Procurement Design with Optimal Sequential R&D

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Introduction

- Procurement
  - **A buyer** seeks to procure a service/good among multiple potential **suppliers**
- Procurement bidding
  - The buyer elicits private provision costs
  - Pay information rent
- We consider: suppliers don't endowed with information about own provision costs
  - To learn own provision cost, must go through costly R&D process
  - R&D cost
    - e.g., testing, accounting, proposals

Introduction Cont.

- To elicit information about provision cost
  - information rent, as well as R&D cost (provide incentive for them to learn provision cost)
- Whether to elicit information about provision cost?
  - R&D cost?
  - Contribution to procurement cost reduction?
- Optimal procurement mechanisms in this environment?
  - When to elicit?

Procurement Mechanism

- Suppliers
  - R&D cost: initial private information
  - Provision cost: after incur R&D cost
- Procurement Mechanisms
  - A sequential shortlisting procedure + final procurement bidding stage
- Shortlisting: inviting candidate suppliers to go through the R&D process and participate final bidding stage.
  - Seq. Shortlisting: contingent on seq. reports

Related Literature

- Auctions with costly entry
  - McAfee and McMillan, 1987; Engelbrecht-Wiggans, 1993; Tan, 1992; Levin and Smith, 1994; and Ye, 2004
  - Samuelson, 1985; Stegeman, 1996; Campbell, 1998; Menezes and Monteiro, 2000; Tan and Yilankaya, 2006; Cao and Tian, 2009; and Lu, 2009
  - Ye, 2007; Quint and Hendricks, 2013
  - Lu and Ye, 2013, 2016
- Dynamic revenue-maximizing mechanism design
  - Baron and Besanko, 1984; Courty and Li, 2000; Eso and Szentes, 2007; Mezzetti, 2007; Li and Shi, 2016
    - Two-stage sequential screening problem
  - Battaglini, 2005; Pavan, Segal, and Toikka, 2014; and Bergemann and Strack, 2015
    - Infinitehorizon Markovian environments

Related Literature Cont.

- Information acquisition
  - Persico, 2000; Compte and Jehiel, 2001; Bergemann et al., 2009; and Rezende, 2013
    - fix the mechanism, study information acquisition
  - Bergemann and Valimaki (2002); Shi (2012)
    - mechanism design approach and taking information acquisition into account

The Model

- A buyer needs to acquire a good/service from N potential suppliers
  - minimizing the procurement costs
  - $\Omega = \{1, 2, ..., N\}$
- Each supplier
  - R&D cost c_i: initial private information
    - $c_i \sim \Phi$ over $[\underline{c}, \overline{c}]$, density function φ
  - provision cost α_i: after incur R&D cost
    - $\alpha_i \sim F$ over $[\underline{\alpha}, \overline{\alpha}]$, density function f

Assumption

- c_i and α_i are independent
- (c_i, α_i) are independent across i
- Assumption 1: $c + \frac{\Phi(c)}{\varphi(c)}$ increases in c

Mechanism

- Mechanism: $(\mathbf{p}, \mathbf{x}, M)$
- $M(\geq 1)$ shortlisting stage with $(M+1)th$ final bidding stage
  - Stage 1: All N potential suppliers report initial R&D costs $c_i s$, denote $\mathbf{m}_1 = (m_{1,i})$ where $m_{1,i} = c_i$.
    - $\forall g_1 \in 2^{\Omega}$, shortlisting with prob. $p^{g_1}(\mathbf{m}_1)$; $\forall i$, transfer $x_{1,i}(\mathbf{m}_1)$
    - If shortlisting g_1, discover provision cost α_i at expense of c_i
  - Stage 2: Based on additional reports from g_1, denote $\mathbf{m}_2 = (m_{2,i})$ where $m_{2,i} = \begin{cases} \alpha_i & i \in g_1 \\ \phi & i \notin g_1 \end{cases}$.
    - $\forall g_2 \in 2^{\Omega \setminus g_1}$, shortlisting with prob. $p^{g_2}(\mathbf{m}_1, \mathbf{m}_2 | g_1)$; $\forall i$, transfer $x_{2,i}(\mathbf{m}_1, \mathbf{m}_2)$
    - If shortlisting g_2, discover provision cost α_i at expense of c_i
  - Stage Continues

Mechanism Cont.

- Stage M: Based on additional reports from g_{M-1}, denote $\mathbf{m}_M = (m_{M,i})$ where $m_{M,i} = \begin{cases} \alpha_i & i \in g_{M-1} \\ \phi & i \notin g_{M-1} \end{cases}$.
    - $\forall g_M \in 2^{\Omega \setminus \cup_{i=1}^{M-1} g_i}$, prob. $p^{g_M}(\mathbf{m}_1, ..., \mathbf{m}_M | g_1, ..., g_{M-1})$; $\forall i$, transfer $x_{M,i}(\mathbf{m}_1, ..., \mathbf{m}_M)$
    - If shortlisting g_M, discover provision cost α_i at expense of c_i
- Stage M+1: $m_{M+1,i} = \begin{cases} \alpha_i & i \in g_M \\ \phi & i \notin g_M \end{cases}$
    - outcome $g = \{g_1, g_2, ..., g_M\}$, $G_g = \cup_{i=1}^{M} g_M$
    - $\forall i \in G_g$, $p_i^{G_g}(\mathbf{m}_1, ..., \mathbf{m}_{M+1})$; $\forall i$, transfer $x_{M+1,i}(\mathbf{m}_1, ..., \mathbf{m}_{M+1})$
- Focus on $M \geq N$, and observable α_i first
    - can be relaxed

Objective Function

$$TC = E_c E_\alpha[\sum_{\forall \mathbf{g}} \Pr(\mathbf{g}|\mathbf{c},\boldsymbol{\alpha})(\sum_{i \in G_{\mathbf{g}} \cup \{0\}} p_i^{G_{\mathbf{g}}}(\mathbf{c}, \mathbf{m}_2^{\boldsymbol{\alpha}}, ..., \mathbf{m}_{M+1}^{\boldsymbol{\alpha}})\alpha_i)]$$
$$+E_{\mathbf{c}} E_{\boldsymbol{\alpha}}[\sum_{G \in 2^\Omega} \Pr(G|\mathbf{c},\boldsymbol{\alpha}) \sum_{i \in G}(c_i + \frac{\Phi(c_i)}{\varphi(c_i)})] + \sum_i U_i(\overline{c}).$$

Lemma

For any $\{\Pr(G|\mathbf{c},\boldsymbol{\alpha}), \forall G \in 2^\Omega, \mathbf{c}, \boldsymbol{\alpha}\}$*, the principal should set* $U_i(\overline{c}) = 0$ *and adopt an efficient procurement in the final stage.*

$$TC = E_{\mathbf{c}} E_{\boldsymbol{\alpha}}\{\sum_{G \in 2^\Omega} \Pr(G|\mathbf{c},\boldsymbol{\alpha})(\min\{\{\alpha_i\}_{i \in G}, \alpha_0\} + \sum_{i \in G}(c_i + \frac{\Phi(c_i)}{\varphi(c_i)}))\}. \quad (1)$$

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  - Optimal $\{\Pr(G|\mathbf{c},\boldsymbol{\alpha}), \forall G \in 2^\Omega, \mathbf{c}, \boldsymbol{\alpha}\}$?

Optimal Shortlisting

Lemma

Shortlisting one agent at a stage until the last being shortlisted yields weakly lower procurement cost than other rules.

- Any $\{\Pr(G|\mathbf{c}, \boldsymbol{\alpha}), \forall G \in 2^{\Omega}, \mathbf{c}, \boldsymbol{\alpha}\}$ derived from a general shortlisting procedure can be duplicated by this rule

Lemma

At the optimum, at each stage there is no loss of generality for the principal to either shortlists an agent with probability 1 *or stop shortlisting.*

- Compare TCs

Lemma

At any stage, the principal should shortlist the one who has the lowest virtue cost $c_i + \frac{\Phi(c_i)}{\varphi(c_i)}$ *among the remaining players or stop shortlisting.*

Optimal Shortlisting Rule

Theorem

(i) $\forall t_0 \in \{1, ..., N\}$ *and* G^{t_0-1}, *let*
$i^*_{t_0} \in \arg\min_{i \in \Omega \setminus G^{t_0-1}} [c_i + \frac{\Phi(c_i)}{\varphi(c_i)}]$ *and*
$\delta_{t_0} = \min\{\{\alpha_i\}_{i \in G^{t_0-1}}, \alpha_0\} - E_{\alpha_{i^*_{t_0}}} \min\{\alpha_{i^*_{t_0}}, \{\alpha_i\}_{i \in G^{t_0-1}}, \alpha_0\}$. *If*
$\delta_{t_0} \geq (c_{i^*_{t_0}} + \frac{\Phi(c_{i^*_{t_0}})}{\varphi(c_{i^*_{t_0}})})$, *shortlisting* $i^*_{t_0}$ *with probability* 1 *is optimal; if*
$\delta_{t_0} < (c_{i^*_{t_0}} + \frac{\Phi(c_{i^*_{t_0}})}{\varphi(c_{i^*_{t_0}})})$, *the shortlisting process stops. (ii) The last stage procurement is efficient.*

Optimal M

- W.L.O.G., $M = N$.
  - $M > N$: optimal shortlisting procedure lasts N stages at most
  - $M < N$: a shortlisting procedure $(\mathbf{p}, \mathbf{x}, M)$ with $M < N$ can be duplicated by $(\mathbf{p}, \mathbf{x}, M)$ with $M = N$
    - no shortlisting prob., no transfer

Private Provision costs

Theorem

Under Assumption 1*, the shortlisting rule and the final provider allocation rule of Theorem 1 are truthfully implementable when both R&D and provision costs are private information of the agents.*

Private Provision costs

- Report on provision cost α_{i_k}
- At a shortlisting stage $k+1$, agent i_k, i.c. requires that $\pi_{i_k}(\alpha_{i_k}, \alpha_{i_k}; \mathbf{c}, (\alpha_j)_{j=1}^{k-1}) - \pi_{i_k}(\alpha_{i_k}, \widehat{\alpha}_{i_k}; \mathbf{c}, (\alpha_j)_{j=1}^{k-1}) \geq 0$
- By the envelop theorem

$$\pi_{i_k}(\alpha_{i_k}, \alpha_{i_k} | \mathbf{c}, (\alpha_j)_{j=1}^{k-1})$$

$$= \int_{\alpha_i}^{\bar{\alpha}} E_{(\alpha_{i_{k+1}}, \dots, \alpha_{i_N})} \sum_{\forall h=k}^{M} \Pr^*(\mathbf{g}_{k,h} | \mathbf{c}, \boldsymbol{\alpha}_{-i_k}, y) p_{i_k}^{*G_{\mathbf{g}_{k,h}}}(\mathbf{c}, \boldsymbol{\alpha}_{-i_k}, y) dy,$$

  - where $\mathbf{g}_{k,h} = (g_1 = \{i_1\}, g_2 = \{i_2\}, \dots, g_{k-1} = \{i_{k-1}\}, \dots, g_h = \{i_h\}, g_{h+1} = \emptyset, \dots, g_M = \emptyset)$, $h \geq k \geq 1$ is a sequence of the shortlisted suppliers

- $\sum_{\forall h=k}^{M} \Pr^*(\mathbf{g}_{k,h} | \mathbf{c}, \boldsymbol{\alpha}_{-i_k}, \hat{\alpha}_{i_k}) p_{i_k}^{*G_{\mathbf{g}_{k,h}}}(\mathbf{c}, \boldsymbol{\alpha}_{-i_k}, \hat{\alpha}_{i_k})$ decreases with $\hat{\alpha}_{i_k}$
  - implies i.c

Private Provision costs

- Initial reporting stage: we have to examine a bidder's incentive to report his R&D cost c_i
  - A miss-reported R&D cost would change the shortlisting sequence
- However, when the agent is called on to report his provision cost α_i, the incentive does not depend on his R&D cost
- When turn to the incentive compatibility at the first stage, it is WLOG to consider a candidate must report his provision cost truthfully
  - When called on, i must report his provision cost truthfully regardless of his first stage report.

Private Provision costs

- Initial reporting stage: i.c. requires $U_i(c_i, c_i) \geq U_i(c_i, \widehat{c}_i)$
- By setting $U_i(\bar{c}, \bar{c}) = 0$,

$$U_i(c_i, c_i) = E_{\mathbf{c}_{-i}} \int_{c_i}^{\bar{c}} E_{\boldsymbol{\alpha}} \{ \sum_{\forall h \text{ s.t. } k \leq h \leq M, . \widehat{c}_i \leq c_{i_h}} \Pr^*(\mathbf{g}_{k,h} | \mathbf{c}_{-i}, y, \boldsymbol{\alpha}) \} dy$$

- The transfer $x_i(c_i, \mathbf{c}_{-i})$ is constructed following the envelope condition

Concluding Remarks

- Optimal Sequential Shortlisting in Procurement Bidding
  - suppliers doesn't know provision costs after costly R&D process
- Rank the candidate and Compare cost and contribution
- Shortlisting one by one
  - Better coordinate entry
  - Batter control information
- Whether to observe provision cost after discovery doesn't matter
  - Transfer

Thanks!