

Incentive Design for Agile Teams

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Motivation

An agile team is

- ▶ A cross-functional group of people with various expertise, collaborating on a high-yield project on a temporary basis.
 - ▶ E.g., Amazon's "two-pizza teams", special teams in China, ...
- ▶ Flexible in designing workflow, job assignment, payments, etc.

Internal information is critical to organization design

- ▶ Employees' job attitudes respond to observed efforts of peers.
- ▶ Organization design can profoundly affect internal information.

Question

- ▶ How to design agile teams by leveraging internal information?

Overview

Holmstrom's classic remark (Holmstrom, 1982)

- ▶ What determines the choice of monitors?
- ▶ How should output be shared to provide the best incentives?
- ▶ “A big step toward understanding nonmarket organization”

We propose a novel framework of moral hazard in team

- ▶ Complementary technology + network-based peer monitoring
- ▶ Least-cost effort-inducing mechanism: workflow and rewards

Key insights

- ▶ Transparency of agents' actions reduce their incentive costs.
- ▶ Effectiveness of transparency on incentives is diminishing.

Results

- ▶ In the optimal sequence, the agents work sequentially.
- ▶ Better connected agents work in intermediate stages.
- ▶ More important agents and sub-teams work in later stages.
- ▶ Large sub-teams are assigned to either end of the sequence.
- ▶ Simple algorithms are offered to characterize the optimum.

Implications

- ▶ Sequential moves improve transparency and reduce wages.
- ▶ Ex ante identical agents may earn different wages ex post.
- ▶ Better connected agents act as information intermediaries.
- ▶ More important agents act as monitors and earn higher wages.
- ▶ Peer-monitoring is effective but costly to provide incentives.

Literature

Theoretical works on incentive design with multiple agents

- ▶ Alchian & Demsetz (1972), Holmstrom (1982), Itoh (1991)
- ▶ Lazear & Rosen (1981), Gershkov et al. (2009, 2016)
- ▶ Strausz (1999), Che and Yoo (2001), Au and Chen (2019)
- ▶ Winter (2004, 2006, 2010), Zhou (2016), Halac et al. (2021)
- ▶ McAfee & McMillan (1991), Segal (1999, 2003), Bernstein & Winter (2012), Babaioff et al. (2012), Balmaceda (2016, 2018)

Empirical works on the role of internal information

- ▶ Ichino & Maggi (2000), Knez & Simester (2001), Heywood & Jirjahn (2004), Gould & Winter (2009), Mas & Moretti (2009)
- ▶ Carpenter et al. (2009), Steiger & Zultan (2014)

MODEL

Model

Players and actions

- ▶ A set I of n agents manage a project owned by a principal.
- ▶ Each agent chooses whether to exert effort or not: $a \in \{0, 1\}$.
- ▶ Exerting effort is costly ($c = 1$) while shirking is costless.

Network

- ▶ Organizational structure is given by an undirected graph g .
- ▶ Agents i and j are directly linked (*neighbors*) if $ij \in g$.
- ▶ Examples: workplace architecture, authority structure, etc.

Technology

- ▶ The project succeeds with probability $p(W)$, $W = \{i | a_i = 1\}$.
- ▶ Monotonicity: if $T \subset S$, then $p(T) < p(S)$.

Mechanism

- ▶ Principal chooses a mechanism $\{\pi, v\}$ that consists of:
 1. A work sequence π s.t. agent i is the π_i -th to perform.
 2. A reward scheme v s.t. agent i receives $v_i \geq 0$ upon success.

Information

- ▶ Principal observes *only* whether the project succeeds or not.
- ▶ Agent i observes j 's action (i sees j) iff $ij \in g$ and $\pi_i > \pi_j$.
- ▶ Let $N_i := \{j | ij \in g, \pi_i > \pi_j\}$ be the agents whom i sees.
- ▶ Let $M_i := \{j | j \text{ sees } k_1 \text{ sees } \dots k_r \text{ sees } i\}$ be the agents who could ultimately learn i 's action if agents could communicate.

More on Technology

Importance

- ▶ Agent i is more *important* than j if for any S s.t. $i, j \in S$,

$$p(S \setminus \{i\}) \leq p(S \setminus \{j\}).$$

Complementarity

- ▶ p is *complementary* if for any S, T s.t. $T \subset S$ and for $i \notin S$,

$$p(S \cup \{i\}) - p(S) > p(T \cup \{i\}) - p(T).$$

Substitutability

- ▶ p is *substitutable* if for any S, T s.t. $T \subset S$ and for $i \notin S$,

$$p(S \cup \{i\}) - p(S) \leq p(T \cup \{i\}) - p(T).$$

Principal's Problem

Agent's payoff

- ▶ A (pure) strategy of agent i is a mapping $s_i : 2^{N_i} \rightarrow \{0, 1\}$.
- ▶ Given a strategy profile s , agent i 's expected utility equals

$$U_i(s) := p(W(s))v_i - \mathbb{1}(s_i = 1),$$

where $\mathbb{1}(\cdot)$ is the indicator function.

Effort-inducing (EFI) mechanism

- ▶ A mechanism is EFI if there exists a *PBE* s.t. $W(s) = I$.
- ▶ Principal seeks the EFI mechanism with minimal total rewards.
- ▶ Denote the optimal mechanism $\{\pi^*, v^*(\pi^*)\}$.

PRELIMINARY ANALYSIS

Optimal Reward Scheme under Complementarity

Proposition 1.

Suppose p is complementary. For any fixed sequence π , the optimal reward scheme $v^*(\pi)$ pays agent i

$$v_i^*(\pi) = \frac{1}{p(I) - p(I \setminus (\{i\} \cup M_i))}.$$

Idea

- ▶ Agents shirk whenever they see anyone shirks.

Implications

- ▶ Agents face *implicit threats of shirking* if move sequentially.
- ▶ A more transparent action leads to a lower incentive cost.

Optimal Reward Scheme under Substitutability

Proposition 1'.

Suppose p is substitutable. For any fixed sequence π , the optimal reward scheme $v^(\pi)$ is invariant w.r.t. π and pays agent i*

$$v_i^*(\pi) = \frac{1}{p(I) - p(I \setminus \{i\})}.$$

Idea

- ▶ Agents substitute own efforts for observed shirking actions.

Implications

- ▶ Internal information has no impacts on the incentive costs.
- ▶ In what follows, assume that p is a complementary technology.

Sequential Moves and Importance Ranking

Lemma 1.

For any two agents i and j , if $ij \in g$, then $\pi_i^ \neq \pi_j^*$.*

Idea

- ▶ Simultaneous moves reduce the transparency of actions.

Lemma 2.

For any two agents i and j s.t. i is more important than j and $\{k | ik \in g, k \neq j\} = \{k | jk \in g, k \neq i\}$, if in π^ either $i \in M_j^*$ or $j \in M_i^*$, then $\pi_i^* > \pi_j^*$.*

Idea

- ▶ More important successors pose greater implicit threats.

FULL TRANSPARENCY BENCHMARK

Optimal Mechanism for Complete Networks

Complete network

- ▶ In a complete network, any two agents are neighbors.

Identity permutation

- ▶ Relabel the agents s.t. agent i is less important than $i + 1$.

Proposition 2.

If g is a complete network and the agents are increasingly important, then the optimal mechanism $\{\pi^, v^*\}$ satisfies that (i) π^* is the identity permutation; (ii) agent i has a reward*

$$v_i^* = \frac{1}{p(I) - p(\{j | j < i\})}.$$

Incentives and Discrimination

Corollary 1.

If g is a complete network, then under the optimal mechanism $\{\pi^, v^*\}$, v_i^* is increasing and strictly convex in i .*

Idea

- ▶ Transparency of agents' actions reduce their incentive costs.
- ▶ Effectiveness of transparency on incentives is diminishing.

Implications

- ▶ Differential rewards may occur even among identical agents.
- ▶ Similar agents may differ greatly under internal information.
- ▶ More important agents perform later and serve as monitors.
- ▶ Monitor incentivizes high efforts but is costly to incentivize.

Optimality of Complete Network

Corollary 2.

A complete network generates minimal total payoffs to the agents, and thus maximal payoff to the principal.

Idea

- ▶ Complete network yields the richest transparency.

Implications

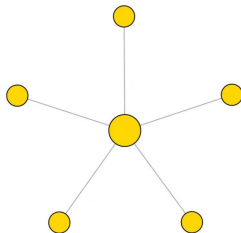
- ▶ Principal may wish to transform g into a complete network.
- ▶ “Open space” improves peer monitoring and reduces shirking.
- ▶ E.g., FB’s “war room”, RBS’s new headquarters building, etc.

A SINGLE TEAM

Star Network

Star network

- ▶ There is a unique node i s.t. every link in g involves i ;
- ▶ Agent i is the *center*, and the others are *peripheral agents*.
- ▶ Examples: scientific lab, construction, book editing, etc.



A Star Network

Center's Successors are More Important Peripherals

Lemma 3.

If in π^ the center has a nonempty set of predecessors and a nonempty set of successors, then the successors are uniformly more important than the predecessors.*

A sufficient statistic for the optimal sequence

- ▶ Let m be the number of center's successor(s), $0 \leq m \leq n - 1$.
- ▶ It suffices to pin down m given Lemma 3.

Identity permutation

- ▶ Relabel peripheral agents by rising importance from 1 to $n - 1$.
- ▶ Let center be the n -th (not necessarily the most important).

Total Rewards to Agents

According to Proposition 1

- ▶ Total rewards to agents are given by

$$\begin{aligned}
 V^*(m) = & \underbrace{\sum_{i=1}^{n-1-m} \frac{1}{p(I) - p(\{j|j < n - m\} \setminus \{i\})}}_{\text{payoffs to the predecessors}} \\
 & + \underbrace{\frac{1}{p(I) - p(\{j|j < n - m\})}}_{\text{payoff to the center}} + \underbrace{\sum_{i=n-m}^{n-1} \frac{1}{p(I) - p(I \setminus \{i\})}}_{\text{payoffs to the successors}}.
 \end{aligned}$$

Effects of Increasing Center's Successors

Marginal benefit of increasing m

- ▶ Reducing total rewards to center and his predecessors by

$$MB(m) := \sum_{i=1}^{n-2-m} \left[\frac{1}{p(I) - p(\{j|j < n - m\} \setminus \{i\})} - \frac{1}{p(I) - p(\{j|j < n - m - 1\} \setminus \{i\})} \right] + \frac{1}{p(I) - p(\{j|j < n - m\})}.$$

Marginal cost of increasing m

- ▶ Increasing total rewards to center's successors by

$$MC(m) := \frac{1}{p(I) - p(I \setminus \{n - m - 1\})}.$$

Optimal Sequence

Lemma 4.

$MB(m)$ is decreasing in m , while $MC(m)$ is nondecreasing in m .

Idea

- ▶ Effectiveness of transparency on incentives is diminishing.
- ▶ Fewer actions are observable as center has more successors.
- ▶ Each new successor is less important than the current ones.

Implications

- ▶ The optimal sequence is characterized by the integer

$$m^* := \min\{m \mid MB(m) \leq MC(m)\}. \quad (1)$$

- ▶ The sub-sequence of predecessors (successors) doesn't matter.

Optimal Mechanism for Star Networks

Proposition 3.

If g is a star network, then under the optimal mechanism $\{\pi^*, v^*\}$:

- (i) The center has m^* successor(s), each of them is more important than the center's predecessors, where m^* is given by (1) with $0 \leq m^* \leq n - 2$;
- (ii) v^* is given by Proposition 1 accordingly.
- (iii) Moreover, if $[p(I) - p(I \setminus \{n - 1\})] < \delta [p(I) - p(I \setminus \{n\})]$ for some small $\delta > 0$, then $m^* = 0$, where agent $n - 1$ is the most important peripheral agent and agent n is the center.

A simple algorithm to search the optimum

- ▶ Increase m from 0 in descending order of importance.
- ▶ Continue this process until $MB(m) \leq MC(m)$.

Comparative Statics: Importance of Individual Task

Parametric setting (Winter 2006)

- ▶ Let w be the number of agents who exert effort, $w \leq n$.
- ▶ The probability of success is $p(w) = \alpha^{n-w}$, $\alpha \in (0, 1)$.
- ▶ Lower α means the failure of individual task is more crucial.

Corollary 3.

In the optimal sequence π^ , the number of the center's successors $m^*(\alpha)$ is nondecreasing in α for $\alpha \in (0, 1)$.*

Idea

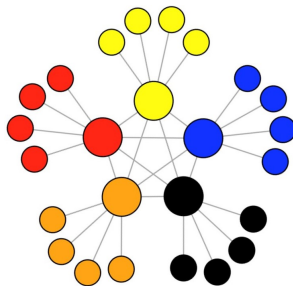
- ▶ If each task is important, agents are more willing to work.
- ▶ Implicit threat of shirking is not crucial in providing incentive.
- ▶ Thus, marginal benefit of increasing m is relatively low.

MULTIPLE COLLABORATING TEAMS

Multi-Star Network

Multi-star network

- ▶ Multiple ($t \geq 2$) stars with centers completely interconnected
- ▶ Examples: cross-laboratory research, modular design, etc.



A Multi-Star Network

Work Sequence cross and within Stars

Relative order of stars

- ▶ Let $\hat{n}_i \geq 3$ be the number of agents in star i , $i \in \{1, \dots, t\}$.
- ▶ Let c_i be the center of star i and $C := \{c_i\}$ the set of centers.
- ▶ Let π^C be the sub-sequence of centers confined to C .
- ▶ Lemma 1 implies that π^C should be completely sequential.

Internal sequence of stars

- ▶ Call a peripheral agent moving before own center *predecessor*.
- ▶ Call a peripheral agent moving after own center *successor*.
- ▶ Let m_i be the number of successors of star i , $0 \leq m_i \leq \hat{n}_i - 1$.

Homogeneous Agent Importance

- ▶ First, suppose that all the agents are equally important.

Marginal benefit of increasing m_i

- ▶ Reducing the rewards to c_i and each agent j s.t. $c_i \in M_j$.
- ▶ Marginal benefit of increasing m_i is higher if c_i moves later.

Marginal cost of increasing m_i

- ▶ Increasing the total rewards to c_i 's successors by

$$MC \equiv \frac{1}{p(n) - p(n-1)}.$$

Optimal Sequence with Homogeneous Importance

Lemma 5.

Suppose in π^* c_i moves before c_j , then (i) if $m_i > 0$, then $m_j = \hat{n}_j - 1$; (ii) if $m_j < \hat{n}_j - 1$, then $m_i = 0$.

Proposition 4.

The optimal sequence satisfies that for any two stars i and j such that i moves before j , (i) if $m_i = m_j = 0$, then $\hat{n}_i \geq \hat{n}_j$; (ii) if $m_i = \hat{n}_i - 1$, $m_j = \hat{n}_j - 1$, then $\hat{n}_i \leq \hat{n}_j$.

Implications

- ▶ The optimal sequence is “V-shaped” in terms of team size.
- ▶ The centers serve as internal information intermediaries.
- ▶ Proposition 4 rules out most suboptima: $t! - 2^t$ out of $t!$.

Simple Algorithm Given Optimal π^C

Corollary 4.

Suppose the optimal sub-sequence π^C has been determined, then π^ can be fully characterized by the following algorithm:*

- 1. Set each star i such that $m_i = 0$, $i \in \{1, \dots, t\}$;*
- 2. From the last star to the first star in π^C , increase m_i until*

$$MB \left(\sum m_i \right) \leq MC.$$

Two-stage algorithm for small numbers of teams

1. For each undominated π^C , apply the algorithm in Corollary 4;
2. Compare the total rewards in step 1 and select the optimum.

Bounds of the Total Number of Successors

Proposition 5.

Suppose π^* contains totally $\sum m_i^*$ successors. Then,

1. Align the stars in ascending order of \hat{n}_i , $i \in \{1, \dots, t\}$;
2. Apply Corollary 4 to this π^C , and let \bar{m} be the associated total number of successors;
- 1' Align the stars in descending order of \hat{n}_i , $i \in \{1, \dots, t\}$;
- 2' Apply Corollary 4 to this π^C , and let \underline{m} be the associated total number of successors.

It follows that $\underline{m} \leq \sum m_i^* \leq \bar{m}$.

Idea

- ▶ Increasing m_i is more profitable if actions are less transparent.
- ▶ Least action transparency when π^C is in ascending order of \hat{n}_i .

A Small Fraction of Agents are Monitors

Assumption 1.

For any positive integer $m \leq n - 1$, we have

$$\frac{1}{m}[p(n-1) - p(n-m-1)] \geq K[p(n) - p(n-1)]$$

for some constant $K > 0$.

Proposition 6.

Given Assumption 1, the optimal sequence satisfies that $\sum m_i^*$ is bounded above by some number of order \sqrt{n} .

Proof sketch

- ▶ $\sum m_i^*$ is smaller than m^* of a single star with the same size n .
- ▶ m^* is bounded above by some number that is of order \sqrt{n} .

Homogeneous Team Size

- ▶ Now, suppose that every team has the same size $\hat{n} \geq 3$.

Relative importance of stars

- ▶ Let r_i^k be the k -th important peripheral agent of star i .
- ▶ For stars i and j , i is more important than j if
 1. c_i is more important than c_j ;
 2. r_i^k is more important than r_j^k , for all $1 \leq k \leq \hat{n} - 1$.
- ▶ Assume that the teams are totally ordered w.r.t. importance.

Optimal Sequence with Homogeneous Team Size

Assumption 2.

For any subsets of agents S , S' and T such that S is more important than S' and $T \cap (S \cup S') = \emptyset$, we have

$$p(S \cup T) - p(S) \geq p(S' \cup T) - p(S').$$

Proposition 7.

The optimal sequence π^ satisfies that*

- (i) In each star, successors are more important than predecessors;*
- (ii) Each successor in star i is more important than every predecessor in each star that moves after i .*
- (iii) If Assumption 2 holds, then the stars move in ascending order of importance; thus, m_i^* is nondecreasing along π^* .*

Simple Algorithm for Highly Differential Importance

Corollary 5.

Given Assumption 2. Suppose for any two stars i and j such that i is more important than j , $r_i^{\hat{n}-1}$ is more important than r_j^1 , then π^ can be fully characterized by the following algorithm:*

- 1. Align the stars in ascending order of importance, and set each star i such that $m_i = 0$;*
- 2. In the last star, make the most important peripheral agent a successor, then the second important peripheral agent, etc. When every peripheral agent becomes successor, move backward one star and continue this procedure;*
- 3. Continue until the total rewards start to increase.*

Summary

We studied a team incentive design problem in which

- ▶ Agents are located on a network and work on a joint project.
- ▶ Principal chooses the work sequence and the reward scheme.
- ▶ Network and sequence jointly determine internal information.
- ▶ Principal seeks the least-cost effort-inducing mechanism.

Main results

- ▶ Under complementarity, action transparency motivates efforts.
- ▶ Effectiveness of transparency on incentives is diminishing.
- ▶ Agents work sequentially and more important ones work later.
- ▶ Larger sub-teams are assigned to either end of the sequence.
- ▶ Monitors account for a small share and cluster in later stages.