Innovation Contests with Distinct Approaches

Simon Block

University of Bonn

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Innovation Contests

- Principal sets up a contest to induce agents to create an innovation.
- Principal’s objective: successful innovation (not just effort).
- Common uncertainty: is innovation feasible?
- Agents engage in a race:
  - fixed quality standard
  - variable date of discovery
**Idea:** There may be distinct approaches leading to the desired innovation.
Distinct Approaches

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**Example:** Vaccines can be categorized into distinct approaches.

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**Figure 1:** *from "The race for coronavirus vaccines"* (Ewan Callaway, nature news feature, 28.4.20)
Distinct Approaches

Idea: There may be distinct approaches leading to the desired innovation.

Example: Different technologies to remove $CO_2$ from the atmosphere.

Figure 2: $100M XPRIZE for a carbon removal technology (site: xprize.org)
Correlated Successes

Figure 3: Stock prices BioNTech and Moderna, November 2020

- **9 Nov**: Biontec ↑↑, Moderna ↑
- **16 Nov**: Biontec ↓, Moderna ↑
How do approaches differ?

1. *Viability*: different costs, and probabilities of success.
2. *Correlation* of successes within approaches.

Main results: Are approach-independent contests efficient? In general not. Why not? Correlation of success on promising approaches; fast approaches crowding out slower approaches. How to identify the efficient assignment of agents to approaches? With a greedy algorithm if costs are equal. How can a desired behavior be implemented? Contest with approach-specific prizes.
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1. Viability: different costs, and probabilities of success.
2. Correlation of successes within approaches.
3. Timing of successes: fast or slow.

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- *How to identify the efficient assignment of agents to approaches?*
  - With a greedy algorithm if costs are equal.
- *How can a desired behavior be implemented?*
  - Contest with approach-specific prizes.
Related Literature


Model: Agents and Approaches

- $N$ identical, risk-neutral agents; 2 Periods.
- $K$ distinct approaches $\{a_1, ..., a_K\} =: \mathcal{A}$.
- Unobservable state of the world: $(\theta_{a_1}, ..., \theta_{a_K}) \in \{\text{Good, Bad}\}^K$. 

Actions and successes publicly observed.
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- $\theta_{a_1}, ..., \theta_{a_K}$ independent, common prior:
  \[ P_a := \mathbb{P}(\theta_a = \text{Good}) \quad \text{for all} \quad a \in \mathcal{A}. \]
- Approach $a \in \mathcal{A}$ described by:
  \[ (\lambda_{a,1}, c_{a,1}), (\lambda_{a,2}, c_{a,2}). \]
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**Period 1:**

1. Each agent chooses
   - to follow an approach $a \in \mathcal{A}$,
   - or to abstain.

2. All agents following $a \in \mathcal{A}$
   - incur cost $c_{a,1}$,
   - succeed with prob. $\lambda_{a,1}$
     - if $\theta_a = \text{Good}$. 

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Model: Agents and Approaches

- $N$ identical, risk-neutral agents; 2 Periods.
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- Unobservable state of the world: $(\theta_{a_1}, \ldots, \theta_{a_K}) \in \{\text{Good, Bad}\}^K$.
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   - Actions and successes publicly observed.

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Model: Principal and Contests

- **Principal:**
  - valuation $v$ for first success, 0 for subsequent,
  - cares about the rewards she has to pay, risk-neutral,
  - selects a *contest* before period 1.
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  1. is anonymous,
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- **Equilibrium:**
  - Perfect Bayesian equilibrium in pure strategies,
  - potentially asymmetric.
Static Case \([\lambda_{a,2} = 0]\)

- Notation: for all \(a \in A\),
  - \(P_a := \mathbb{P}(\theta_a = \text{Good})\),
  - \(\lambda_a := \lambda_{a,1} := \mathbb{P}(\text{"i succeeds by following } a\text{"} | \theta_a = \text{Good})\),
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- Unconditional probability of success: \(P_a \lambda_a\)

- Correlation of successes within approach:
  \[
  \rho_a = \text{Corr}(\mathbb{1}_{\{i\text{ succeeds on \(a\)}\}}, \mathbb{1}_{\{j\text{ succeeds on \(a\)}\}}) = 1 - \frac{1 - \lambda_a}{1 - P_a \lambda_a}.
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- Holding \(P_a\lambda_a\) fixed:
  - \(\lambda_a \uparrow \implies \rho_a \uparrow\)
  - \(P_a \uparrow \implies \lambda_a \downarrow \implies \rho_a \downarrow\)
- Extremes:
  - \(\lambda_a = 1 \implies \rho_a = 1\)
  - \(P_a = 1 \implies \rho_a = 0\)
Example 1:

- 2 agents: 1 and 2
- 2 approaches: A and B:
  - identical costs: \( c_A = c_B = c \)
  - A more viable: \( P_B \lambda_B = \frac{1}{4} < P_A \lambda_A = \frac{2}{3} \)

- large \( v \), large approach-independent prize \( w \)
Correlation Matters

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  \[ P_B \lambda_B (1 - P_A \lambda_A) \leq P_A \lambda_A (1 - \lambda_A) \iff \lambda_A \leq \frac{7}{8} \]
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**Insight**

An approach-independent contest may induce inefficient equilibrium behavior.
Efficient Assignment

Proposition 1

If all approaches have equal costs, then a greedy algorithm that always adds the approach with the highest marginal benefit, until no approach has a positive marginal benefit, or until all agents are assigned identifies the social optimum.
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identifies the social optimum.
Pseudo marginal social benefit: Denote by $mb_{a,i}(\pi)$ the hypothetical marginal social benefit of
an additional agent following $a$,
conditional on $i$ failures on $a$, and
given that some other agent will succeed with probability $\pi$. 

$$mb_{a,i}(\pi) := \mu_i(a) \lambda a (1 - \pi) \cdot v - c_a 0 1 v P a \lambda a \cdot v - c_a \mu_1(a) \lambda a \cdot v - c_a \mu_2(a) \lambda a \cdot v - c_a - c_a mb_{a,0}(\pi) mb_{a,1}(\pi) mb_{a,2}(\pi)$$
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mb_{a,i}(\pi) := \mu_i(a) \lambda_a (1 - \pi) \cdot v - c_a
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$m_{ba,i}(\pi)$
Proposition 2

If $c > 0$ and $P_a > 0$ for all approaches, then the principal can uniquely implement any action profile, and extract (almost) the entire social surplus at the same time, by selecting suitable approach-specific prizes $w_{a_1}, \ldots, w_{a_k}$ excluding permutations

$w_a := \#(\text{agents the principal wants to follow } a) P(\text{At least one of these agents succeeds}) (c_a + \epsilon)$

Corollary

It is optimal for the principal to implement the social optimum.
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It is optimal for the principal to implement the social optimum.
Two Periods: crowding-out

Example 2

- Approach-independent prize \( w \)
- Two agents 1 and 2
- Two approaches \( A \) and \( B \): \( P_A = P_B = 1 \),

Equilibria for varying \( w \):

- Both abstain: \( \pi = 0 \)
- 1 agent follows \( B \): \( \pi = \frac{2}{3} \)
- 1 agent follows \( A \): \( \pi = \frac{1}{2} \)
- Both follow \( A \): \( \pi = \frac{3}{4} \)

Insights

- Increasing \( w \) can cause decrease in probability of success. (crowding-out)
- Even for large \( w \), equilibrium behavior can be inefficient.
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A \text{ is faster: } (\lambda_{A,1}, c_{A,1}), (\lambda_{A,2}, c_{A,2}) = \left( \frac{1}{2}, c \right), (0, 0),
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B \text{ is more effective: } (\lambda_{B,1}, c_{B,1}), (\lambda_{B,2}, c_{B,2}) = (0, c), \left( \frac{2}{3}, 0 \right).
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\begin{align*}
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Two Periods: crowding-out

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Equilibria for varying $w$:

- Both abstain: $\pi = 0$
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- $2c$: $\pi = \frac{1}{2}$
- $\frac{8}{3}c$: $\pi = \frac{3}{4}$
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**Insights**
- Increasing \( w \) can cause decrease in probability of success. (crowding-out)
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**Insights**
- Increasing $w$ can cause decrease in probability of success. (crowding-out)
- Even for large $w$, equilibrium behavior can be inefficient.
Approach-independent contests are potentially inefficient. Possible causes:

1. High correlation on most viable approaches.
2. Crowding-out effect.

When costs are equal, a greedy algorithm determines the efficient assignment. (Otherwise this is a hard problem.)

Approach-specific prizes: strong tool to implement desired behavior in the static case. (Can be extended to dynamic setting if v and N are large enough.)