible by the lack of overlapping team comparisons. This is especially true when ranking consecutive edges in a network, where only a single agent is capable of making the comparison. In fact, the result would also hold if instead of considering every clique in $\mathcal{C}$, we considered any subset of cliques that includes all connected pairs.

One reasonable concern is whether this result could be affected by the coarseness of the principal's ranking. Suppose that instead of assigning better prizes to higher-ranking teams, the principal chooses to implement a *team selection mechanism* that simply assigns a prize to the k highest-ranking teams in $\mathcal{C}$ (similar in spirit to Lev et al. (2023) and Bloch and Olckers (2021)). Under this new ranking scheme, an agent i prefers σ^i over $\tilde{\sigma}^i$ if and only if the number of teams with rank $\sigma_j \geq m - k + 1$ is greater in σ^i than in $\tilde{\sigma}^i$ (where $m = |\mathcal{C}|$). The next result shows that adopting a coarser ranking leaves our previous theorem virtually unchanged.

Theorem 2. *If σ selects $k > 1$ winning teams, there exists an ex-post incentive compatible and efficient team selection mechanism if and only if the network g is a star. If σ selects a single winner, there exists an ex-post incentive compatible and efficient team selection mechanism if and only if the network g is a triangle or a star.*

[11] The argument does not rely on this particular arbitrary rule, as is shown in the Appendix.

[12] Since the proof only relies on specific realizations of δ, the result remains true if we allowed ties in team characteristics. Since agents have perfect local observations, the result is also robust to any correlation structure between teams.

For team selection mechanisms that select two or more winning teams, similar constructions of δ to those used in the proof of Theorem 1 reveal that certain agents can increase the number of winning teams they are on by misreporting. In the special case where the mechanism only awards the prize to the highest-ranking team, the triangle no longer fails to admit a mechanism. This is because the counterexample previously used to rule out mechanisms in the triangle showed that successful misreporting takes the form of a cycle among pairs. Note, however, that an agent is capable of inducing a cycle only if he belongs to the highest-ranking pair. Therefore, any agent capable of creating a cycle must already be on the winning team and has no incentive to misreport.

5 Ranking a Subset of Teams

Is it possible to expand the set of organizations that admit a team ranking mechanism by discarding certain cliques from the analysis? In most applications, it is unlikely that the principal will want to compare each and every clique in a social network. Due to equity concerns, a manager may only be interested in ranking teams that are large enough, and can choose to omit smaller teams from her rankings. In other contexts, it may be appropriate to exclusively consider maximal cliques as proper teams.

Given a set of agents N, a principal is now interested in ranking an arbitrary set of teams $\mathcal{G}$, each element of which is a set of two or more agents. Equivalently, one can always view $\mathcal{G}$ as a subset of $\mathcal{C}$, where an edge is drawn between two agents if they have a mutual team. Call an organization $(N, \mathcal{G})$ *informative* if for any realization of δ the information in $\mathbf{T}$ results in a complete order $\succ_{\mathbf{T}}$. By the same logic as Lemma 1, note that if two teams do not share an agent in common one can find a realization of characteristics for which the two teams cannot be compared. Thus, an organization $(N, \mathcal{G})$ is informative if and only if every pair of teams shares an agent in common.

Depending on the structure of teams in $\mathcal{G}$, the principal may also end up with a higher proportion of comparisons made by multiple agents. For these specific comparisons, she can now detect and punish agents who send conflicting rankings—a common technique in peer selection. In line with this reasoning, define an organization $(N, \mathcal{G})$ to be *highly-connected* if whenever two teams share an agent in common, they share at least two agents in common. For an example of an informative and highly-connected organization, consider Figure 1 when $\mathcal{G}$ only contains teams of size three or bigger.

The objective is to construct an incentive compatible mechanism for any highly-connected organization. The mechanism I propose has the following ingredients: if $\mathbf{T}$ contains conflicting reports, the principal first *detects* all agents who are potential liars.[13] If a detected agent's report contradicts that of multiple agents, then the mechanism *identifies* him as a liar and immediately disregards his report. If a pair of agents i, j disagree on the ranking of some teams $\mathcal{G}' \subset \mathcal{G}$, but neither i nor j contradict other agents in the organization, identifying which of them is lying is significantly more challenging. To circumvent this, the mechanism punishes both i and j by assigning to their

[13] An agent i is detected if for some pair G_l, G_m we have $t^i_{lm} \neq t^j_{lm}$ for some agent j and $t^i_{lm}, t^j_{lm} \neq 0$.

mutual teams $\mathcal{G}^{i\cap j} = \{G_k \in \mathcal{G} \mid G_k \in G^i \cap G^j\}$ the lowest ranks $1, ..., |\mathcal{G}^{i\cap j}|$.[14] All other ranks assigned by σ are set according to $\mathbf{T} \setminus T^i, T^j$ and the principal's arbitrary rule.

The final result offers two easy-to-check sufficient conditions for the existence of an incentive compatible and efficient team ranking mechanism.

Theorem 3. *An organization $(N, \mathcal{G})$ admits an ex-post incentive compatible and efficient team ranking mechanism if one of the following holds:*
(i) There exists an agent i such that $G^i = \mathcal{G}$.
(ii) The organization is highly-connected.

Generally, if there exists a central agent who belongs to every team in the organization (like in the star, for example), the principal can exclusively consider that agent's report and discard all other reports from her ranking. In organizations that do not feature a central agent, the principal can still construct a mechanism provided that whenever two teams share a member in common, they share at least two members in common. This guarantees that there are no local comparisons that rely on a single agent's observation. If an agent manages to lie and the principal is unable to determine whether the agent or his colleague is at fault, the proposed mechanism penalizes both the agent and his colleague by assigning the lowest ranks to their mutual teams. Importantly, the proof shows that the deviating agent is unable to improve the relative rank of a team outside this set of mutual teams.

To end this section, the following example confirms that the conditions stated in Theorem 3 are indeed sufficient but not necessary for a mechanism to exist.

Example 3. Consider an organization made up of five agents that work in three teams $\mathcal{G} = \{\{1, 2, 3\}, \{1, 4, 5\}, \{2, 3, 4, 5\}\}$. Clearly, this organization satisfies neither condition in Theorem 3. This is also an informative organization, since every pair of teams shares an agent in common. Thus, if agents report truthfully, the principal always extracts a ranking that is free of incompletions and cycles. Now observe that agents $2, 3, 4, 5$ can never profitably misreport: the only realizations of δ for which they can misreport are those where they can create a cycle. If one of them creates a cycle however, the mechanism σ immediately identifies him as a liar (since his colleague's report would not induce a cycle, and is therefore the true report). The only agent capable of creating a cycle without directly contradicting any of his colleagues' reports is agent 1, since he is the only one who can locally compare teams $\{1, 2, 3\}$ and $\{1, 4, 5\}$. To mitigate this kind of manipulation, the principal can implement a mechanism that flips agent 1's report whenever she obtains a cycle with no contradictory reports, and that ignores other agents' reports if they are identified as liars.

[14] σ cannot assign the lowest ranks to $\mathcal{G}^i \cup \mathcal{G}^j$ since we might have $\mathcal{G} = \mathcal{G}^i \cup \mathcal{G}^j$. The exact order of ranks assigned to the teams in $\mathcal{G}^{i\cap j}$ does not matter, since i and j both belong to all teams in $\mathcal{G}^{i\cap j}$.

6 Conclusion

This paper discusses the design of team ranking mechanisms when a principal wants to reward groups based on a trait she cannot observe. The main message is that agents can manipulate their teams' rankings in ways that differ from individual peer ranking settings. For example, even if agents care about all of their teams' ranks, they may be willing to falsely rank one team below another if it increases the sum of their teams' ranks. Generically, when individuals' payoffs are invariant to permutations of their teams' ranks, an impossibility result is obtained: the principal can design an ex-post incentive compatible and efficient mechanism that ranks every team if and only if the organizational network is a star. I also show that this result mostly persists when the principal's ranking is coarsened, but can be relaxed when the principal omits some teams from the ranking.

More importantly, this paper introduces a new class of peer mechanism problems—*team evaluation problems*—in which agents are asked to evaluate their teams, rather than their peers. As the analysis illustrates, it is unclear how established results from the peer mechanism literature extend to this new framework. For example, how would reporting behavior change if agents were asked to nominate one of their teams, or to flexibly grade their teams to determine the allocation of rewards? And is it possible to design an impartial but approximately efficient mechanism when agents have noisy information about their teams? A final direction for future research is to formalize the relationship between team rankings and individual rankings, when the ordering of teams is inherently related to the characteristics of team members. For instance, what is the best method to infer the ranking of individuals from the ranking of teams in an organization? It is my view that further exploration of these questions could provide valuable insights to organizations that distribute group rewards based on crowd-sourced evaluations.

A Appendix

A.1 Proof of Lemma 1

Proof. ($\Leftarrow$) Let g be a connected graph in which every pair of cliques share a node in common. Then for any two teams C_l, C_m, we have $t^i_{l,m} = 1, -1$ for some agent i, and the information in $\mathbf{T}$ allows us to order C_l and C_m according to $\succ_{\mathbf{T}}$.

($\Rightarrow$) Let C_l, C_m be two teams that do not share a node in common. Since $t^i_{l,m} = 0$ for all i, it is not possible to directly compare C_l, C_m. The only other way to compare them is indirectly, through transitivity. Following the proof of Lemma 1 in Bloch and Olckers (2022), consider any realization of δ in which δ_l, δ_m are consecutive in the ranking. Such a realization clearly prevents us from comparing C_l, C_m indirectly, thus rendering the pair uncomparable. ■

A.2 Proof of Theorem 1

Proof. ($\Leftarrow$) Let g be a star graph. Then there is only one central agent i who can compare teams, and we have $\mathbf{T} = T^i$. In this case, agent i has no incentive to misreport since his rank is constant across any report, $\sigma^i(T^i) = \sigma^i(\tilde{T}^i)$ for any possible $\tilde{T}^i$.
($\Rightarrow$) If g is not a star then it is either a triangle or it is not clique informative.

Case 1. Suppose that g is a triangle. Let i, j, k denote its nodes, and C_1, C_2, C_3, C_4 denote the teams made up of $(i, j), (j, k), (i, k)$ and (i, j, k), respectively. The proof strategy consists of finding a realization of team characteristics for which one agent can increase his payoff by creating a cycle among teams C_1, C_2, C_3. Recall that in case of a cycle, the principal must have a rule that assigns an arbitrary ranking. Without loss of generality, suppose the arbitrary rule assigns $C_1 \succ C_2 \succ C_3$, when these teams cannot be compared according to $\succ_{\mathbf{T}}$. Now consider the following realization of team characteristics: $\delta_1 > \delta_3 > \delta_2 > \delta_4$. Under this realization, the only agent capable of creating a cycle is j, by announcing $C_2 \succ_{\tilde{T}^j} C_1$. Holding i and k's announcements truthful, the full reported rankings are:

$$C_1 \succ_{T^i} C_3 \succ_{T^i} C_4$$
$$C_3 \succ_{T^k} C_2 \succ_{T^k} C_4$$
$$C_2 \succ_{\tilde{T}^j} C_1 \succ_{\tilde{T}^j} C_4$$

All agents rank C_4 last, and $\succ_{\mathbf{T}}$ includes the following cycle:

$$C_1 \succ_{\mathbf{T}} C_3 \succ_{\mathbf{T}} C_2 \succ_{\mathbf{T}} C_1 \succ_{\mathbf{T}} C_3 \succ_{\mathbf{T}} \dots$$

According to the principal's arbitrary rule, the mechanism assigns the following ranking: $C_1 \succ C_2 \succ C_3 \succ C_4$. To see that agent j is better off by lying, we compare his payoff under truthful report T^j and the alternative report $\tilde{T}^j$:

$$\sigma^j\left(T^j, T^{-j}\right) = (\sigma_1, \sigma_2, \sigma_4) = (4, 2, 1)$$
$$\sigma^j\left(\tilde{T}^j, T^{-j}\right) = (\sigma_1, \sigma_2, \sigma_4) = (4, 3, 1)$$

Importantly, the principal is unable to detect who lied, since each individual report contradicts the other two reports regarding C_1, C_2, C_3. Therefore, we have found a realization of team characteristics for which one agent strictly prefers lying and cannot be detected for doing so, thus violating ex-post incentive-compatibility.[15]

Case 2. Suppose that g is not clique informative. By Corollary 1, g must have $n \geq 4$ nodes, $m \geq 3$ cliques, and an open path of length three as featured in Figure 2. For one of these open paths, let i, j, k, l denote the nodes and $\delta_1, \delta_2, \delta_3$ denote the characteristics of $(i, j), (j, k), (k, l)$ respectively. Consider a realization of δ such that $\delta_2 > \delta_1 > \delta_3$ are consecutive and are the three lowest characteristics in the organization, and all other entries in δ are chosen arbitrarily. This realization satisfies the following: j is the only one capable of comparing C_1 and C_2, and there is no path of comparison between C_1 and C_3 except the one going through C_2. Without loss of generality, assume that the mechanism favors team C_3 over team C_1 when they cannot be compared according to $\succ_{\mathbf{T}}$. Now let T^j be agent j's truthful report which includes $C_2 \succ_{T^j} C_1$, and $\tilde{T}^j$ be agent j's report if he lies and announces $C_1 \succ_{\tilde{T}^j} C_2$. Holding agent k's report truthful, including $C_2 \succ_{T^k} C_3$, agent j's possible payoffs are:

$$\sigma^j \left(T^j, T^{-j}\right) = (\sigma_2, \sigma_1, (\sigma)_{C \in \mathcal{C}^i \setminus C_1, C_2}) = (1, 3, (\sigma)_{C \in \mathcal{C}^i \setminus C_1, C_2})$$
$$\sigma^j \left(\tilde{T}^j, T^{-j}\right) = (\tilde{\sigma}_1, \tilde{\sigma}_2, (\sigma)_{C \in \mathcal{C}^i \setminus C_1, C_2}) = (3, 2, (\sigma)_{C \in \mathcal{C}^i \setminus C_1, C_2})$$

By lying, agent j increases the sum of his ranks across teams C_1, C_2 without affecting the rank of any other team he may be part of. Since j is the only node capable of comparing C_1, C_2, his report will not contradict the information in T^{-j}. Moreover, the sequence of comparisons $C_1 \succ_{T^j} C_2$ and $C_2 \succ_{T^k} C_3$ is the only way to compare C_1, C_3, thus the mechanism must assign $\sigma_1 = 3$ and $\sigma_3 = 1$. Therefore, this realization of δ prevents the principal from achieving ex-post incentive compatibility and efficiency. If we assume that the principal's arbitrary rule favors team C_1 over team C_3, the proof can easily be modified to show that agent k would strictly prefer to lie. Since g is an arbitrary graph violating clique informativeness, we conclude that every graph that is not clique informative does not admit an ex-post incentive compatible and efficient mechanism. ■

A.3 Proof of Theorem 2

Proof. Let g be a star graph. By the same reasoning as Theorem 1, the central agent i is always part of the k highest-ranking teams for any $k < m$ and for any choice of T^i. Let g be a triangle graph with nodes i, j, k, let $\delta_1, \delta_2, \delta_3, \delta_4$ denote the characteristics of teams $(i, j), (j, k), (i, k)$ and (i, j, k), and assume that the principal's arbitrary rule assigns $C_1 \succ C_2 \succ C_3$ in case of a cycle. The mechanism σ must select $k < 4$ teams.

[15] The argument does not rely on a specific arbitrary rule: Fixing a rule that ranks $x \succ y \succ z$ in case of a cycle, we can find a realization where x is first and y is third in the true ranking, and the agent who belongs to both x and y can create a cycle to his benefit.

If $k = 2$, then the same construction of δ used in Theorem 1 shows that agent j can improve his teams' ranks by falsely reporting $C_2 \succ_{\tilde{T}^j} C_1$ and creating a cycle. In particular, he goes from being on teams ranked first, third, and fourth to teams ranked first, second, and fourth.

If $k = 3$, then consider the following realization: $\delta_4 > \delta_1 > \delta_3 > \delta_2$. Under truthful reporting, agent j is on the first, second, and fourth team. In total, two of his teams are selected by σ. By reporting $C_2 \succ_{\tilde{T}^j} C_1$, he can create a cycle to his advantage. Under the false report $\tilde{T}^j$, the principal's mechanism assigns the lowest rank to team C_4. Consequently, three of j's teams are selected by σ.

If $k = 1$, we claim that no agent can profitably misreport and that the mechanism $\sigma(\mathbf{T}) \equiv \succ_{\mathbf{T}}$ is ex-post incentive compatible. First, note that any realization of δ where δ_4 is the largest characteristic implies that all agents are part of the winning team. Therefore, we can restrict our attention to any other realization of δ. Moreover, assuming that all agents report truthfully, no single agent can misreport regarding the ranking of team (i, j, k), as this report would contradict the other two agents' reports. Therefore the only remaining type of manipulation left to consider is for an agent to misreport the local ranking of the pairs he belong to. For example, agent k can lie about the ranking of pairs $(i, k), (j, k)$. Fixing a realization of δ, the only agent capable of increasing the ranking of the pairs he belongs to is the agent capable of creating a cycle between C_1, C_2, C_3. Note however that in order to create a cycle between C_1, C_2, C_3, this agent must be part of the first and last team among C_1, C_2, C_3 according to δ. Since we have already ruled out realizations of δ in which δ_4 is the largest number, this implies that any other realization of δ in which some agent can create a cycle to his benefit, must be such that this agent is already part of the team with the highest characteristic in δ. Since we have exhausted all possible realizations of δ, we conclude that when $k = 1$, no agent in the triangle can successfully manipulate the ranking.

Finally, suppose that g has an open path of length three with nodes i, j, k, l, let $\delta_1, \delta_2, \delta_3$ denote the characteristics of $(i, j), (j, k)$ and (k, l) respectively, and let $k < m$ denote the cutoff rank that determines the set of winning teams. Without loss of generality, assume that the principal's arbitrary rule favors C_1 over C_3 when they cannot be compared. Now consider a realization such that $\delta_3 > \delta_2 > \delta_1$ are consecutive and δ_3 is the k-th largest characteristic in δ. If agent j reports truthfully, the principal assigns the following ranks: $\sigma_3 = m - k + 1$, $\sigma_2 = m - k$, and $\sigma_1 = m - k - 1$. In total, agent j is on no winning teams. If instead, agent j reports $C_1 \succ_{T^j} C_2$, the principal is now unable to compare C_1 and C_3, and assigns the ranks $\sigma_1 = m-k+1$, $\sigma_2 = m-k-1$ and $\sigma_3 = m - k$. In total, agent j is on one winning team, (i, j). ■

A.4 Proof of Theorem 3

Proof. (i) Let $(N, \mathcal{G})$ be a connected organization. If there exists an agent i who belongs to every team, then $\succ_{T^i}$ is a complete order. By the same reasoning as Theorem 1, the mechanism $\sigma(\mathbf{T}) \equiv \succ_{T^i}$ is ex-post incentive compatible and efficient.

(ii) The mechanism described in Section 5 is ex-post efficient by construction as it respects all non-contradictory reports in $\mathbf{T}$. For sake of contradiction, suppose it is not ex-post incentive compatible. Then there exists a highly-connected organization $(N, \mathcal{G})$ and a realization δ, for which some agent i can achieve a higher rank by misreporting $\tilde{T}^i$ instead of truthfully reporting T^i. We arrive at a contradiction by establishing a series of claims about the deviating agent, i.

Claim 1. *An agent i who profitably misreports is detected but not identified by σ.*

Proof. This follows from the structure of highly-connected organizations. If agent i lies about the ranking of any pair G_l, G_m, there must exist another agent j who belongs to G_l, G_m and whose truthful report disagrees with i. The mechanism σ detects both i and j as potential liars. Moreover, agent i cannot be identified by σ, since otherwise, only his report $\tilde{T}^i$ would be discarded, which would violate $\sigma^i(\tilde{T}^i, T^{-i}) \succ_i \sigma^i(T^i, T^{-i})$. Therefore, it must be that agent i's report only disagrees with agent j about some set of teams $\mathcal{G}' \subseteq \mathcal{G}^{i \cap j}$. ■

Claim 2. *An agent i who profitably misreports about some teams $\mathcal{G}' \subseteq \mathcal{G}^{i \cap j}$ must improve the rank of at least one team $G_k \in \mathcal{G}^i \backslash \mathcal{G}^{i \cap j}$ relative to another team $G_n \in \mathcal{G} \backslash \mathcal{G}^i$.*

Proof. By Claim 1, the mechanism detects i and j but cannot identify which one of them is the liar. As punishment, each team in $\mathcal{G}^{i \cap j}$ receives one of the lowest ranks from $\sigma = 1$ through $\sigma = |\mathcal{G}^{i \cap j}|$. In other words, agent i is weakly worse off by lying regarding his mutual teams with agent j. But according to our premise, agent i must be made better off by reporting $\tilde{T}^i$:

$$\sigma^i(\tilde{T}^i, T^{-i}) \succ_i \sigma^i(T^i, T^{-i})$$

For this to hold, there must be at least one team $G_k \in \mathcal{G}^i \setminus \mathcal{G}^{i \cap j}$ and another team $G_n \in \mathcal{G} \setminus G^i$ such that the following is true:

$$\sigma_n > \sigma_k \text{ and } \tilde{\sigma}_k > \tilde{\sigma}_n$$

■

Claim 3. *An agent i who misreports about some teams $\mathcal{G}' \subseteq \mathcal{G}^{i \cap j}$ cannot affect the ranking of a team in $\mathcal{G}^i \setminus \mathcal{G}^{i \cap j}$ relative to a team outside $\mathcal{G}^i$.*

Proof. Consider any team $G_k \in \mathcal{G}^i \setminus \mathcal{G}^{i \cap j}$ and any other team $G_n \in \mathcal{G} \setminus \mathcal{G}^i$ such that $\sigma_n > \sigma_k$. We want to show that holding other agents' reports truthful, any alternative report $\tilde{T}^i$ still yields $\tilde{\sigma}_n > \tilde{\sigma}_k$. If G_k, G_n were uncomparable under truthful reporting, they must also be uncomparable when i lies because the principal disregards $\tilde{T}^i$ and T^j, and learns no additional information to compare G_k, G_n. Therefore she uses the same arbitrary ranking rule and we get $\tilde{\sigma}_n > \tilde{\sigma}_k$. Now suppose that G_k, G_n were previously comparable. If G_k and G_n share an agent in common then that same agent correctly ranks them in $\mathbf{T} \setminus \tilde{T}^i, T^{-i}$ and the resulting ranking includes $\tilde{\sigma}_n > \tilde{\sigma}_k$. If G_k and G_n do not share an agent in common, then they must have been previously comparable through a transitive path of comparisons. In other words, there exists a sequence of teams $G_n = G_1, ..., G_M = G_k$ and a sequence of agents $i^1, ..., i^{M-1}$ such that $i^m \in G_m, G_{m+1}$ and $t^{im}_{m,m+1} = 1$ for $m = 1, ..., M-1$. Moreover, since the organization is highly-connected, there also exists two agents $i^{1'}$ and $i^{M-1'}$ different from i, j who belong to G_{M-1}, G_m and G_1, G_2, respectively:

$$G_n \succ G_2 \succ ... \succ G_{M-1} \succ G_k$$

The only case to worry about is if this path of comparisons going from G_n to G_k passes through two of i, j's mutual teams, and no other agent is capable of comparing these teams. Such a situation is depicted below, where G_a, G_b are only comparable by i, j:

$$G_n \succ G_a \succ_{T^i,T^j} G_b \succ G_k$$

To resolve this worry, observe that there always exists a shorter path to compare G_n and G_k that goes through at most one of i, j's mutual teams. In the example above, G_a and G_k share agent i in common, and since $G_k \in \mathcal{G}^i \setminus \mathcal{G}^{i \cap j}$ it must be that j does not belong to G_k. Since the organization is highly-connected, there exists some agent $i' \neq i, j$ who can compare G_a and G_k directly, avoiding the path going through G_a, G_b. This new path is shorter, and does not rely on the information in T^i, T^j. This argument can be used to shorten any path that goes through multiple of agent i, j's mutual teams, to one that goes through only one of their mutual teams and does not rely on T^i, T^j.

To conclude, there is always enough information in $\mathbf{T} \setminus T^i, T^j$ to infer $\tilde{\sigma}_n > \tilde{\sigma}_k$. As we have exhausted all cases, we confirm that $\tilde{T}^i$ does not affect the relative ranking of any team $G_k \in \mathcal{G}^i \setminus \mathcal{G}^{i \cap j}$ relative to another team $G_n \in \mathcal{G} \setminus \mathcal{G}^i$. ■

Now to put everything together. By Claim 1, for an agent i to profitably misreport without being identified it must be that he is only lying about a subset of his mutual teams $\mathcal{G}^{i \cap j}$ with some agent j. To achieve a higher payoff despite the principal's punishment, his misreporting must lead at least one of his teams G_k outside of $\mathcal{G}^{i \cap j}$ to now rank above some team $G_n \in \mathcal{G} \setminus \mathcal{G}^{i \cap j}$ where it was previously not the case under T^i, T^{-i}. But as the last claim makes clear, no alternative report $\tilde{T}^i$ can possibly alter the relative ranking of G_k and G_n, which concludes our proof that the proposed mechanism satisfies ex-post incentive compatibility. ■

References

ALCALDE-UNZU, J., D. BERGA, AND R. GJORGJIEV (2022): "Impartial Social Rankings: Some Impossibilities," *Available at SSRN 4068178*.

ALON, N., F. FISCHER, A. PROCACCIA, AND M. TENNENHOLTZ (2011): "Sum of us: Strategyproof selection from the selectors," in *Proceedings of the 13th Conference on Theoretical Aspects of Rationality and Knowledge*, 101–110.

AMORÓS, P. (2023): "Implementing optimal scholarship assignments via backward induction," *Mathematical Social Sciences*, 125, 1–10.

AMORÓS, P., L. C. CORCHÓN, AND B. MORENO (2002): "The scholarship assignment problem," *Games and Economic behavior*, 38, 1–18.

AZIZ, H., O. LEV, N. MATTEI, J. ROSENSCHEIN, AND T. WALSH (2016): "Strategyproof peer selection: Mechanisms, analyses, and experiments," in *Proceedings of the AAAI Conference on Artificial Intelligence*, vol. 30.

AZIZ, H., O. LEV, N. MATTEI, J. S. ROSENSCHEIN, AND T. WALSH (2019): "Strategyproof peer selection using randomization, partitioning, and apportionment," *Artificial Intelligence*, 275, 295–309.

BABICHENKO, Y., O. DEAN, AND M. TENNENHOLTZ (2020): "Incentive-compatible classification," in *Proceedings of the AAAI Conference on Artificial Intelligence*, vol. 34, 7055–7062.

BAMBERGER, P. A. AND R. LEVI (2009): "Team-based reward allocation structures and the helping behaviors of outcome-interdependent team members," *Journal of Managerial Psychology*, 24, 300–327.

BANDIERA, O., I. BARANKAY, AND I. RASUL (2013): "Team incentives: Evidence from a firm level experiment," *Journal of the European Economic Association*, 11, 1079–1114.

BAUMANN, L. (2023): "Robust implementation with peer mechanisms and evidence," *SSRN Research Archive*.

BAUMANN, L. AND R. DUTTA (2022): "Strategic Evidence Disclosure in Networks and Equilibrium Discrimination," *Available at SSRN 4325129*.

BLOCH, F. AND M. OLCKERS (2021): "Friend-based ranking in practice," in *AEA Papers and Proceedings*, American Economic Association 2014 Broadway, Suite 305, Nashville, TN 37203, vol. 111, 567–571.

——— (2022): "Friend-based ranking," *American Economic Journal: Microeconomics*, 14, 176–214.

Boning, B., C. Ichniowski, and K. Shaw (2007): "Opportunity counts: Teams and the effectiveness of production incentives," *Journal of Labor Economics*, 25, 613–650.

Cembrano, J., F. Fischer, and M. Klimm (2023): "Impartial Rank Aggregation," *arXiv preprint arXiv:2310.13141*.

De Alfaro, L. and M. Shavlovsky (2014): "CrowdGrader: A tool for crowdsourcing the evaluation of homework assignments," in *Proceedings of the 45th ACM technical symposium on Computer science education*, 415–420.

De Clippel, G., H. Moulin, and N. Tideman (2008): "Impartial division of a dollar," *Journal of Economic Theory*, 139, 176–191.

DeMatteo, J. S., L. T. Eby, and E. Sundstrom (1998): "Team-based rewards: Current empirical evidence," *Research in organizational behavior*, 20, 141–183.

Dhull, K., S. Jecmen, P. Kothari, and N. B. Shah (2022): "Strategyproofing peer assessment via partitioning: The price in terms of evaluators' expertise," in *Proceedings of the AAAI Conference on Human Computation and Crowdsourcing*, vol. 10, 53–63.

Edelman, P. H. and A. Por (2021): "A new axiomatic approach to the impartial nomination problem," *Games and Economic Behavior*, 130, 443–451.

Englmaier, F., S. Grimm, D. Grothe, D. Schindler, and S. Schudy (2024): "The Effect of Incentives in Nonroutine Analytical Team Tasks," *Journal of Political Economy*, 132, 000–000.

Fischer, F. and M. Klimm (2014): "Optimal impartial selection," in *Proceedings of the fifteenth ACM conference on Economics and computation*, 803–820.

Friebel, G., M. Heinz, M. Krueger, and N. Zubanov (2017): "Team incentives and performance: Evidence from a retail chain," *American Economic Review*, 107, 2168–2203.

Garbers, Y. and U. Konradt (2014): "The effect of financial incentives on performance: A quantitative review of individual and team-based financial incentives," *Journal of occupational and organizational psychology*, 87, 102–137.

Holzman, R. and H. Moulin (2013): "Impartial nominations for a prize," *Econometrica*, 81, 173–196.

Kahng, A., Y. Kotturi, C. Kulkarni, D. Kurokawa, and A. Procaccia (2018): "Ranking wily people who rank each other," in *Proceedings of the AAAI Conference on Artificial Intelligence*, vol. 32.

Kurokawa, D., O. Lev, J. Morgenstern, and A. D. Procaccia (2015): "Impartial Peer Review." in *IJCAI*, Citeseer, vol. 15, 582–588.

Lawler, E. E. and S. G. Cohen (1992): "Designing pay systems for teams," *ACA journal*, 1, 6–19.

Lev, O., N. Mattei, P. Turrini, and S. Zhydkov (2023): "PeerNomination: A novel peer selection algorithm to handle strategic and noisy assessments," *Artificial Intelligence*, 316, 103843.

Mackenzie, A. (2015): "Symmetry and impartial lotteries," *Games and Economic Behavior*, 94, 15–28.

Merriman, K. (2008): "Low trust teams prefer individualized pay," *harvard business review*, 86, 32.

Olckers, M. and T. Walsh (2024): "Manipulation and peer mechanisms: a survey," *Artificial Intelligence*, 104196.

Smith, T., B. Kirkman, G. Chen, and G. J. Lemoine (2018): "When employees work on multiple teams, good bosses can have ripple effects," *Harvard Business Review Digital Articles*, 1–5.

Stelmakh, I., N. B. Shah, and A. Singh (2021): "Catch me if i can: Detecting strategic behaviour in peer assessment," in *Proceedings of the AAAI Conference on Artificial Intelligence*, vol. 35, 4794–4802.

Tamura, S. and S. Ohseto (2014): "Impartial nomination correspondences," *Social Choice and Welfare*, 43, 47–54.

Xu, Y., H. Zhao, X. Shi, and N. B. Shah (2019): "On strategyproof conference peer review," in *Proceedings of the 28th International Joint Conference on Artificial Intelligence*, 616–622.