Designing Coalition-Proof Mechanisms for Electricity Markets

Orcun Karaca
joint work with M. Kamgarpour

Institut für Automatik, ETH Zürich

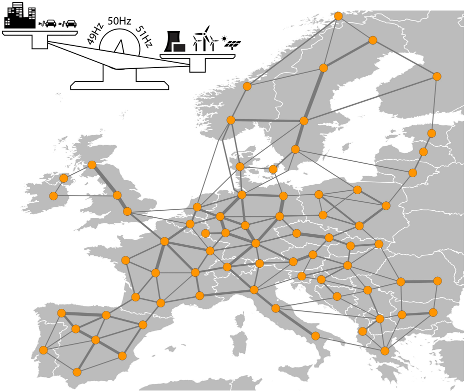
Nodal versus Zonal Prices Revisited:
Lessons from the US Experience and Applicability to Europe

Nov 20th, 2019, the CEEM of the Université Paris-Dauphine

INSTITUT FÜR AUTOMATIK

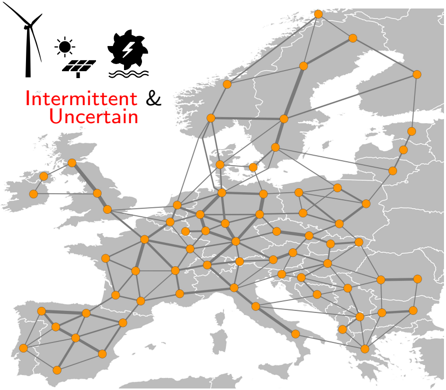
Electricity markets for reliable operation

- Successful transformation to deregulated competitive markets
- *Stability*: Supply and demand balance at every instance
- A transition due to renewables



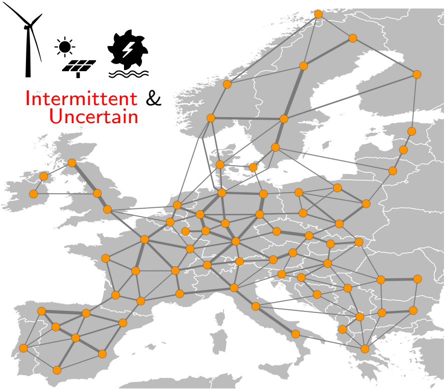
Electricity markets for reliable operation

- Successful transformation to deregulated competitive markets
- *Stability*: Supply and demand balance at every instance
- A transition due to renewables



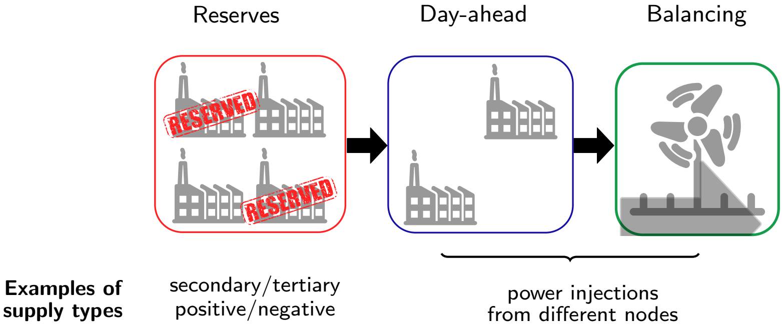
Electricity markets for reliable operation

- Successful transformation to deregulated competitive markets
- *Stability*: Supply and demand balance at every instance
- A transition due to renewables
- Role of different electricity markets in ensuring stability



Electricity markets for reliable operation

- Successful transformation to deregulated competitive markets
- *Stability*: Supply and demand balance at every instance
- A transition due to renewables
- Role of different electricity markets in ensuring stability



Market design criteria

Efficiency: Immunity to strategic manipulations

Market design criteria

Efficiency: Immunity to strategic manipulations

How can we **eliminate strategic manipulations** to achieve a stable and an efficient grid?

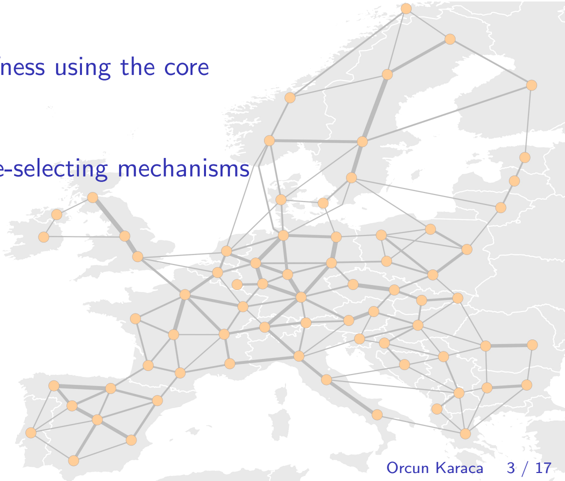
Outline

Electricity market framework

Characterizing coalition-proofness using the core

Design considerations for core-selecting mechanisms

Numerical results



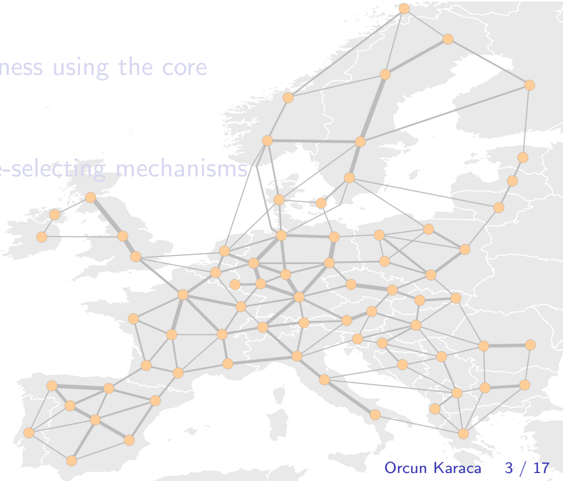
Outline

Electricity market framework

Characterizing coalition-proofness using the core

Design considerations for core-selecting mechanisms

Numerical results



Procurement (reverse) auction setting

- Private true cost of bidder l

$$c_l : \mathbb{X}_l \to \mathbb{R}_+ \text{ s.t. } 0 \in \mathbb{X}_l \subset \mathbb{R}^t_+ \text{ and } c_l(0) = 0$$

- Reported cost of bidder l

$$b_l : \hat{\mathbb{X}}_l \to \mathbb{R}_+ \text{ s.t. } 0 \in \hat{\mathbb{X}}_l \subset \mathbb{R}^t_+ \text{ and } b_l(0) = 0$$

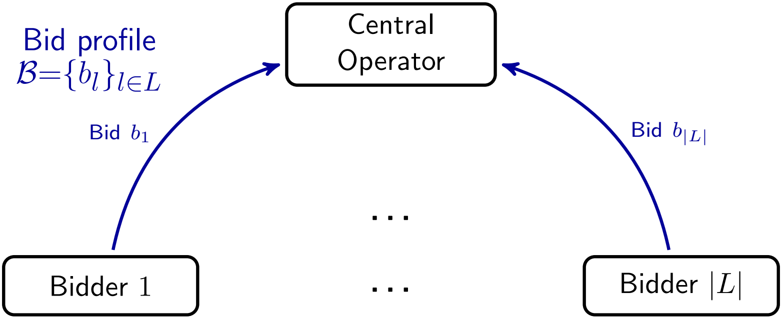
Procurement (reverse) auction setting

- Private true cost of bidder l

$$c_l : \mathbb{X}_l \to \mathbb{R}_+ \ \text{s.t.} \ 0 \in \mathbb{X}_l \subset \mathbb{R}^t_+ \ \text{and} \ c_l(0) = 0$$

- Reported cost of bidder l

$$b_l : \hat{\mathbb{X}}_l \to \mathbb{R}_+ \ \text{s.t.} \ 0 \in \hat{\mathbb{X}}_l \subset \mathbb{R}^t_+ \ \text{and} \ b_l(0) = 0$$



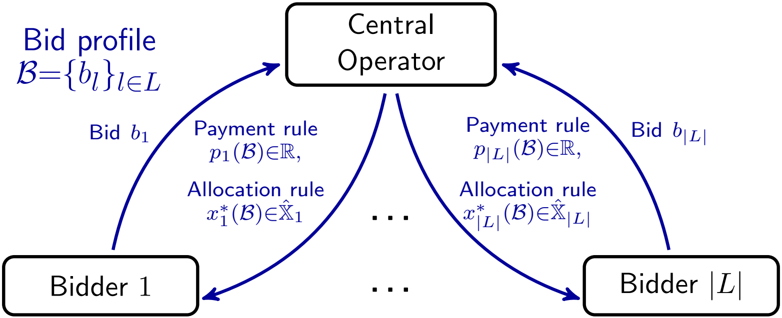
Procurement (reverse) auction setting

- Private true cost of bidder l

$$c_l : \mathbb{X}_l \to \mathbb{R}_+ \text{ s.t. } 0 \in \mathbb{X}_l \subset \mathbb{R}^t_+ \text{ and } c_l(0) = 0$$

- Reported cost of bidder l

$$b_l : \hat{\mathbb{X}}_l \to \mathbb{R}_+ \text{ s.t. } 0 \in \hat{\mathbb{X}}_l \subset \mathbb{R}^t_+ \text{ and } b_l(0) = 0$$



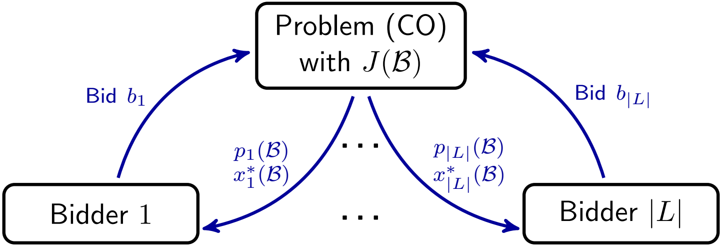
Allocation rule as an optimization problem

- **The central operator (CO) solves for**

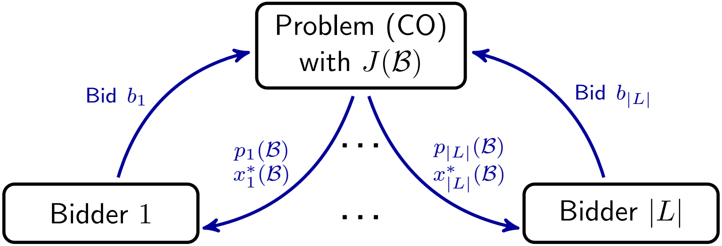
$$J(\mathcal{B}) = \min_{x \in \hat{\mathbb{X}}} \sum_{l \in L} b_l(x_l) \quad \text{s.t.} \sum_{l \in L} x_l \in \mathbb{S} \tag{CO}$$

  - Constraints $\mathbb{S} \subset \mathbb{R}^t_+$—*e.g.*, **security/reliability constraints**
- The allocation rule $x^*(\mathcal{B})$ is the minimizer

Allocation rule as an optimization problem

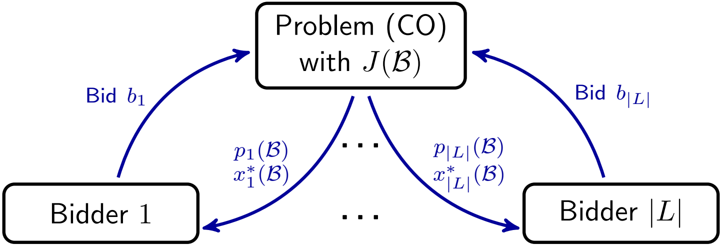


Allocation rule as an optimization problem



- Utilities: $\begin{cases} u_l(\mathcal{B}) = p_l(\mathcal{B}) - c_l(x_l^*(\mathcal{B})): & \textit{linear in payment} \\ u_{\mathsf{CO}}(\mathcal{B}) = -\sum_{l \in L} p_l(\mathcal{B}): & -\textit{total payment} \end{cases}$

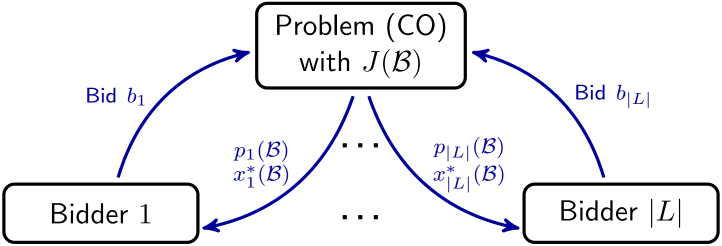
Allocation rule as an optimization problem



- Utilities: $\begin{cases} u_l(\mathcal{B}) = p_l(\mathcal{B}) - c_l(x_l^*(\mathcal{B})) : & \textit{linear in payment} \\ u_{\mathsf{CO}}(\mathcal{B}) = -\sum_{l \in L} p_l(\mathcal{B}) : & -\textit{total payment} \end{cases}$

- Desirable properties in mechanism design
  - *Individually rational:* Nonnegative utilities for bidders
  - *Efficient:* Sum of all utilities is maximized

Allocation rule as an optimization problem

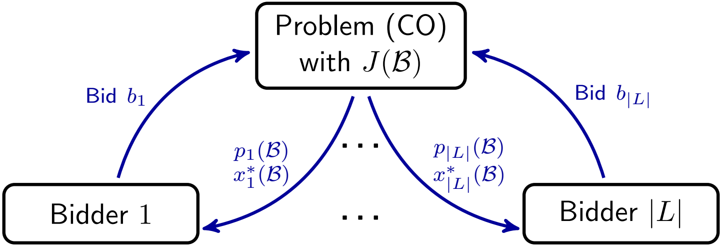


- Utilities: $\begin{cases} u_l(\mathcal{B}) = p_l(\mathcal{B}) - c_l(x_l^*(\mathcal{B})): & \textit{linear in payment} \\ u_{\mathsf{CO}}(\mathcal{B}) = -\sum_{l\in L} p_l(\mathcal{B}): & -\textit{total payment} \end{cases}$

- Desirable properties in mechanism design
  - *Individually rational:* Nonnegative utilities for bidders
  - *Efficient:* Sum of all utilities is maximized

$$\underbrace{u_{\mathsf{CO}}(\mathcal{B}) + \sum_{l\in L} u_l(\mathcal{B})}_{\textbf{maximize}} = -\underbrace{\sum_{l\in L} c_l(x_l^*(\mathcal{B}))}_{\textbf{minimize}}$$

Allocation rule as an optimization problem



- Utilities: $\begin{cases} u_l(\mathcal{B}) = p_l(\mathcal{B}) - c_l(x_l^*(\mathcal{B})): & \textit{linear in payment} \\ u_{\text{CO}}(\mathcal{B}) = -\sum_{l \in L} p_l(\mathcal{B}): & -\textit{total payment} \end{cases}$
- Desirable properties in mechanism design
  - *Individually rational:* Nonnegative utilities for bidders
  - *Efficient:* Sum of all utilities is maximized
  - *Incentive-compatible:* Truthfulness is the dominant strategy

Design of payment rules

- *Individually rational:* Nonnegative utilities for bidders
- *Efficient:* Sum of all utilities is maximized
- *Incentive-compatible:* Truthfulness is the dominant strategy

Design of payment rules

- *Individually rational:* Nonnegative utilities for bidders
- *Efficient:* Sum of all utilities is maximized
- *Incentive-compatible:* Truthfulness is the dominant strategy

- *Pay-as-bid* and *Lagrange multiplier-based* (e.g., LMP) rules: Not incentive-compatible, not efficient

Design of payment rules

- ✓ *Individually rational:* Nonnegative utilities for bidders
- × *Efficient:* Sum of all utilities is maximized
- × *Incentive-compatible:* Truthfulness is the dominant strategy

- *Pay-as-bid* and *Lagrange multiplier-based* (e.g., LMP) rules: Not incentive-compatible, not efficient

Design of payment rules

- ✓ *Individually rational:* Nonnegative utilities for bidders
- × *Efficient:* Sum of all utilities is maximized
- × *Incentive-compatible:* Truthfulness is the dominant strategy

- *Pay-as-bid* and *Lagrange multiplier-based* (e.g., LMP) rules: Not incentive-compatible, not efficient

- Optimal value of (CO) with $x_l = 0$

$$J(\mathcal{B}_{-l}) \geq J(\mathcal{B})$$

Design of payment rules

- ✓ *Individually rational:* Nonnegative utilities for bidders
- × *Efficient:* Sum of all utilities is maximized
- × *Incentive-compatible:* Truthfulness is the dominant strategy

- *Pay-as-bid* and *Lagrange multiplier-based* (e.g., LMP) rules: Not incentive-compatible, not efficient

- Optimal value of (CO) with $x_l = 0$

$$J(\mathcal{B}_{-l}) \geq J(\mathcal{B})$$

- **The Vickrey-Clarke-Groves (VCG) mechanism:**

$$p_l(\mathcal{B}) = \underbrace{b_l(x_l^*(\mathcal{B}))}_{\textbf{pay-as-bid}} + \underbrace{(J(\mathcal{B}_{-l}) - J(\mathcal{B}))}_{\textbf{a marginal contribution term}}$$

[Vickrey 1961], [Clarke 1971], [Groves 1973], [Xu and Low 2017], [Sessa *et al.* 2017]

Design of payment rules

- ✓ *Individually rational:* Nonnegative utilities for bidders
- ✓ *Efficient:* Sum of all utilities is maximized
- ✓ *Incentive-compatible:* Truthfulness is the dominant strategy

- *Pay-as-bid* and *Lagrange multiplier-based* (e.g., LMP) rules: Not incentive-compatible, not efficient

- Optimal value of (CO) with $x_l = 0$

$$J(\mathcal{B}_{-l}) \geq J(\mathcal{B})$$

- **The Vickrey-Clarke-Groves (VCG) mechanism:**

$$p_l(\mathcal{B}) = \underbrace{b_l(x_l^*(\mathcal{B}))}_{\textbf{pay-as-bid}} + \underbrace{(J(\mathcal{B}_{-l}) - J(\mathcal{B}))}_{\textbf{a marginal contribution term}}$$

[Vickrey 1961], [Clarke 1971], [Groves 1973], [Xu and Low 2017], [Sessa *et al.* 2017]

The lovely but lonely VCG mechanism [Ausubel and Milgrom 2006]

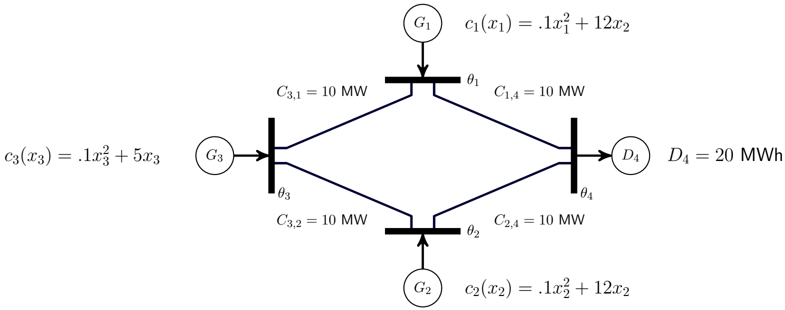


Table: VCG outcomes for the model (CHF) (p: payment, u: utility)

	Truthful Bidding			
	p (u)	x		
Generator 1	0 (0)	0		
Generator 2	0 (0)	0		
Generator 3	260 (120)	20		

The lovely but lonely VCG mechanism [Ausubel and Milgrom 2006]

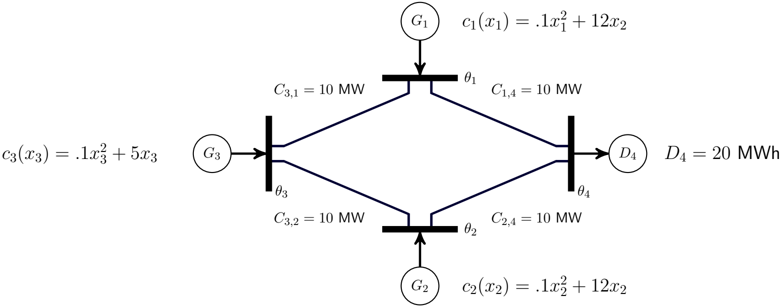


Table: VCG outcomes for the model (CHF) (p: payment, u: utility)

	Truthful Bidding			
	p (u)	x		
Generator 1	0 (0)	0		
Generator 2	0 (0)	0		
Generator 3	260 (120)	20		

Truthful bidding is the dominant strategy

The lovely but lonely VCG mechanism [Ausubel and Milgrom 2006]

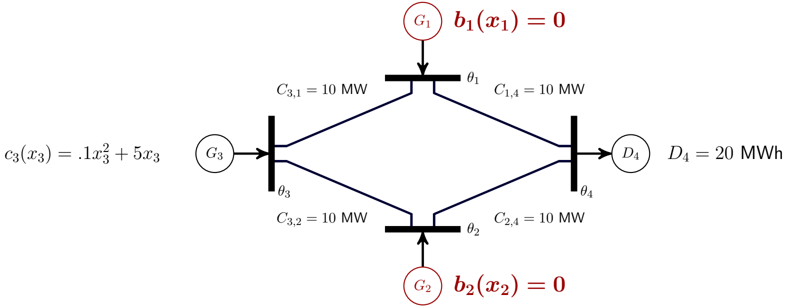


Table: VCG outcomes for the model (CHF) (p: payment, u: utility)

	Truthful Bidding		1 and 2 collude	
	p (u)	x	p (u)	x
Generator 1	0 (0)	0		
Generator 2	0 (0)	0		
Generator 3	260 (120)	20		

The lovely but lonely VCG mechanism [Ausubel and Milgrom 2006]

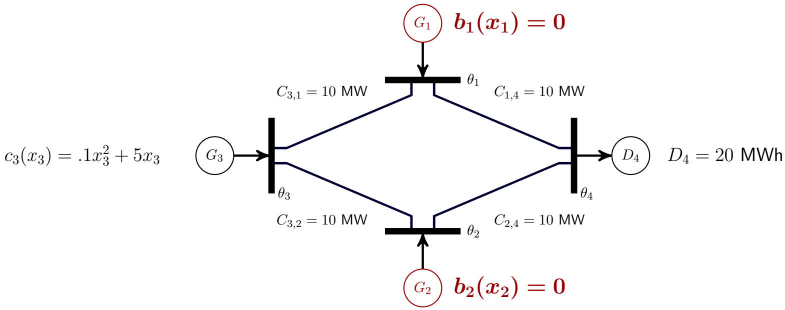
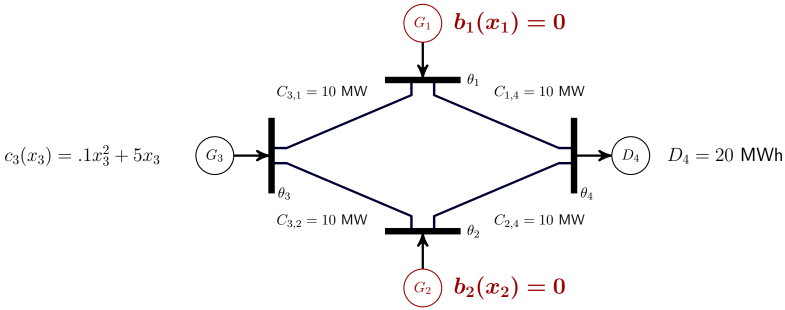


Table: VCG outcomes for the model (CHF) (p: payment, u: utility)

	Truthful Bidding		1 and 2 collude	
	p (u)	x	p (u)	x
Generator 1	0 (0)	0	140 (10)	10
Generator 2	0 (0)	0	140 (10)	10
Generator 3	260 (120)	20	0 (0)	0

The lovely but lonely VCG mechanism [Ausubel and Milgrom 2006]



- Another important property:
- **Coalition-proofness**
  - Bidding with multiple identities is not profitable

Which mechanisms attain the **coalition-proofness** property?

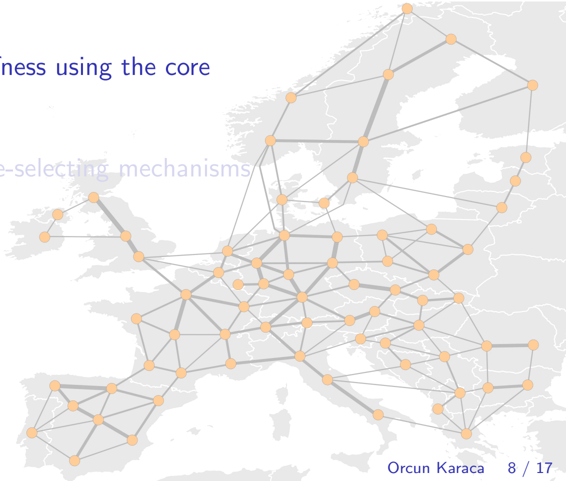
Outline

Electricity market framework

Characterizing coalition-proofness using the core

Design considerations for core-selecting mechanisms

Numerical results



Bringing in the core from coalitional game theory

- Core-selecting payment rule

$$p_l(\mathcal{B}) = b_l(x_l^*(\mathcal{B})) + \bar{u}_l(\mathcal{B}),\ \forall l,\ \text{where } \bar{u}(\mathcal{B}) \in Core(\mathcal{B}) \subset \mathbb{R}_+^{|L|}$$

that is, pay-as-bid + **a revealed utility** from the core

Bringing in the core from coalitional game theory

- Core-selecting payment rule

  $p_l(\mathcal{B}) = b_l(x_l^*(\mathcal{B})) + \bar{u}_l(\mathcal{B}), \forall l,$ where $\bar{u}(\mathcal{B}) \in Core(\mathcal{B}) \subset \mathbb{R}_+^{|L|}$

  that is, pay-as-bid + **a revealed utility** from the core

- Objective value under the profile $\mathcal{B}_{-S} = \{b_l\}_{l \in L \setminus S}$, $S \subseteq L$

$$J(\mathcal{B}_{-S}) = \min_{x \in \hat{\mathbb{X}}} \sum_{l \in L \setminus S} b_l(x_l)$$
$$\text{s.t.} \sum_{l \in L} x \in \mathbb{S}, \; x_S = 0$$

Bringing in the core from coalitional game theory

- Core-selecting payment rule

$$p_l(\mathcal{B}) = b_l(x_l^*(\mathcal{B})) + \bar{u}_l(\mathcal{B}),\ \forall l,\ \text{where } \bar{u}(\mathcal{B}) \in Core(\mathcal{B}) \subset \mathbb{R}_+^{|L|}$$

that is, pay-as-bid + **a revealed utility** from the core

$$\boxed{\begin{aligned} J(\mathcal{B}_{-S}) = & \min_{x \in \hat{\mathbb{X}}} \sum_{l \in L \setminus S} b_l(x_l) \\ & \text{s.t. } \sum_{l \in L} x_l \in \mathbb{S},\ x_S = 0 \end{aligned}}$$

Bringing in the core from coalitional game theory

- Core-selecting payment rule

  $$p_l(\mathcal{B}) = b_l(x_l^*(\mathcal{B})) + \bar{u}_l(\mathcal{B}),\ \forall l,\ \text{where } \bar{u}(\mathcal{B}) \in Core(\mathcal{B}) \subset \mathbb{R}_+^{|L|}$$

  that is, pay-as-bid + **a revealed utility** from the core

- The *core*: set of revealed utilities that cannot be disputed by any coalition of bidders

$$\boxed{\begin{aligned} J(\mathcal{B}_{-S}) = \min_{x \in \hat{\mathbb{X}}} & \sum_{l \in L \setminus S} b_l(x_l) \\ \text{s.t.} & \sum_{l \in L} x_l \in \mathbb{S},\ x_S = 0 \end{aligned}}$$

Bringing in the core from coalitional game theory

- Core-selecting payment rule

  $$p_l(\mathcal{B}) = b_l(x_l^*(\mathcal{B})) + \bar{u}_l(\mathcal{B}),\ \forall l,\ \text{where } \bar{u}(\mathcal{B}) \in Core(\mathcal{B}) \subset \mathbb{R}_+^{|L|}$$

  that is, pay-as-bid + **a revealed utility** from the core

- The *core*: set of revealed utilities that cannot be disputed by any coalition of bidders

$$Core(\mathcal{B}) = \Big\{ \bar{u} \in \underbrace{\mathbb{R}_+^{|L|}}_{} \ \big| \underbrace{\sum_{l \in S} \bar{u}_l \leq \underbrace{J(\mathcal{B}_{-S}) - J(\mathcal{B})}_{} \ , \forall S \subset L}_{} \Big\}$$

$$\boxed{\begin{aligned} J(\mathcal{B}_{-S}) = \min_{x \in \hat{\mathbb{X}}} & \sum_{l \in L \setminus S} b_l(x_l) \\ \text{s.t.} & \sum_{l \in L} x_l \in \mathbb{S},\ x_S = 0 \end{aligned}}$$

Bringing in the core from coalitional game theory

- Core-selecting payment rule

  $$p_l(\mathcal{B}) = b_l(x_l^*(\mathcal{B})) + \bar{u}_l(\mathcal{B}),\ \forall l,\ \text{where } \bar{u}(\mathcal{B}) \in Core(\mathcal{B}) \subset \mathbb{R}_+^{|L|}$$

  that is, pay-as-bid + **a revealed utility** from the core

- The *core*: set of revealed utilities that cannot be disputed by any coalition of bidders

$$Core(\mathcal{B}) = \Big\{\bar{u} \in \underbrace{\mathbb{R}_+^{|L|}}_{\text{indiv. rational}} \mid \underbrace{\sum_{l \in S} \bar{u}_l \leq \underbrace{J(\mathcal{B}_{-S}) - J(\mathcal{B})}\ ,\ \forall S \subset L}\Big\}$$

$$\boxed{\begin{aligned} J(\mathcal{B}_{-S}) = \min_{x \in \hat{\mathbb{X}}} & \sum_{l \in L \setminus S} b_l(x_l) \\ \text{s.t.} & \sum_{l \in L} x_l \in \mathbb{S},\ x_S = 0 \end{aligned}}$$

Bringing in the core from coalitional game theory

- Core-selecting payment rule

$$p_l(\mathcal{B}) = b_l(x_l^*(\mathcal{B})) + \bar{u}_l(\mathcal{B}),\ \forall l,\ \text{where } \bar{u}(\mathcal{B}) \in Core(\mathcal{B}) \subset \mathbb{R}_+^{|L|}$$

that is, pay-as-bid + **a revealed utility** from the core

- The *core*: set of revealed utilities that cannot be disputed by any coalition of bidders

$$Core(\mathcal{B}) = \Big\{ \bar{u} \in \underbrace{\mathbb{R}_+^{|L|}}_{\text{indiv. rational}} \mid \underbrace{\sum_{l \in S} \bar{u}_l \leq \underbrace{J(\mathcal{B}_{-S}) - J(\mathcal{B})}_{\text{marg. contribution of } S}}\ , \forall S \subset L \Big\}$$

$$\boxed{\begin{aligned} J(\mathcal{B}_{-S}) = \min_{x \in \hat{\mathbb{X}}} & \sum_{l \in L \setminus S} b_l(x_l) \\ \text{s.t.} & \sum_{l \in L} x_l \in \mathbb{S},\ x_S = 0 \end{aligned}}$$

Bringing in the core from coalitional game theory

- Core-selecting payment rule

$$p_l(\mathcal{B}) = b_l(x_l^*(\mathcal{B})) + \bar{u}_l(\mathcal{B}),\ \forall l,\ \text{where } \bar{u}(\mathcal{B}) \in Core(\mathcal{B}) \subset \mathbb{R}_+^{|L|}$$

that is, pay-as-bid + **a revealed utility** from the core

- The *core*: set of revealed utilities that cannot be disputed by any coalition of bidders

$$Core(\mathcal{B}) = \left\{ \bar{u} \in \underbrace{\mathbb{R}_+^{|L|}}_{\text{indiv. rational}} \mid \underbrace{\sum_{l \in S} \bar{u}_l \leq \underbrace{J(\mathcal{B}_{-S}) - J(\mathcal{B})}_{\text{marg. contribution of } S},\ \forall S \subset L}_{\text{cannot be disputed by coalition } L \setminus S} \right\}$$

$$\boxed{\begin{aligned} J(\mathcal{B}_{-S}) = \min_{x \in \hat{\mathbb{X}}} & \sum_{l \in L \setminus S} b_l(x_l) \\ \text{s.t. } & \sum_{l \in L} x_l \in \mathbb{S},\ x_S = 0 \end{aligned}}$$

Characterization of coalition-proof mechanisms

Theorem 1

Core-selecting mechanism $\Longleftrightarrow$ *Coalition-proof mechanism*

- Generalizes a result from [Day and Milgrom 2006] to continuous goods

Characterization of coalition-proof mechanisms

Theorem 1

Core-selecting mechanism $\Longleftrightarrow$ *Coalition-proof mechanism*

- Generalizes a result from [Day and Milgrom 2006] to continuous goods
- *Remark:* Core-selecting payments are upper bounded by the VCG payments

$$\bar{u}_l^{\mathsf{VCG}}(\mathcal{B}) = J(\mathcal{B}_{-l}) - J(\mathcal{B}) = \max\left\{\bar{u}_l \,\middle|\, \bar{u} \in Core(\mathcal{B})\right\}$$

Characterization of coalition-proof mechanisms

Theorem 1

Core-selecting mechanism $\iff$ *Coalition-proof mechanism*

- Generalizes a result from [Day and Milgrom 2006] to continuous goods
- *Remark:* Core-selecting payments are upper bounded by the VCG payments

$$\bar{u}_l^{\mathsf{VCG}}(\mathcal{B}) = J(\mathcal{B}_{-l}) - J(\mathcal{B}) = \max\left\{\bar{u}_l \,|\, \bar{u} \in Core(\mathcal{B})\right\}$$

Characterization of coalition-proof mechanisms

Theorem 1

Core-selecting mechanism $\Longleftrightarrow$ *Coalition-proof mechanism*

- Generalizes a result from [Day and Milgrom 2006] to continuous goods
- *Remark:* Core-selecting payments are upper bounded by the VCG payments

$$\bar{u}_l^{\mathsf{VCG}}(\mathcal{B}) = J(\mathcal{B}_{-l}) - J(\mathcal{B}) = \max\left\{\bar{u}_l \,|\, \bar{u} \in Core(\mathcal{B})\right\}$$

- An alternative characterization

Characterization of coalition-proof mechanisms

Theorem 1

Core-selecting mechanism $\iff$ *Coalition-proof mechanism*

- Generalizes a result from [Day and Milgrom 2006] to continuous goods
- *Remark:* Core-selecting payments are upper bounded by the VCG payments

$$\bar{u}_l^{\mathsf{VCG}}(\mathcal{B}) = J(\mathcal{B}_{-l}) - J(\mathcal{B}) = \max\left\{\bar{u}_l \,|\, \bar{u} \in Core(\mathcal{B})\right\}$$

- An alternative characterization

Theorem 2

Core-selecting mechanisms are those that attain a competitive equilibrium if we allow nonlinear prices

Characterization of coalition-proof mechanisms

Theorem 1

Core-selecting mechanism $\iff$ *Coalition-proof mechanism*

- Generalizes a result from [Day and Milgrom 2006] to continuous goods
- *Remark:* Core-selecting payments are upper bounded by the VCG payments

$$\bar{u}_l^{\mathsf{VCG}}(\mathcal{B}) = J(\mathcal{B}_{-l}) - J(\mathcal{B}) = \max\left\{\bar{u}_l \,\middle|\, \bar{u} \in Core(\mathcal{B})\right\}$$

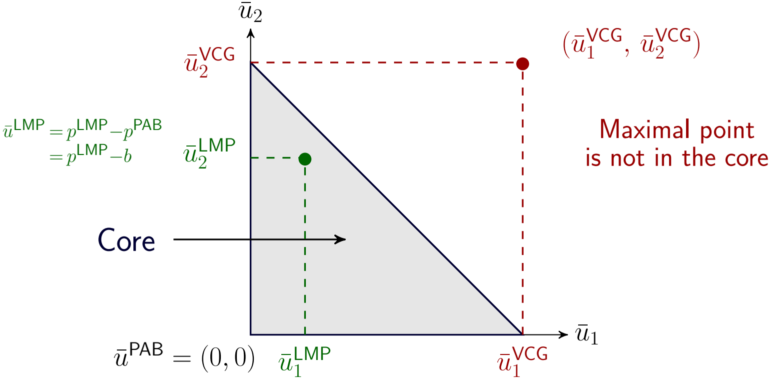
- An alternative characterization

Theorem 2

Core-selecting mechanisms are those that attain a competitive equilibrium if we allow nonlinear prices

- *Corollary:* Lagrange multiplier-based mechanisms are core-selecting

Summary so far:



Core-selecting is in general **not incentive-compatible** and there are **many points** to choose from the core...

Can core-selecting mechanisms **approximate incentive-compatibility**?

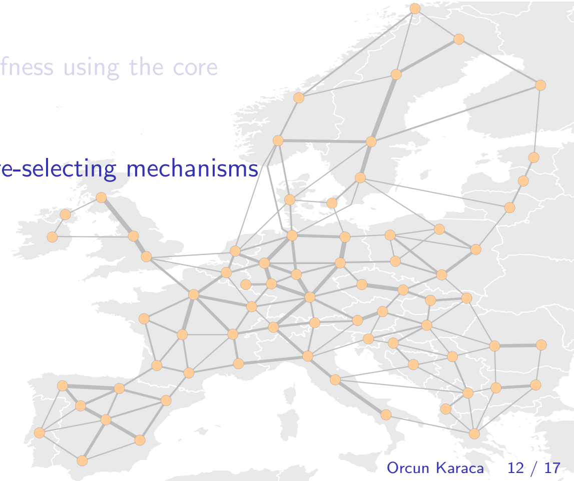
Outline

Electricity market framework

Characterizing coalition-proofness using the core

Design considerations for core-selecting mechanisms

Numerical results



Approximating incentive-compatibility using core-selecting

Lemma 1

The maximum gain of bidder l by a unilateral deviation from its true cost is tightly upperbounded by

$$p_l^{\textsf{\textit{VCG}}}(\mathcal{C}_l, \mathcal{B}_{-l}) - p_l^{\textsf{\textit{Core-Selecting}}}(\mathcal{C}_l, \mathcal{B}_{-l})$$

Approximating incentive-compatibility using core-selecting

Lemma 1

The maximum gain of bidder l by a unilateral deviation from its true cost is tightly upperbounded by

$$p_l^{\textit{VCG}}(\mathcal{C}_l, \mathcal{B}_{-l}) - p_l^{\textit{Core-Selecting}}(\mathcal{C}_l, \mathcal{B}_{-l})$$

- *Maximum payment core-selecting* (MPCS) mechanism:

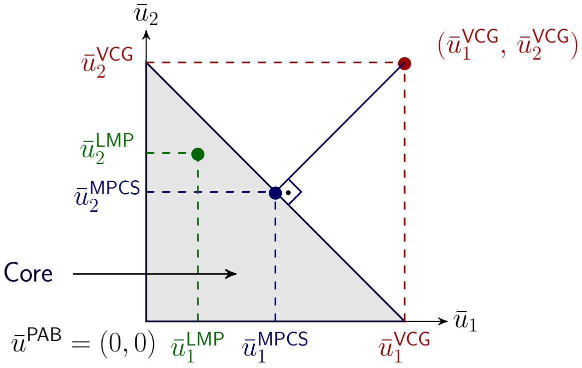
$$\bar{u}^{\mathsf{MPCS}}(\mathcal{B}) = \underset{u \in \mathsf{Core}(\mathcal{B})}{\arg\max} \sum_{l \in L} u_l - \epsilon \left\| u_l - \bar{u}_l^{\mathsf{VCG}}(\mathcal{B}) \right\|_2^2$$

Theorem 3

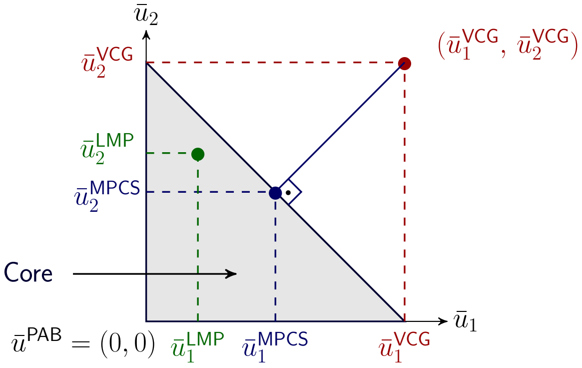
The MPCS mechanism minimizes the sum of maximum gains from unilateral deviations

- Generalizes proposals from [Day and Raghavan 2007] to continuous goods

Comparison of revealed utilities under different mechanisms



Comparison of revealed utilities under different mechanisms



The MPCS mechanism:

+ Approximate incentive-compatibility + Coalition-proofness $\implies$ **Higher efficiency!**
+ Applicable to the general **nonconvex** setting
+ Extends to two-stage markets and two-sided markets

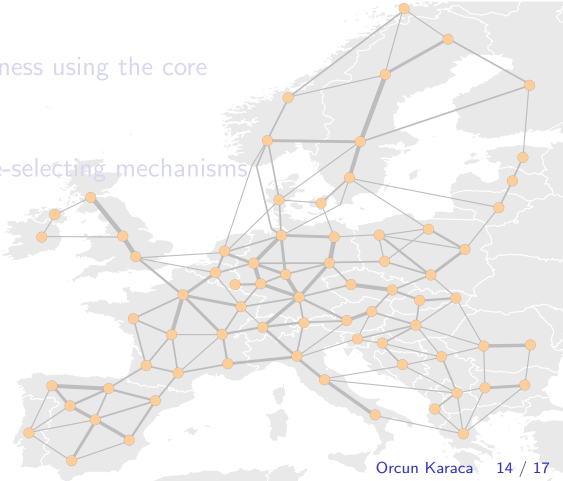
Outline

Electricity market framework

Characterizing coalition-proofness using the core

Design considerations for core-selecting mechanisms

Numerical results



Swiss reserve procurement auctions

- Two-stage stochastic weekly market for secondary and tertiary reserves [Abbaspourtobati and Zima 2016]
- *Mutually exclusive* bids are submitted

$$J(\mathcal{B}) = \min_{x \in \hat{\mathbb{X}}, y} \sum_{l \in L} b_l(x_l) + d(y)$$
$$\text{s.t. } g(x, y) \leq 0$$

- $x \in \hat{\mathbb{X}}$: Power to be purchased in the weekly market
- $y \in \mathbb{R}^p_+$: Power to be purchased in the daily market
- $d : \mathbb{R}^p_+ \to \mathbb{R}$: Expected daily market cost
- Reserves ensure a deficit probability of less than 0.2%

Comparison of different mechanisms

- Based on 2014 data—67 bidders

Table: Total payments under truthful bidding

Total Pay-as-bid payment	2.293 million CHF
Total MPCS payment	2.437 million CHF
Total VCG payment	2.529 million CHF

- If the bidders were to inflate their true costs by 11%, total pay-as-bid payment would have been 2.545 million CHF

- Computation times for different mechanisms
  - VCG: 580.6 seconds
  - MPCS: 659.2 seconds

Conclusion

- Summary
  - Mechanism design is essential for future electricity markets if we want to achieve stable and efficient grid
  - In this talk, we designed core-selecting mechanisms that achieve coalition-proofness, and approximate incentive-compatibility for electricity markets
  - Results were verified with the Swiss reserve market and OPF test systems
- Outlook
  - Coalitional games for spatial and intertemporal market coordination
  - Ways to reallocate budget surplus in core-selecting mechanisms

Thank you for your attention

My questions to you

- What are acceptable changes for electricity markets?
- What are the problems to address in pricing from your perspective?

You may contact me: okaraca@ethz.ch

The results from this talk appear in

- Karaca, Sessa, Walton, and Kamgarpour, "Designing coalition-proof reverse auctions over continuous goods", IEEE Transactions on Automatic Control, 2019
- Karaca and Kamgarpour, "Core-selecting mechanisms in electricity markets", under review, ArXiv:1811.09646, 2019
- Karaca, Sessa, Leidi, and Kamgarpour, "No-regret learning from partially observed data in repeated auctions", under review, 2019