Uncertainty in Procurement Contracting with Time Incentives

Wenzheng Gao	Daiqiang Zhang	Naibao Zhao
Nankai University	University at Albany	RIEM, SWUFE

School of Economics
Sichuan University
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Motivation

Public procurement: a government agency purchases of goods and services

- with 10-20% of a country's GDP (World Bank Procurement Statistics, 2018)
- In US, 19% of GDP in FY 2017 (USspending.gov)

Auctions plays a critical role in public procurement

- Standard: first-price low-bid auction
- Innovative contracting practices: multiple attributes mechanism

Post-auction uncertainty is an inherent component in many auctions

- e.g: construction, oil tracts, timber auctions (Eso and White, 2004; Luo, Perrigne, and Vuong, 2018a)

Motivation

a highway construction example

- A+B auction in a California highway procurement

	A (costs: \$M)	B (length: days)	score (\$M = A+\$13,800×B)
Harzard Construction Company	10.250	200	13.010
Hanson SJH Construction	11.162	185	13.715
F C I Constructions Inc	10.295	124	12.006

- Unexpected shocks in construction stage
  - technical and logistical shocks (Perry and Hayes, 1985)

Research Questions

To evaluate the efficiency of multi-attribute mechanisms in the presence of uncertainty:

1. Ex-post efficient
   Regardless of which contractor wins the contract,whether or not the winner can always maximizes social welfare?
2. Ex-ante efficient
   If the contract is always awarded to the bidder who generates the highest social welfare in equilibrium for all uncertainties?

This Paper

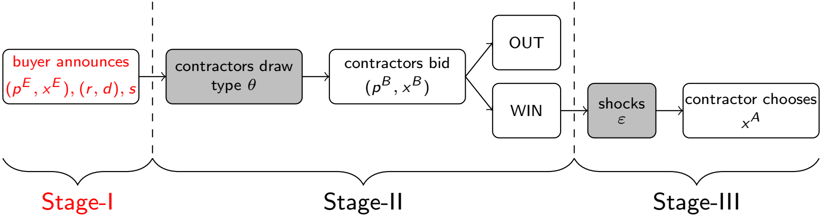
1. Develops a structural model of A+B procurement contract with time incentives and post-auction construction uncertainty.
2. Presents a semi-parametric identification of model primitives including contractor's cost function, distribution of the private type, distribution of post-auction uncertainty.
3. Proposes a constructive multi-step semi-parametric estimation procedure.
4. Compares welfare between A+B and lane rental contracts in California through a counterfactual analysis.

Related Literature

1. Ex post uncertainty (Eso and White, 2004; Hendricks and Porter, 1988; Haile, 2001; Bajari, Houghton, and Tadelis, 2014; Luo, Perrigne, and Vuong, 2018a).
2. Multidimensional mechanisms in procurement situations (Che, 1993; Branco, 1997; Fang and Morris, 2006; Asker and Cantillon, 2008)
3. Identification of auctions/contracts (Guerre, Perrigne, and Vuong, 2000; Jofre-Bonet and Pesendorfer, 2003; Krasnokutskaya, 2011; Hu, McAdams, and Shum, 2013; Gentry and Li, 2014; Li, Lu, and Zhao, 2015; Luo, Perrigne, and Vuong, 2018a,b; An and Tang, 2019)
4. Empirical literature on auctions with multidimensional contract attributes (e.g., Levin and Athey, 2001; Lewis and Bajari, 2011; Bajari, Houghton, and Tadelis, 2014; Koning and Van De Meerendonk, 2014; Krasnokutskaya, Song, and Tang, 2018).

Setup

timing and decisions

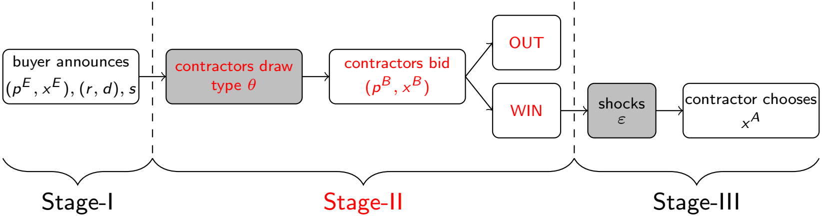


S-I: Pre-contractual: A risk-neutral buyer seeks to procurer a highway project

- (p^E, x^E): engineer's estimates of project cost and working days
- $s = p^B + x^B c_u$: a continuous preference of the procurer over (p^B, x^B)
- (r, d): daily cash bonus for early completion and penalty for late completion

Setup

timing and decisions

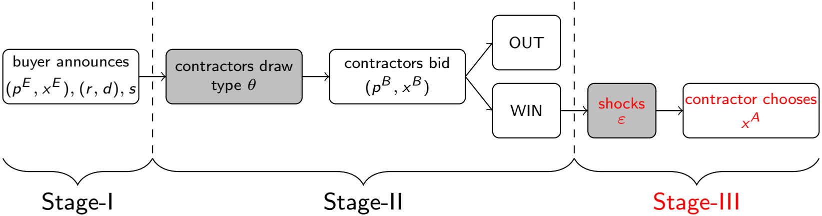


S-II: Bidding : $N \geq 2$ potential risk-neutral bidders compete

- private type $\theta_i \overset{i.i.d}{\sim} F_\Theta(\cdot)$ with $\mathcal{S}_\Theta \subset \mathbb{R}_+$ for bidder $i \in \mathcal{N} = \{1, \cdots, N\}$
- submit bid pair (p^B, x^B)

Setup

timing and decisions



S-III: Construction:

- ε: post-auction uncertainty
- x^A: actual working days

Setup

contractor's realized costs

$$\underbrace{TC(x^A, x^B, r, d, \theta, \varepsilon)}_{\text{total costs}} = \underbrace{\varepsilon c(x^A, \theta)}_{\text{construction costs}} + \underbrace{K(x^A, x^B, r, d)}_{\text{incentive costs}}$$

– Mutiplicative structure

- construction uncertainty $\varepsilon \sim F(\cdot)$, and ε is independent of θ.
- deterministic cost $c(x, \theta)$

A1. The deterministic cost function $c(x^A, \theta)$ satisfies:

- $c(x^A, \theta)$ is strictly decreasing convex in working days x^A.
- $c(x^A, \theta)$ is strictly increasing in private type θ.
- $c_1(x^A, \theta)$ is strictly decreasing in type θ.

Setup

contractor's realized costs

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- Incentive costs are given by:

$$K(x^A, x^B, r, d) = \left[r \cdot \mathbb{1}_{x^A < x^B} + d \cdot \mathbb{1}_{x^A > x^B}\right]\left(x^A - x^B\right)$$

  - x^A are actual working days, x^B are bidding days.
  - r is the daily incentive rate, d is the daily disincentive rate, $r < d$.

Equilibrium
backward induction

2nd In the construction stage, for any given (p^B, x^B), (r, d), θ and ε,

$$\widetilde{x}^{A^*}(x^B, r, d, \theta, \varepsilon) = \operatorname*{argmin}_{x^A}\Big\{ TC(x^A, x^B, r, d, \theta, \varepsilon) \Big\}$$

Equilibrium

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1st In the bidding stage,

$$\Big(p^{B^*}(r, d, c_u, \theta), x^{B^*}(r, d, c_u, \theta)\Big) = \underset{p^B, x^B}{\operatorname{argmax}} \Bigg\{ \Bigg(p^B - \mathbb{E}_\varepsilon \Big[TC(\widetilde{x}^{A^*}, x^B, r, d, \theta, \varepsilon) \Big] \Bigg) \times \Pr\Big(\text{win} \,\Big|\, s = p^B + x^B c_u \Big) \Bigg\}$$

Equilibrium

in the bidding (1st) stage

$$\left(p^{B^*}(r,d,c_u,\theta), x^{B^*}(r,d,c_u,\theta)\right) = \operatorname*{argmax}_{p^B, x^B} \Bigg\{ \left(p^B - \mathbb{E}_\varepsilon\left[TC(\widetilde{x}^{A^*}, x^B, r, d, \theta, \varepsilon)\right]\right) \times \Pr\left(\text{win} \,\middle|\, s = p^B + x^B c_u\right) \Bigg\}$$

Equilibrium

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$$\left(p^{B^*}(r,d,c_u,\theta), x^{B^*}(r,d,c_u,\theta)\right) = \underset{p^B,x^B}{\operatorname{argmax}} \left\{ \left(p^B - \mathbb{E}_\varepsilon\left[TC(\widetilde{x}^{A^*}, x^B, r, d, \theta, \varepsilon)\right]\right) \times \Pr\left(\text{win} \,\middle|\, s = p^B + x^B c_u\right) \right\}$$

which is equivalent to

$$s(v(r,d,c_u,\theta)) = \underset{b}{\operatorname{argmax}} \left\{ \big(b - v(r,d,c_u,\theta)\big) \Pr(\text{win} \mid b) \right\} \tag{1}$$

where

$$v(r,d,c_u,\theta) = \min_{x^B} \left\{ c_u x^B + \mathbb{E}_\varepsilon\left[TC(\widetilde{x}^{A^*}, x^B, r, d, \theta, \varepsilon)\right] \right\} \tag{2}$$

Equilibrium

Proposition 1

Under A1, there exists a unique symmetric psBNE $\left(p^{B^*}, x^{B^*}, x^{A^*}\right)$ for the A+B contract such that for any θ:

(i) The equilibrium bid for working days is

$$x^{B^*}(r, d, c_u, \theta) = \underset{x^B}{\operatorname{argmin}} \Big\{ c_u x^B + \mathbb{E}_\varepsilon \Big[TC(\widetilde{x}^{A^*}, x^B, r, d, \theta, \varepsilon) \Big] \Big\}.$$

Moreover,

$$dx^{B^*}(\theta)/d\theta > 0.$$

Equilibrium

Proposition 1

Under A1, there exists a unique symmetric psBNE $\left(p^{B^*}, x^{B^*}, x^{A^*}\right)$ for the A+B contract such that for any θ:

(ii) The equilibrium actual number of working days is

$$x^{A^*}(r,d,c_u,\theta,\varepsilon) = \widetilde{x}^{A^*}(x^{B^*},r,d,\theta,\varepsilon) = \begin{cases} x^r(r,d,\theta,\varepsilon), & \text{if } \ \varepsilon \leq e^r \\ x^{B^*}(r,d,c_u,\theta), & \text{if } \ \varepsilon \in [e^r, e^d] \\ x^d(r,d,\theta,\varepsilon), & \text{if } \ \varepsilon \geq e^d \end{cases}$$

where,

$$\varepsilon^r(\theta, x^{B^*}(r,d,c_u,\theta)) = e^r \quad < \quad \varepsilon^d(\theta, x^{B^*}(r,d,c_u,\theta)) = e^d$$

Equilibrium

Proposition 1

Under A1, there exists a unique symmetric psBNE $\left(p^{B^*}, x^{B^*}, x^{A^*}\right)$ for the A+B contract such that for any θ:

(iii) The equilibrium bid for cost is

$$
\begin{aligned}
p^{B^*}(r, d, c_u, \theta) = & \mathbb{E}_\varepsilon\Big[TC(x^{A^*}(r, d, c_u, \theta, \varepsilon), x^{B^*}, r, d, \theta, \varepsilon)\Big] \\
& + \int_\theta^{\overline{\theta}} \mathbb{E}_\varepsilon[\varepsilon \cdot c_2(x^{A^*}(r, d, c_u, \theta, \varepsilon), \theta)] \left[\frac{1 - F_\Theta(t)}{1 - F_\Theta(\theta)}\right]^{N-1} dt
\end{aligned}
$$

Efficiency

definitions

In a similar spirit to Lewis and Bajari (2011), social welfare is defined as:

$$\underbrace{W(x^A, c_s, \theta, \varepsilon)}_{\text{social welfare}} = \underbrace{V_c}_{\text{social value}} - \Big[\underbrace{\varepsilon \cdot c(x^A, \theta)}_{\text{construction cost}} + \underbrace{c_s x^A}_{\text{commuter cost}} \Big]$$

Efficiency

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- Ex-post efficiency: for all θ and ε,

$$x_o^A(c_s, \theta, \varepsilon) = \operatorname*{argmin}_{x^A} \Big\{ \varepsilon \cdot c(x^A, \theta) + c_s x^A \Big\}$$

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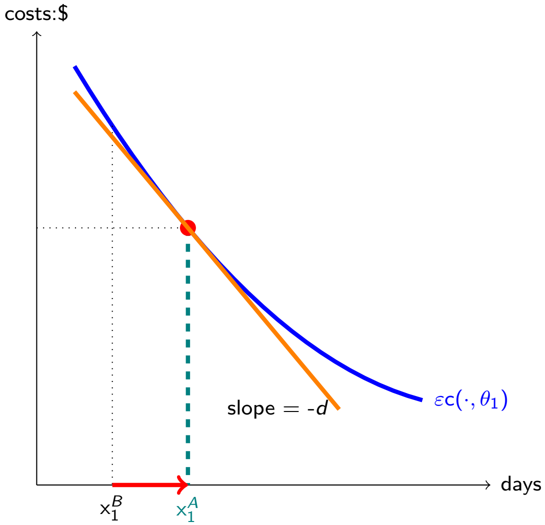
– Ex-ante efficiency: for all ε,

$$\partial W^*(r, d, c_u, c_s, \theta, \varepsilon)/\partial\theta = \partial W(x^{A^*}(r, d, c_u, \theta, \varepsilon), c_s, \theta, \varepsilon)/\partial\theta < 0$$

Efficiency

an illustration of ex-ante inefficiency under a “negative” shock



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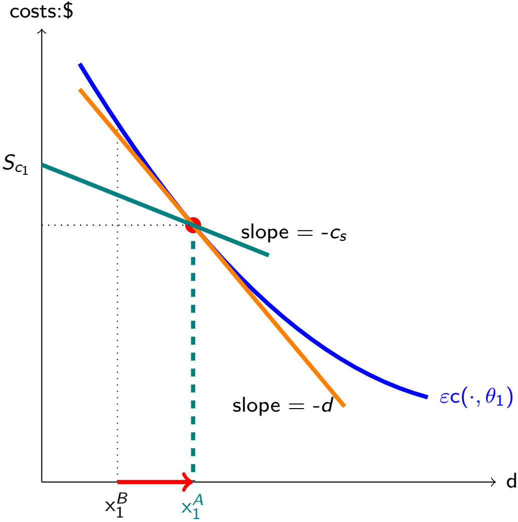

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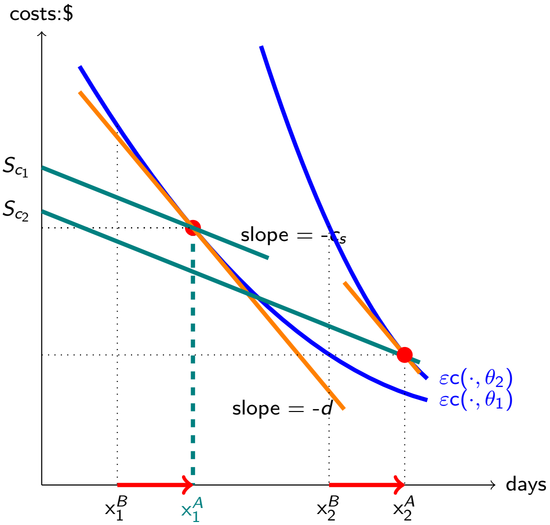

Efficiency

Proposition 2

Under A1, the A+B contract in the presence of uncertainty is ex ante efficient if $r < d \leq c_S$, but it cannot be ex post efficient.

Recap Research Questions

To quantify the difference in efficiency between alternative mechanisms.

The equilibrium social welfare is defined as

$$W^*(x^{A^*}, c_s, \underbrace{\theta, \varepsilon; c(\cdot,\cdot)}_{\text{unknown}})$$

- Need to get estimates of unknown parameters.

Bridge Between Theory and Data

identification problem

If the data report (P^B, X^B, X^A), can the model primitives be identified?

$$p^{B^*}(x^{B^*}, r, d, \theta; F(\cdot), c(\cdot,\cdot)) = p^B$$
$$x^{B^*}(r, d, c_u, \theta; F(\cdot), c(\cdot,\cdot)) = x^B$$
$$\widetilde{x}^{A^*}(x^{B^*}, r, d, \theta, \varepsilon; c(\cdot,\cdot)) = x^A$$

Goal: to recover the model primitives $\mathcal{M} = [F_\Theta(\cdot), F(\cdot), c(\cdot,\cdot)]$

What we have?

- Data: P^B, X^B, X^A, r, d, c_u
- Equilibrium conditions

Strategy

Idea: Use s^{B^*}, rather than p^{B^*}, in identification.

$$s^{B^*}(\underbrace{v^*}_{\text{unknown}}(x^{B^*}, r, d, c_u, \theta; F(\cdot), c(\cdot,\cdot))) = s^B$$

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S-I: Recover v^*.

F.O.C of (1)

$$s'(v) = (N-1)(s(v)-v)\frac{f_V(v)}{1-F_V(v)} > 0$$

with boundary condition $s(\overline{v}) = \overline{v}$, v^* is identified as

$$v^* = s^{B^*} - \frac{1}{N-1}\frac{1-F_S(s^{B^*})}{f_S(s^{B^*})}$$

Strategy

Idea: Assume multiplicative in type, i.e. $c(x, \theta) = \theta \underbrace{c_o(x)}_{\text{base cost}}$

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Issue: Observational Equivalence (Lemma 2)

$$\widetilde{\mathcal{M}} = [\widetilde{F}_\Theta(\cdot), F(\cdot), \widetilde{c}_o(\cdot)] \sim \mathcal{M} = [F_\Theta(\cdot), F(\cdot), c_o(\cdot)]$$

with $\widetilde{F}_{\widetilde{\Theta}}(\cdot) = F_\Theta(\cdot/\delta), \widetilde{c}_o(\cdot) = c_o(\cdot)/\delta$ for some $\delta > 0$.

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with $\widetilde{F}_{\widetilde{\Theta}}(\cdot) = F_\Theta(\cdot/\delta), \widetilde{c}_o(\cdot) = c_o(\cdot)/\delta$ for some $\delta > 0$.

A2: (a) The cost function is $c(x,\theta) = \theta(\alpha_2 x^2 + \alpha_1 x + \alpha_0)$, $\alpha_2 > 0$, $\alpha_1 < 0$, $\alpha_0 \neq 0$.
(b) The lower bound of type support is $\underline{\theta} = 1$.

Strategy

Model primitives is reduced to $\mathcal{M} = [F_\Theta(\cdot), F(\cdot), \alpha_2, \alpha_1, \alpha_0]$, and we have

$$v^*(x^{B^*}, \widetilde{x}^{A^*}, r, d, c_u, \theta; F(\cdot), \alpha_2, \alpha_1, \alpha_0) = V^*$$

$$x^{B^*}(r, d, c_u, \theta; F(\cdot), \alpha_2, \alpha_1) = X^B$$

$$\widetilde{x}^{A^*}(r, \theta, \varepsilon; \alpha_2, \alpha_1) = x^r, \quad \widetilde{x}^{A^*}(d, \theta, \varepsilon; \alpha_2, \alpha_1) = x^d$$

Strategy

Model primitives is reduced to $\mathcal{M} = [F_\Theta(\cdot), F(\cdot), \alpha_2, \alpha_1, \alpha_0]$, and we have

$$v^*(x^{B^*}, \widetilde{x}^{A^*}, r, d, c_u, \theta; F(\cdot), \alpha_2, \alpha_1, \alpha_0) = V^*$$

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$$\widetilde{x}^{A^*}(r, \theta, \varepsilon; \alpha_2, \alpha_1) = x^r, \quad \widetilde{x}^{A^*}(d, \theta, \varepsilon; \alpha_2, \alpha_1) = x^d$$

Idea: Exploit the quantile relationship between X^B and V^* by the correlation between X^B and X^A, as well as two one-to-one mappings between V and θ and between X^B and θ.

$$v^*(X^B, r, d, c_u; F(\cdot), \alpha_2, \alpha_1, \alpha_0) = V^*$$

Strategy

S-II: Construct the key reduced-form relationship between $Q_V(\tau)$ and $Q_{X^B}(\tau)$ as

$$0 = \beta_0 + \beta_1 Q_V(\tau) + \beta_2 Q_V(\tau) Q_{X^B}(\tau) + \beta_3 Q_{X^B}(\tau) + \beta_4 (Q_{X^B}(\tau))^2$$

where $\beta = (\beta_0, \beta_1, \beta_2, \beta_3, \beta_4)$ is a system of equations of

$$(\alpha_0, \alpha_1, \alpha_2, \mathbb{E}(\varepsilon), \mathbb{E}(X^r), \mathbb{E}(X^d), \mathbb{E}(X^B)).$$

- $\beta = (\beta_0, \beta_1, \beta_2, \beta_3, \beta_4)$ can be identified by choosing any five different values of $\tau \in (0, 1)$ to construct five linearly independent equations.

Strategy

S-III: Recover (α_1, α_2).

$$\alpha_1 = f(\beta_1, \beta_2, mc), \alpha_2 = g(\beta_1, \beta_2, \alpha_1)$$

Combining F.O.C of (2) with A2 (b)

$$\underline{X}^B = \frac{mc}{2\alpha_2\underline{\theta}} - \frac{\alpha_1}{2\alpha_2}$$

- (α_1, α_2, mc) can be recovered by $(\beta_1, \beta_2, \underline{\theta}, \underline{X}^B)$. Then,
- θ can be identified and thus $F_\Theta(\cdot)$ on its support $\mathcal{S}_\Theta$ is identified.

Strategy

S-IV Recover α_0 and uncertainty distribution.

$$\alpha_0 = h(\beta_0, \beta_1, \beta_2, \mathbb{E}(\varepsilon), r, d, c_u, \mathbb{E}(X^r), \mathbb{E}(X^d), \mathbb{E}(X^B), F(e^r), F(e^d))$$

$F(e^r), F(e^d)$ can be identified by the early and delay completion contracts:

$$F(e^r) = \Pr(\varepsilon < e^r) = \Pr(X^A < X^B)$$
$$1 - F(e^d) = \Pr(\varepsilon > e^d) = \Pr(X^A > X^B)$$

- Thus, as long as $\mathbb{E}(\varepsilon)$ is known, α_0 can be identified.
- Corresponding uncertainty and the truncated CDF of ε can be identified.

Summary of Identification

Proposition 3

Suppose that A1-2 hold and the mean uncertainty is known. Then, the cost parameters $(\alpha_2, \alpha_1, \alpha_0)$ are identified, and the type distribution $F_\Theta(\cdot)$ and the uncertainty distribution $F(\cdot)$ are identified on the supports $\mathcal{S}_\Theta$ and $\widetilde{\mathcal{S}}_\varepsilon$, respectively.

Corollary 1

Suppose that A1-2 hold and the uncertainty distribution is parameterized. Then, the cost parameters $\alpha = (\alpha_2, \alpha_1, \alpha_0)$ and parameters of the uncertainty distribution are identified, and the type distribution $F_\Theta(\cdot)$ is identified on the support $\mathcal{S}_\Theta$.

A+B Contracts in California

background and data

Introduced in the 1990s as an experiment for emergency-type projects.

Following the criticism that highway construction took too much time, and it was extended to non-emergency-type projects in 2000.

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Following the criticism that highway construction took too much time, and it was extended to non-emergency-type projects in 2000.

Data: 2003–2008 procurement contracts by Caltrans.

- 424 bids submitted by contractors in 80 A+B contracts
- $(P^E, X^E), (P^B, X^B, X^A,), (r, d, c_u, c_s)$, bidders/contracts characteristics.
- ‣ Summary statistics
- ‣ Motivating evidence

Estimation

strategy overview

Goal: Evaluate social welfare $W(\underbrace{X^A, c_s}_{\text{data}}, \underbrace{\theta, \varepsilon; \alpha_0, \alpha_1, \alpha_2}_{\text{need to estimate}})$. Recap identification

$$(N, S) \to V$$

$$\xrightarrow{+X^B} (\beta_0, \beta_1, \beta_2, \beta_3, \beta_4)$$

$$\xrightarrow{+(\mathbb{E}(\varepsilon), \mathbb{E}(X^r), \mathbb{E}(X^d), \mathbb{E}(X^B), F(e^r), F(e^d))} (\alpha_0, \alpha_1, \alpha_2,)$$

$$\xrightarrow{\text{+equilibirum condition for bid days}} \theta$$

$$\xrightarrow{\text{+equilibirum condition for actural workdays}} \text{corresponding } \varepsilon$$

Estimation
procedures

S-I: Estimating $\mathbb{E}(X^r), \mathbb{E}(X^d), \mathbb{E}(X^B)$.

$$\mathbb{E}(X^r|Z=z) = z'\chi^r \quad , \quad \mathbb{E}(X^d|Z=z) = z'\chi^d$$
$$\mathbb{E}(X^B|Z=z) = g(z)$$

Early and late working days regression

Estimation

procedures

S-I: Estimating $\mathbb{E}(X^r), \mathbb{E}(X^d), \mathbb{E}(X^B)$.

$$\mathbb{E}(X^r|Z=z) = z'\chi^r \quad , \quad \mathbb{E}(X^d|Z=z) = z'\chi^d$$
$$\mathbb{E}(X^B|Z=z) = g(z)$$

▸ Early and late working days regression

S-II: Estimating v.

$$\widehat{v}_{ji} = s_{ji} - \frac{1}{n_j - 1} \frac{1 - \widehat{F}_{S|Z}(s_{ji}|z_{ji})}{\widehat{f}_{S|Z}(s_{ji}|z_{ji})}$$

Estimation

procedures

S-III: Estimating $\mathbb{E}(\varepsilon), F(e^r), F(e^d)$.

- Assume $\varepsilon|Z = z \sim \text{logN}(\mu, \sigma^2(z))$ with $\sigma(z) = z'\psi_\sigma$
- Assume $e^d(z) = exp(z'\psi_d)$ to construct a tractable likelihood function

$$\mathcal{L}(\mu, \psi_\sigma, \psi_d) = \prod_{j=1}^{J} [F(e^r(z_j)|z_j)]^{I_j^R} \left[1 - F(e^d(z_j)|z_j)\right]^{I_j^D} \left[F(e^d(z_j)|z_j) - F(e^r(z_j)|z_j)\right]^{I_j^B}$$

Estimation

procedures

S-III: Estimating $\mathbb{E}(\varepsilon), F(e^r), F(e^d)$.

- Assume $\varepsilon | Z = z \sim \log\mathrm{N}(\mu, \sigma^2(z))$ with $\sigma(z) = z'\psi_\sigma$
- Assume $e^d(z) = exp(z'\psi_d)$ to construct a tractable likelihood function

$$\mathcal{L}(\mu, \psi_\sigma, \psi_d) = \prod_{j=1}^{J} [F(e^r(z_j)|z_j)]^{I_j^R} \left[1 - F(e^d(z_j)|z_j)\right]^{I_j^D} \left[F(e^d(z_j)|z_j) - F(e^r(z_j)|z_j)\right]^{I_j^B}$$

S-IV: Estimating $\alpha_0, \alpha_1, \alpha_2$.

- Normalize $\alpha_0 = 1$ for the identification of α_1, α_2 with heterogeneity

$$\min_{(\alpha_1, \alpha_2)} \frac{1}{J} \sum_{j=1}^{J} \left\{ \frac{1}{n_j} \sum_{i=1}^{n_j} \left[\beta_0(z_{ji}) + \beta_1(z_{ji})\widehat{v}_{ji} + \beta_2(z_{ji})\widehat{v}_{ji} x_{ji}^B + \beta_3(z_{ji}) x_{ji}^B + \beta_4(z_{ji})(x_{ji}^B)^2\right]^2 \right\}$$

Results

estimates of model primitives

	Parameters/Variables	Estimates
Distribution of Uncertainty	Mean of log(Uncertainty)	-0.089*
		(0.049)
	SD of log(Uncertainty)	10.073***
		(2.048)
Cutoff Uncertainty	Log (Capacity)/Engineer Days	2.958**
		(1.287)
Cost Parameters	Working Days	-3.599×10^{-4}***
		(6.994×10^{-7})
	Working Days^2	3.246×10^{-8}***
		(1.752×10^{-10})

Notes: Bootstrap standard errors in parentheses are calculated using 500 bootstrap samples.
*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Lane Rental Contracts

Introduced in the United Kingdom, designed to reduce construction time. There has been heated disputes over which contract mechanism should be preferred?

Lane Rental Contracts

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- Under lane rental contracts
  - first-price-low bid: bid cost p^B
  - no required completion date, but need to pay d_L for each working day.

$$p^{B^*}(d_L, \theta) = \underset{p^B}{\text{argmax}} \left\{ \left(p^B - \min_{x^A} \mathbb{E}_\varepsilon \left[\varepsilon c(x^A, \theta) + d_L x^A \right] \right) \times \Pr\left(\text{win} \;\middle|\; p^B \right) \right\}$$

Efficiency: If $d_L = c_s$, the lane rental contract is both ex-ante and ex-post efficient.

Counterfactuals

welfare comparison between A+B and lane rental contracts

	Construction Cost	Commuter Cost	Social Cost
A+B ($M)	31.92	70.52	102.44
Lane Rental ($M)	47.46	10.25	57.71
Absolute Change ($M)	15.54	60.27	44.73
Percentage Change	32.74%	85.47%	43.66%

Notes: Counterfactual welfare results under A+B and lane rental contracts. The counterfactual results are averaged across 1000 simulations and 77 A+B contracts. *Construction Cost* equals realized uncertainty ε times deterministic cost $c(x^A, \theta)$. *Commuter Cost* equals to daily cost c_s times actual working days x^A. *Social Cost* is the sum of construction cost and commuter cost.

Summary and Discussion

- Structural model of A+B contracts:
  - Time incentives and post-auction uncertainty
  - Actual working days may deviate from biding days
  - May be ex-ante efficient but cannot be ex-post efficient
- Multi-step semiparametric identification arguments:
  - Key structural link: quantile relationship between bid days and pseudo type
- Empirical analysis of A+B contracts in California:
  - Multi-step semiparametric estimation procedure
  - Comparing welfare between lane rental and A+B contracts
    - Commuter costs: lane rental < A+B
    - Construction costs: A+B < lane rental
    - Social costs: lane rental < A+B

Summary Statistics
contract level: 77 contracts

Variable	Mean	Std. Dev.	Min	10-th pctile	Median	90-th pctile	Max
Engineer Cost ($M)	22.4	29.6	0.86	4.6	12.5	48.6	198
Engineer Days	322.29	201.72	45	130	250	600	1000
Usercost ($K)	14.83	15.62	1.8	4.2	11.5	25.1	93.99
Incentive Payments ($K)	8.9	9.37	1.08	2.52	6.9	15.06	56.39
Liquidated Damages ($K)	16.11	18.43	1.8	4.1	11.6	27.3	111.5
Engineer Score ($M)	28.1	38.2	1	6.1	15.4	56.8	26.6
Winning Bid ($M)	20.4	28.6	0.7	4.23	10.6	43.9	178
Winning Bid/Engineer Cost	0.91	0.2	0.59	0.65	0.89	1.19	1.38
Number of Bidders	5.64	2.45	2	3	5	8	14
Federal Contract	0.81	0.4	0	0	1	1	1
Firm Capacity ($M)	71.3	78	0	4.9	52.4	252	285
Distance (miles)	65.88	129.38	1.91	7.04	24.93	255.94	802.14
Commuter Cost ($K)	50.54	46.83	0.25	5.31	37.16	129.35	185.15
Contract Days	249.96	209.63	25	70	167	515	950
Working Days	262.73	232.98	42	75	171	602	1120
Working-Contract Days	12.77	82.02	-281	-13	0	88	372
Working/Contract Days	1.10	0.42	0.28	0.92	1	1.38	3.67

Summary Statistics

contract level: 77 contracts

Variable	Mean	Std. Dev.	Min	10-th pctile	Median	90-th pctile	Max
Bid Cost ($M)	19.1	21.8	0.93	4.47	10.8	44.5	106
Bid Cost/Engineer Cost	0.97	0.23	0.61	0.71	0.94	1.26	1.65
Bid Days	207.24	138.24	30	80	172.5	360	750
Bid Days/Engineer Days	0.66	0.19	0.27	0.41	0.66	0.92	1
Firm Capacity ($M)	72.2	76.5	0	4.90	52.4	192	285
Distance (miles)	69.82	121.37	1.75	9.68	29.29	149.05	669.68
Bid Score ($M)	22.2	25	1.02	5.43	12.6	49.8	121

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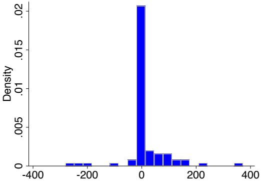
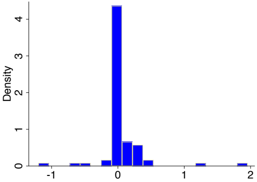
Motivating Evidence

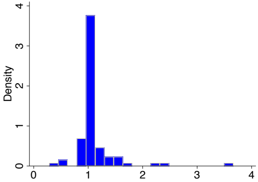
comparison between working days and bid days



(a) Working days-Bid days



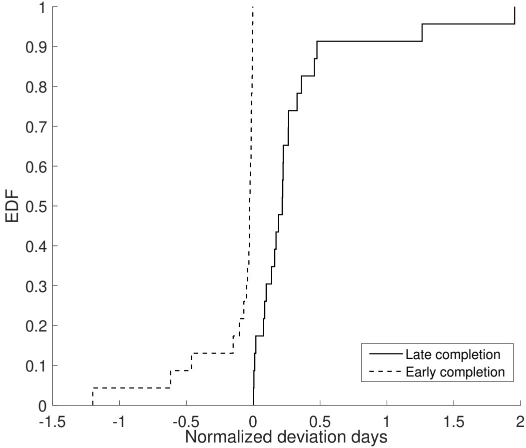
(b) (Working days-Bid days)/Engineer days



(c) Working days/Bid days

Motivating Evidence

empirical distribution function of normalized deviation days



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Estimates of Step 1

early and late working days regression

	Early Working Days			Late Working Days		
Log(Capacity)/Engineer Days	-3610**	-3605.1**	-2702.3*	-2079.9***	-2208.9***	538.9
	(1321.6)	(1387.0)	(1357.0)	(534.5)	(502.2)	(2322.6)
Federal Contract		-5.999	-2.923		-164.3	-34.70
		(46.17)	(48.75)		(160.6)	(137.8)
Log(Distance)/Engineer Days			-6773.3			-9630.0
			(4662.8)			(8404.0)
Constant	454.8***	459.3***	472.5***			553.8***
	(106.8)	(88.26)	(86.74)			(145.1)
Observations	23	23	23	23	23	23
Adjusted R^2	0.384	0.351	0.364	0.152	0.154	0.059

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