Pricing Rules for Electricity Auctions with Non-Convexities

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Join work with Anthony Papavasiliou & Yves Smeers

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HARVARD Kennedy School
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Energy Policy Seminar

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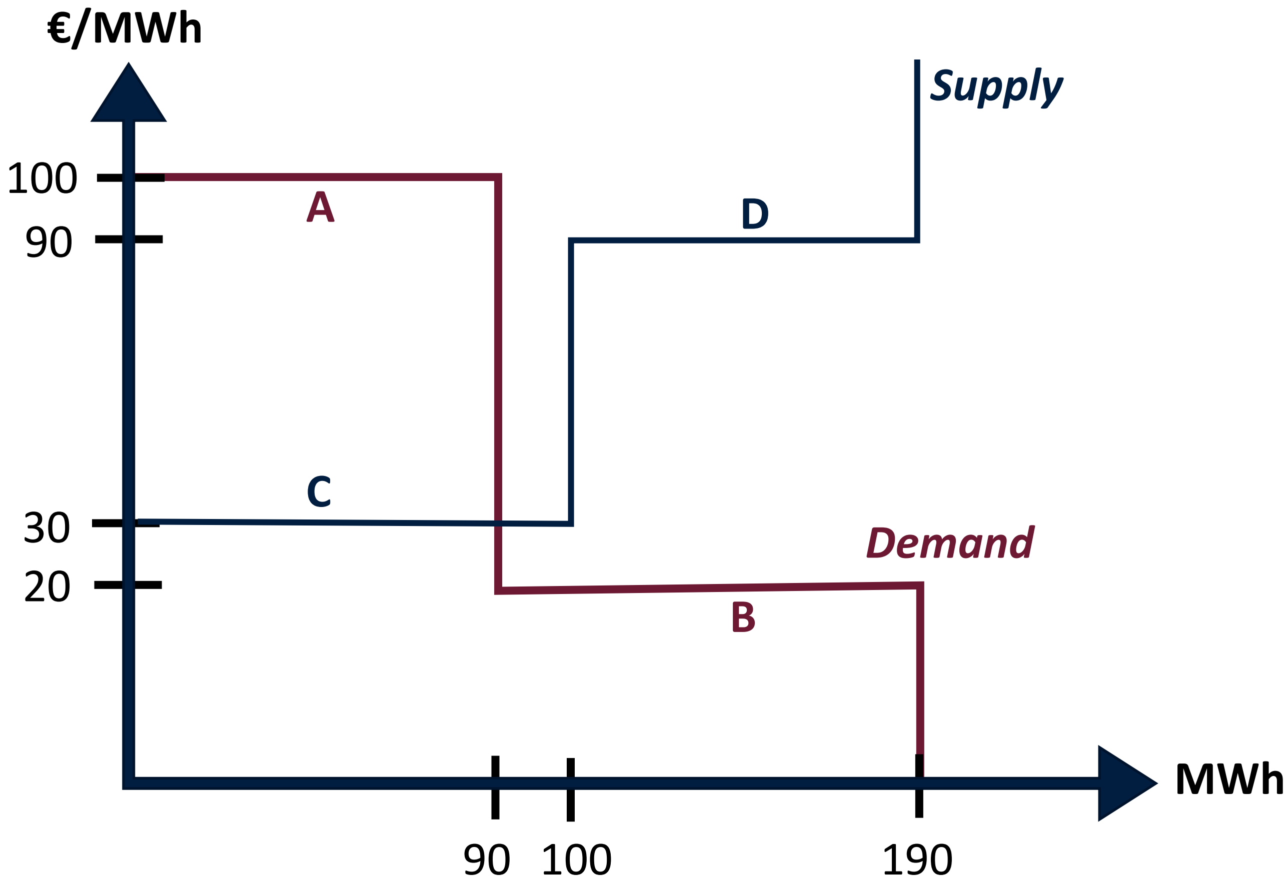
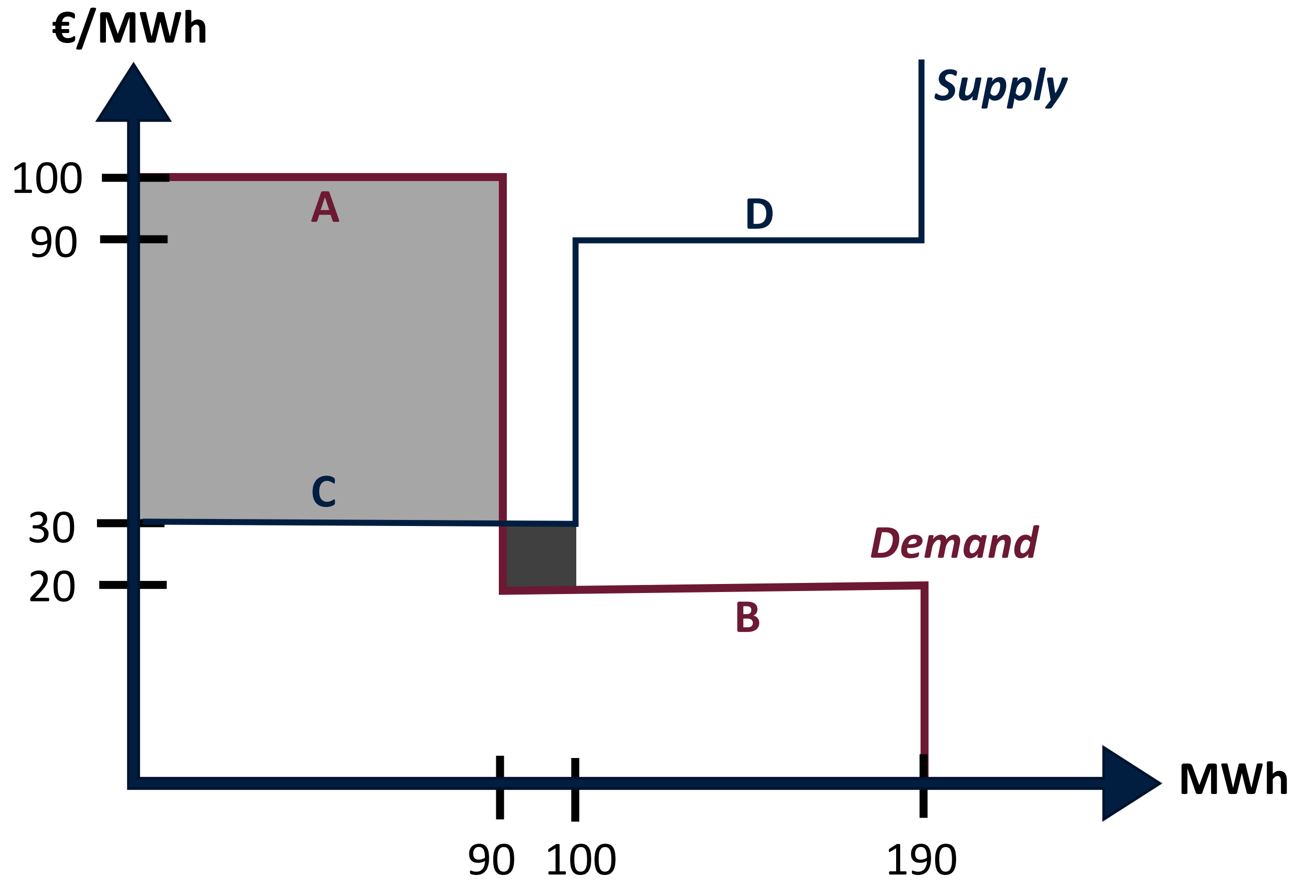
Pricing with indivisibilities



- **C** is *indivisible* (all-or-nothing)
- Welfare optimum solution is to clear **A, C** and a fraction of **B**
- What is the right price?
  - At 20€/MWh C is not willing to produce
  - At 30€/MWh, B is not willing to consume

Pricing with indivisibilities



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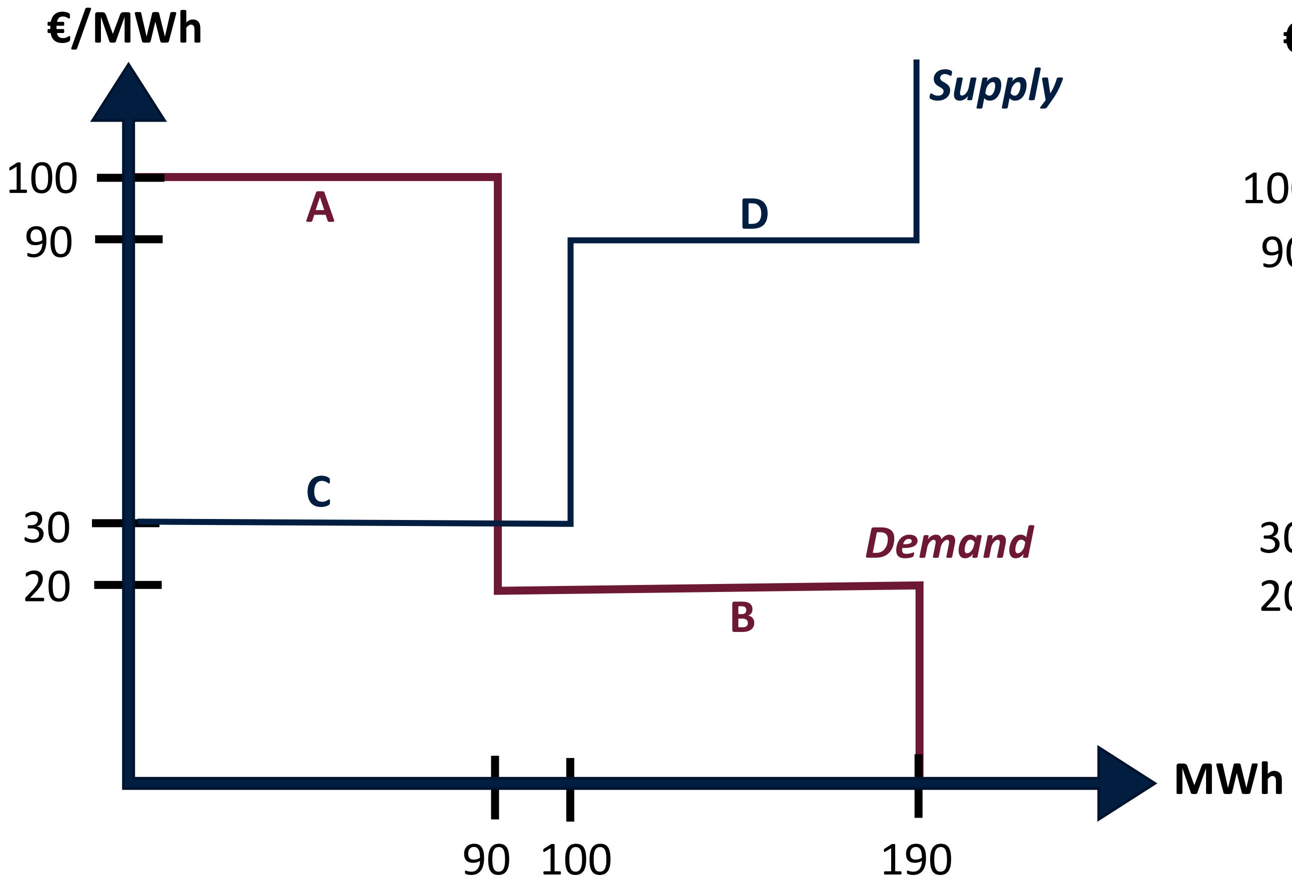
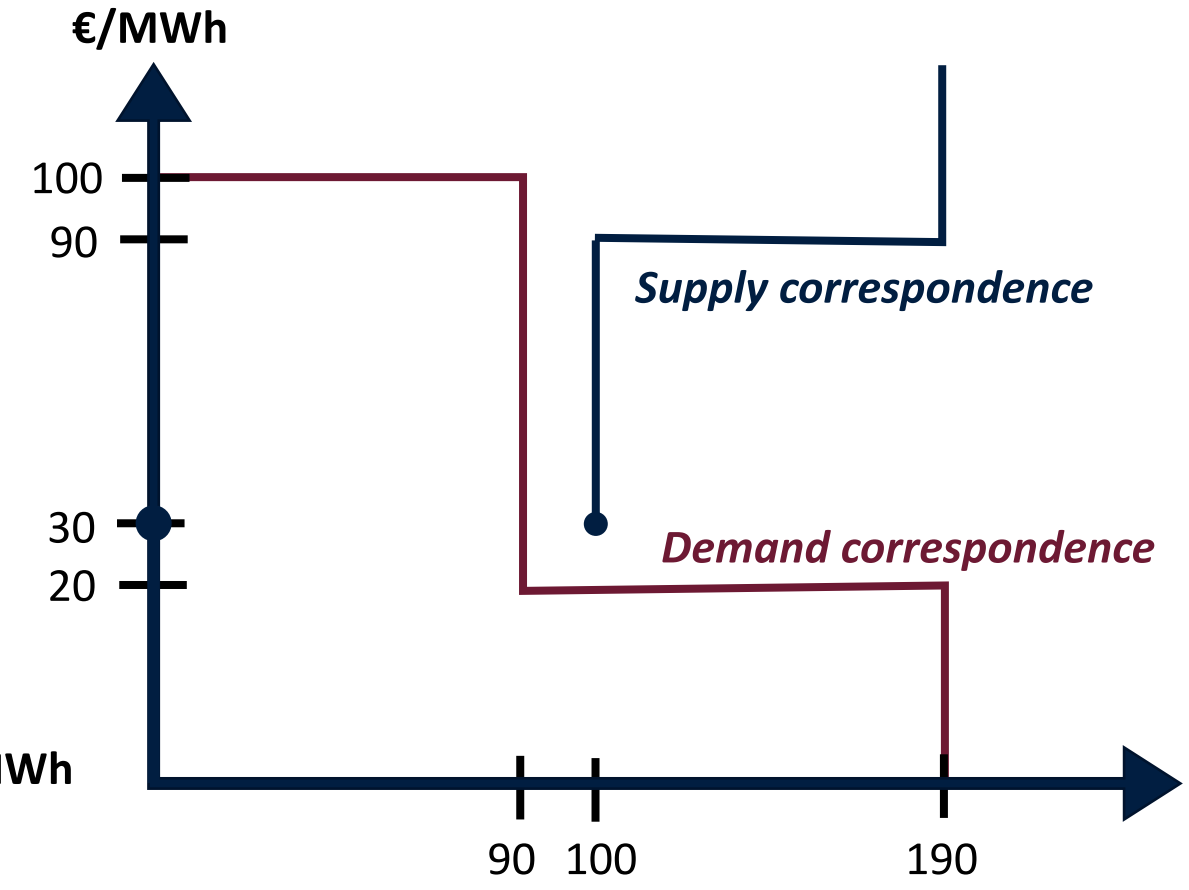
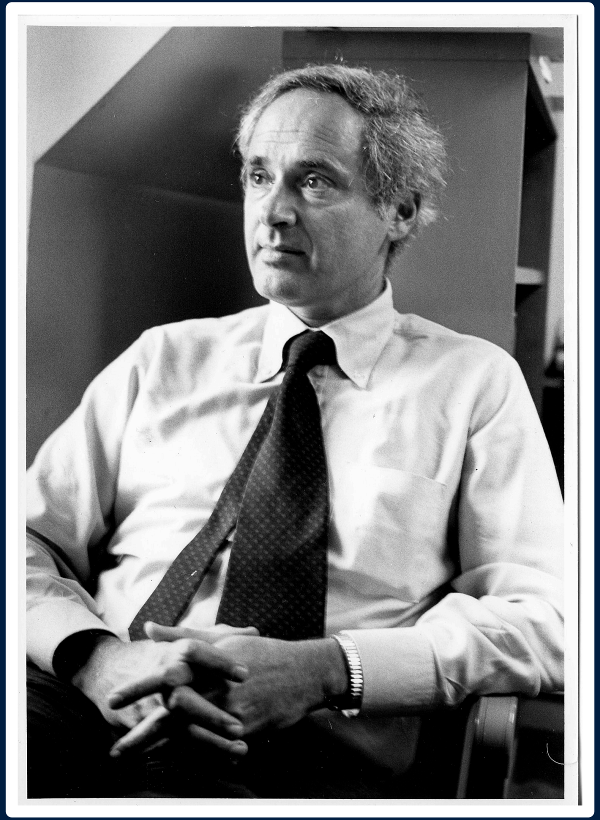




“in the presence of indivisibilities in production, prices simply don’t do the jobs that they were meant to do”

(Scarf, 1994)



Markets for power

- ***Specificities of electricity as a commodity*** → need for coordination
  - Exchanged through an **electrical grid** : physical network constraints
  - Demand must be met just-in-time by production
  - **Difficult/expensive to store**
  - **Low elasticity** of demand (few substitutes & lack of metering)
- ***Deregulation of power systems***:
  - From a **coordination by a a firm to a coordination through *market transactions*** (Coase, 1937)
  - Electricity market design

"The old problem asks which unit should be committed ;
the new problem asks what market design will best solve the old problem."

(Stoft, 2002)

Electricity auctions in a nutshell

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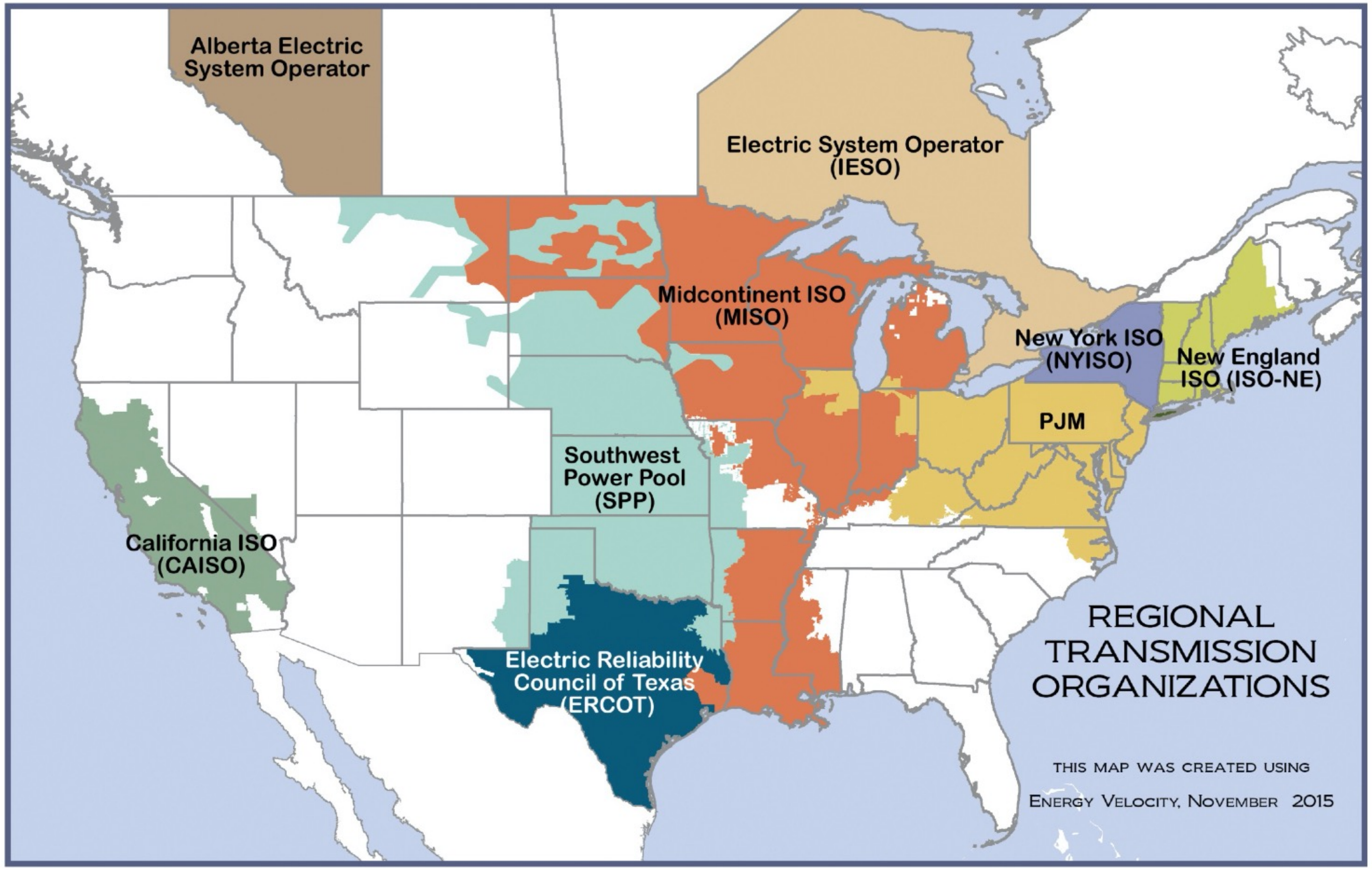
1) **Centralized** market
    - Closed-gate auction
    - Uniform-price auction
2) Integration of **multiple commodities**
    - Electrical energy, transmission capacity & ancillary services products
    - Multi-periods : typically, 24 hours

    → The "pricing problem" is thus a **multi-dimensional problem**: computation of hundreds or even **thousands of prices in a single market session**
3) **Multi-parts, non-convex** bids → *issue discussed in the first slide*
    - Account for the cost structure (production cost, start-up cost, etc.) & operational constraints (ramp, up time constraint, etc.) of suppliers
    - Unit commitment model (US)
    - Portfolio bidding (EU)

Electricity markets in the US



1992 : Energy Policy Act

creation of ISOs that operate the market

Early 2000': NYISO "hybrid pricing"

Marginal pricing traditionally adopted by many ISOs to clear the market + side payments

2014: FERC launches consultation about price formation

2015 : MISO implements ELMP

2017 : PJM made similar proposal

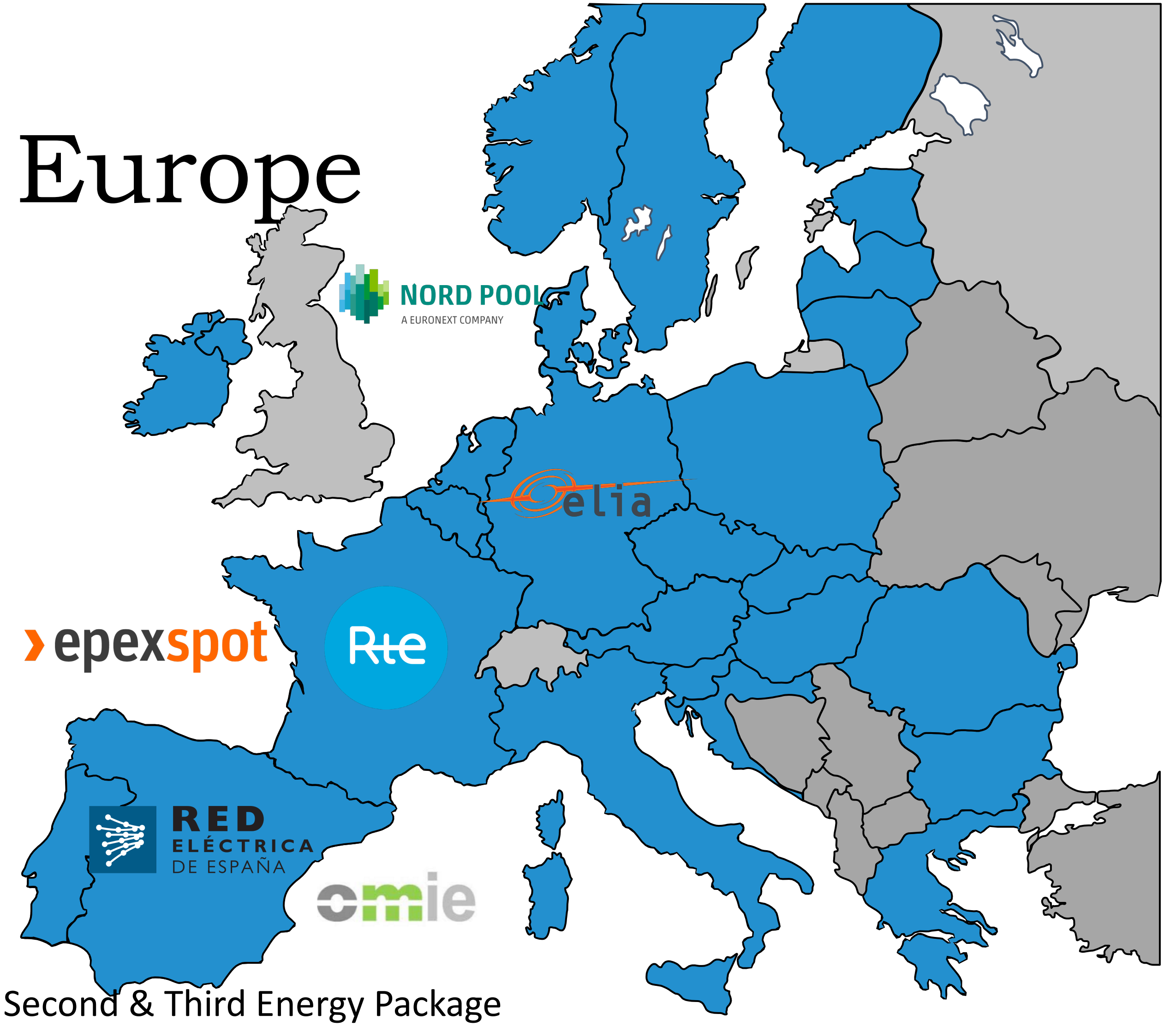
1990

2000

2010

2020

Electricity markets in Europe



- **Institutional framework**:
  - **TSOs** operate the grid
  - "**Nominated Electricity Market Operators**" (NEMOs) operate the market

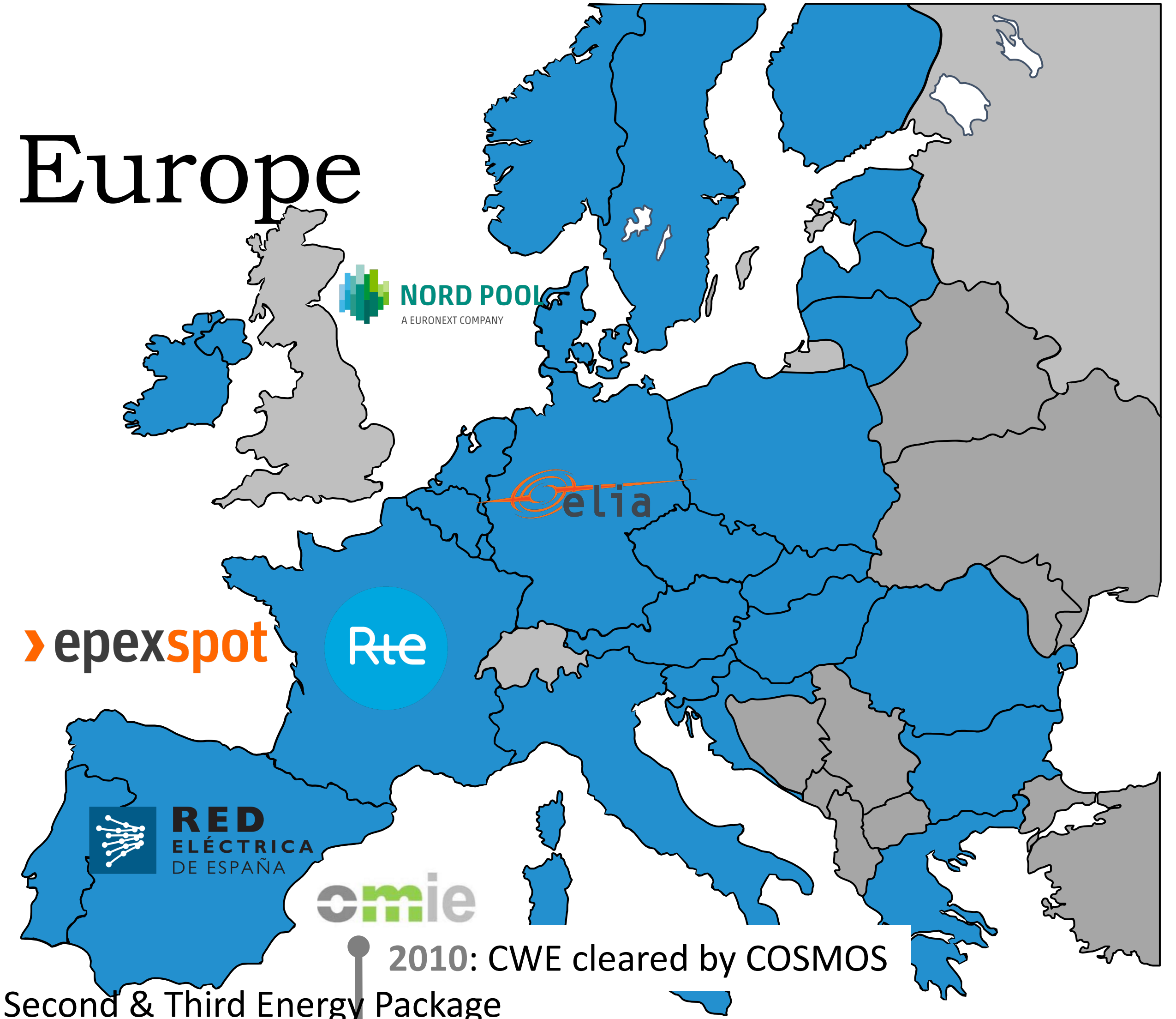
1993 : European Single Market

1996 : First Energy Package (kickoff the liberalization of the power sector)

2003 – 2009 : Second & Third Energy Package (unbundling of competitive and regulated segments)

1990 2000 2010 2020

Electricity markets in Europe



- **Institutional framework**:
  - **TSOs** operate the grid
  - "**Nominated Electricity Market Operators**" (NEMOs) operate the market
- **EU Electricity market — "Price Coupling of Regions"**:
  - 27 countries
  - 30 TSOs
  - 16 NEMOs
  - 4.66 TWh daily trade

1990

1993 : European Single Market

1996 : First Energy Package (kickoff the liberalization of the power sector)

2000

2003 – 2009 : Second & Third Energy Package (unbundling of competitive and regulated segments)

2006: Trilateral Market Coupling

2010

2010: CWE cleared by COSMOS

2014: Single Day-Ahead Coupling (SDAC), Price Coupling of Regions

2020

Objectives of the work

- Ongoing **discussions among European stakeholders** & research undertaken by NEMOs to **reform the current EU pricing rule** (NEMO Committee, 2020a ; MCSC, 2022 ; SDAC, 2023)
- How to price the indivisibilities has also been a **vivid subject of debate in the US** for the past 20 years: heterogeneous and changing policies
- **Objective of the paper** : contribute to these discussions, in particular the reform of the European pricing rules
    - Formalize the problem
    - Theoretical cross-comparison of several pricing approaches
    - Numerical simulations on auction dataset

- SDAC, 2023, Non-uniform pricing: Explanatory note, https://www.nemo- committee.eu/assets/files/ sdac- non- uniform- pricing- explanatory- note.pdf.
- NEMO Committee, 2020a. CACM annual report 2019. URL: http: //www.nemo- committee.eu/assets/files/cacm- annual- report- 2019.pdf.
- MCSC, 2022. Market Coupling Steering Committee: Market Coupling Consultative Group meeting, 1st of December. https: //eepublicdownloads.blob.core.windows.net/public- cdn- container/ clean- documents/events/2022/MCCG- presentation- 01122022final.pdf.

Plan

Motivations

- Theoretical motivation
- Policy relevance: both in US and EU markets

Theoretical framework

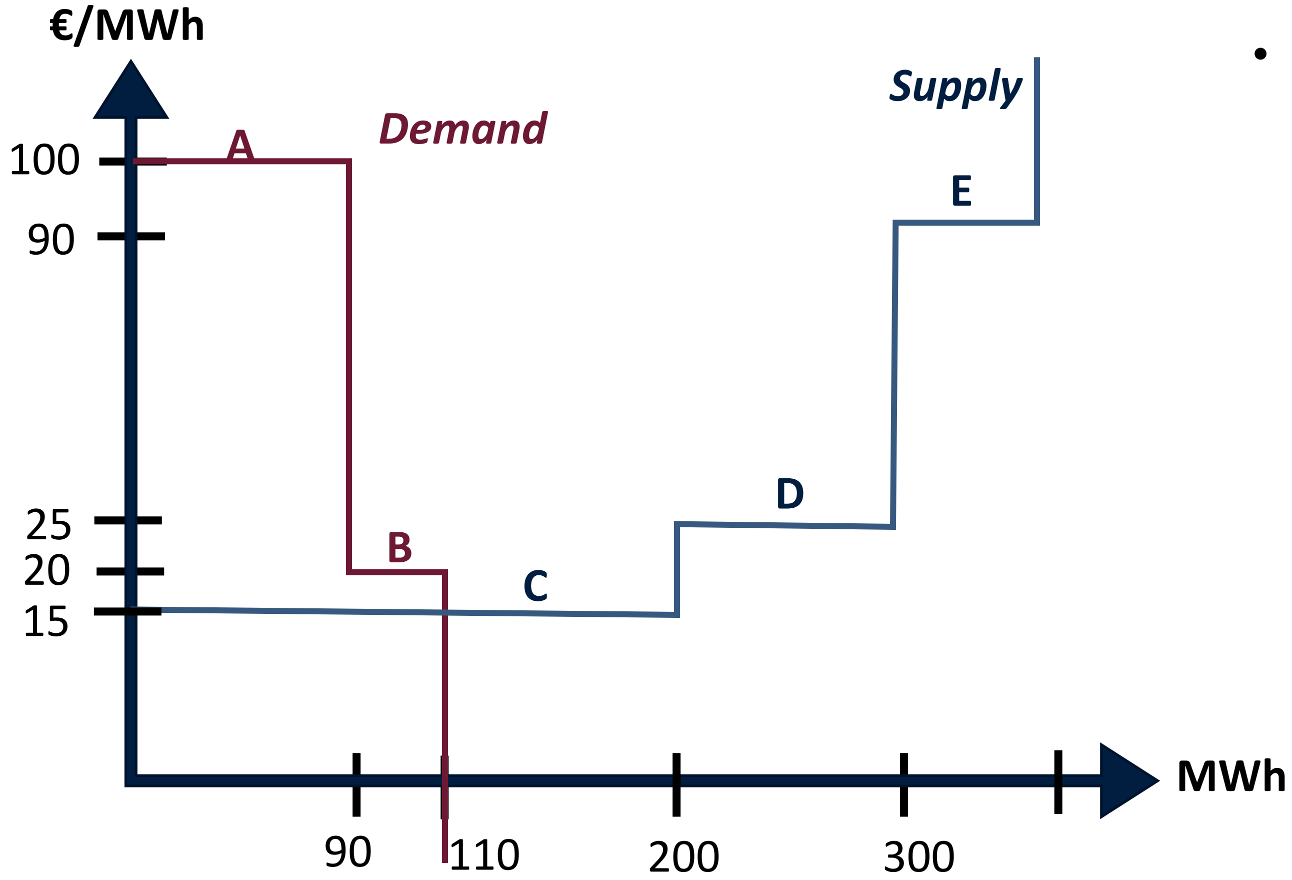
- Formalize the problem
- Solution to the problem — pricing schemes: marginal pricing, convex hull pricing…

Numerical simulations

- Numerical analysis on auction datasets
- Cross comparison of different pricing schemes
- Some advantages of convex hull pricing

Conclusion

How to measure the consistency between price & cleared allocation



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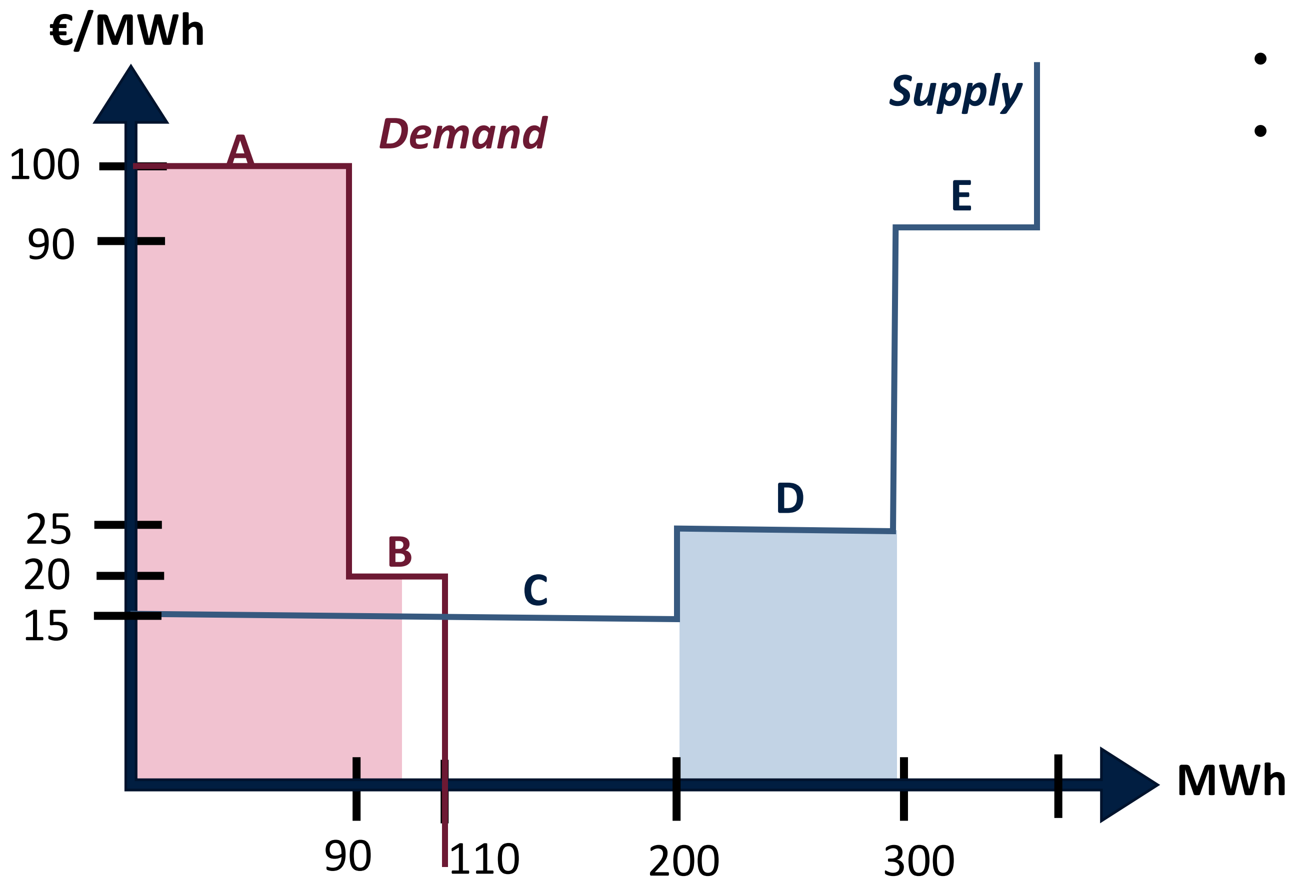

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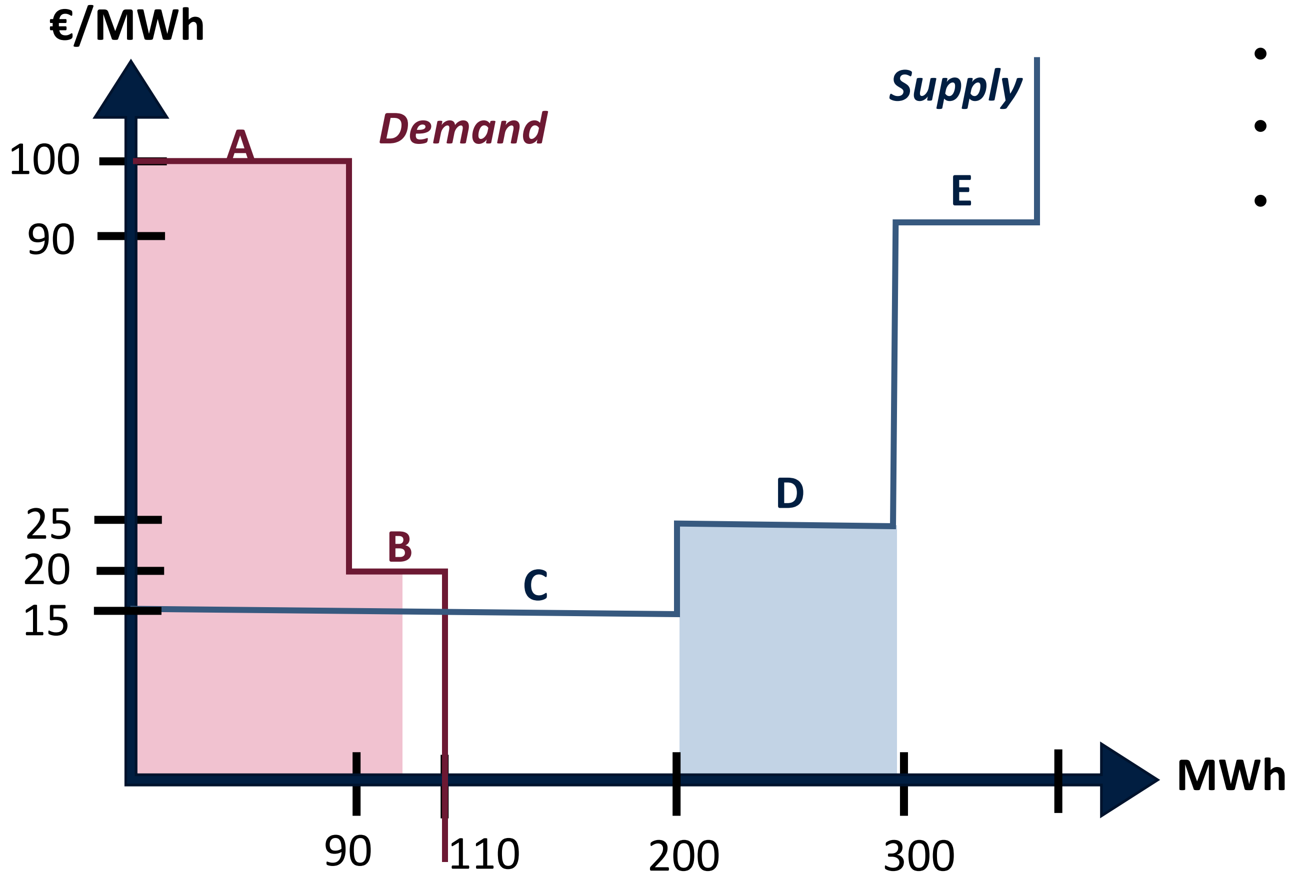


- **C** & **D** are *indivisible* (all-or-nothing)
- Welfare optimum : clear **A**, **D** and 10MW of **B**
- What is the right price?
  - **15€/MWh**
    - B has a lost opportunity of 50€
    - C is ok
    - D has a revenue shortfall of 1,000€
  - **20€/MWh**
    - B is ok
    - C has a lost opportunity of 1,000€
    - D has a revenue shortfall of 500€
  - **25€/MWh**
    - B has a revenue shortfall of 50€
    - C has a lost opportunity of 2,000€
    - D is ok

Two metrics to compare the candidate pricing approaches

- ***Lost opportunity costs (LOC)***

$$LOC = \max(profit\ under\ price\ p^*) - cleared\ profit$$

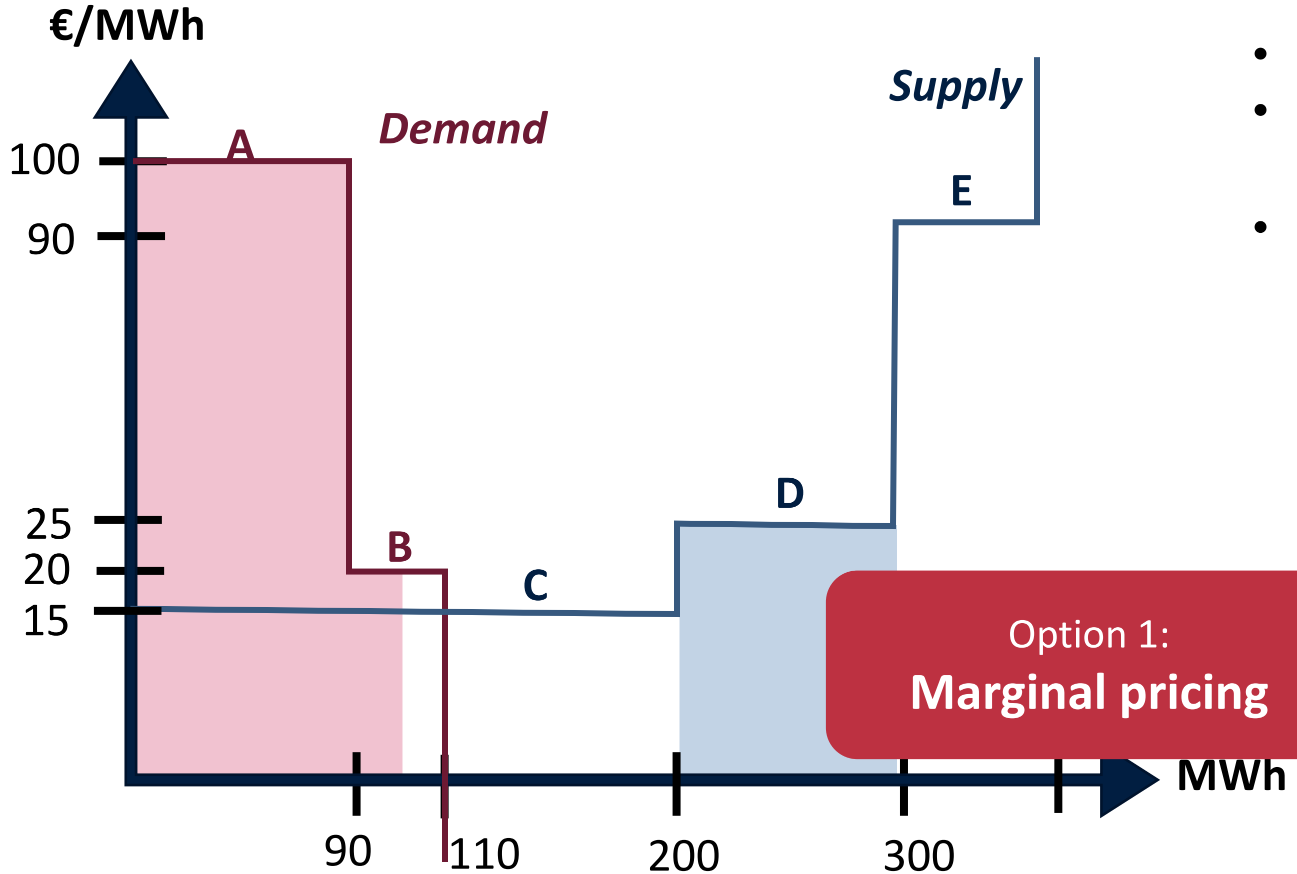
  - ❑ It measure the **incentive-compatibility** of prices and dispatch instructions
  - ❑ **Does the price *support* the cleared allocation?** If not, the dispatch could unravel as suppliers "self-schedule"

- ***Revenue shortfall (RS)*** (or "make-whole payments")

$$RS = -\min(0\ ;\ cleared\ profit)$$

  - ❑ It measure the **revenue-adequacy** of prices and dispatch instructions
  - ❑ **Does the uniform price enable the market participants to break even?**

Three candidate pricing schemes



Option 1:
Marginal pricing

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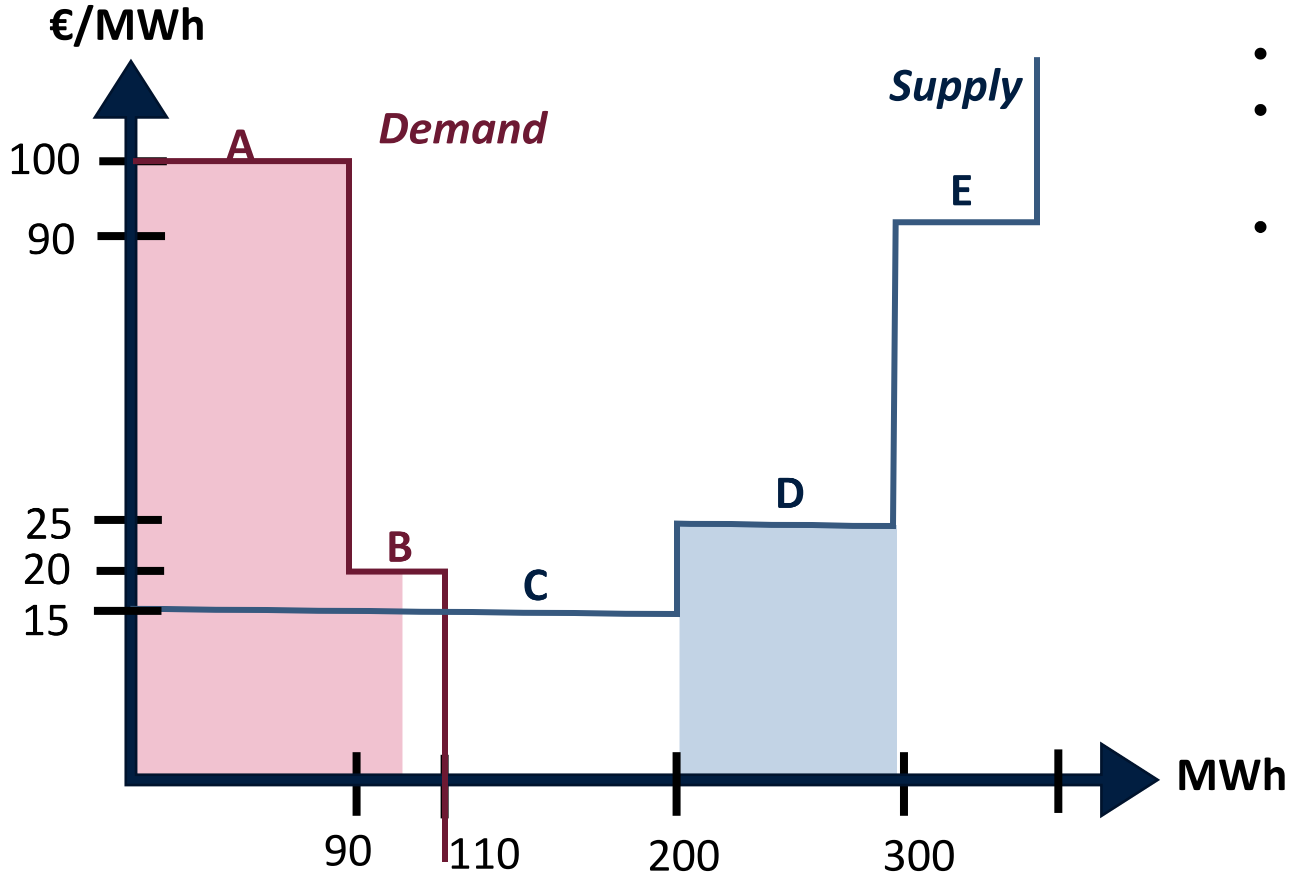

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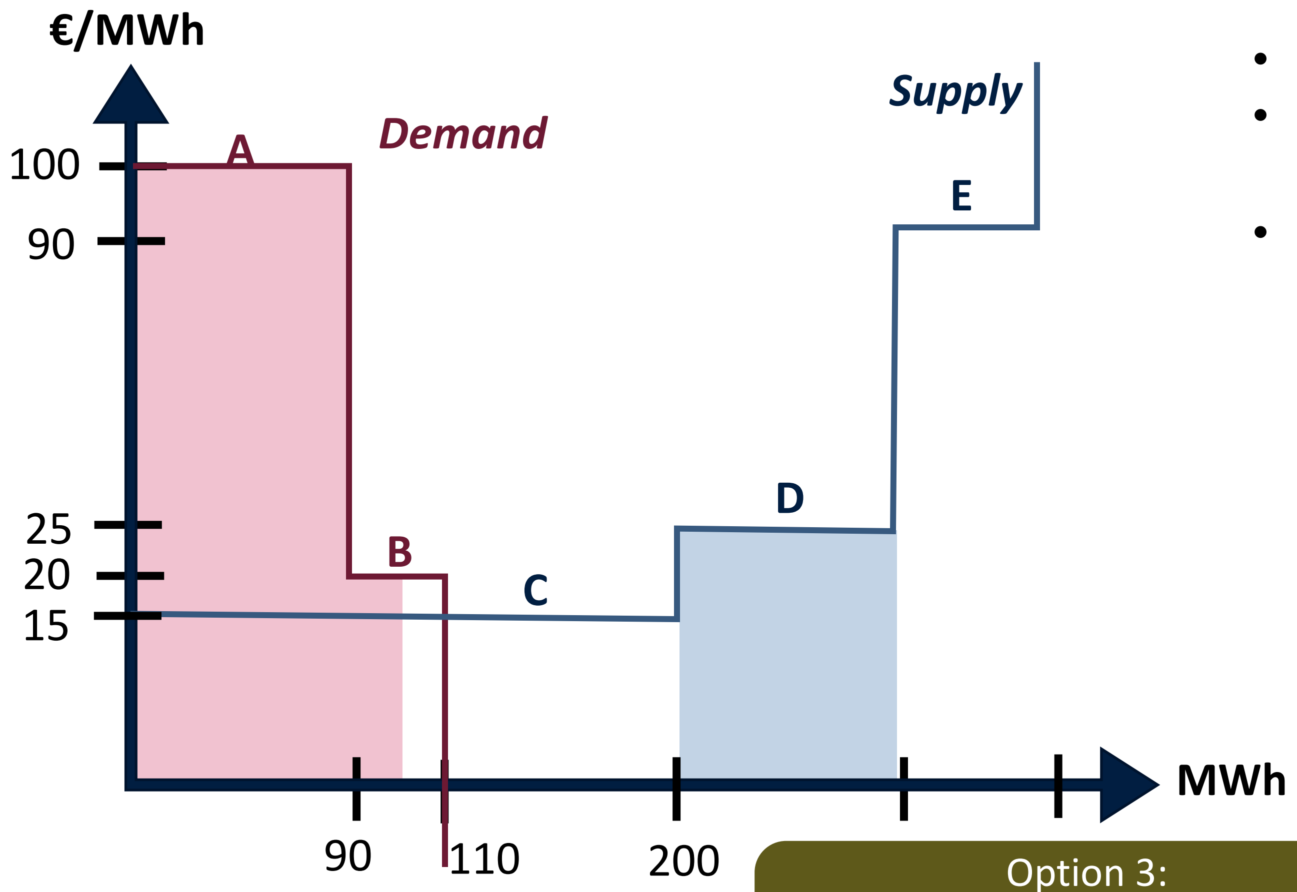
Option 2:
Convex Hull Pricing (CHP)

Three candidate pricing schemes



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Option 3:
Minimal Make-whole Payment Pricing (MMWP)

Three candidate pricing schemes

Pricing scheme	Objective	Computation	Math. Formulation	References
Marginal Pricing **(MP)**		Easy	Fix binary variables (primal-dependent)	O'Neill et al. (2005)
Convex Hull Pricing **(CHP)**	Minimize LOC	***Difficult*** but can be solved: (Stevens and Papavasiliou, 2022)	Convex hull of prod. & cons. sets (primal-dual separated)	Hogan and Ring (2003) and Gribik et al. (2007)
Minimal Make-Whole Payment pricing **(MMWP)**	Minimize RS	Easy	Solve ad-hoc problem	Madani and Papavasiliou (2022), Bichler et al. (2022)

- O'Neill, R.P., Sotkiewicz, P.M., Hobbs, B.F., Rothkopf, M.H., Stewart Jr, W.R., 2005. Efficient market-clearing prices in markets with nonconvexities. European journal of operational research 164, 269–285.
- Gribik, P.R., Hogan, W.W., Pope, S.L., et al., 2007. Market-clearing electricity prices and energy uplift. Cambridge, MA .
- Bichler, M., Knörr, J., Maldonado, F., 2022. Pricing in nonconvex markets:How to price electricity in the presence of demand response. Information Systems Research 34, 652–675.
- Madani, M., Papavasiliou, A., 2022. A note on a revenue adequate pric- ing scheme that minimizes make-whole payments. 18th International Conference on the European Energy Market (EEM) , 1–6.
- PJM, 2017. Proposed enhancements to energy price formation.
- Stevens, N., Papavasiliou, A., 2022. Application of the level method for computing locational convex hull prices. IEEE Transactions on Power Systems 37, 3958–3968.

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Two auction datasets used to compare the pricing schemes

FERC Dataset*	CWE dataset
~1000 power units	**~70 power units**
Sophisticated unit commitment model	Simpler unit commitment model
Convex & non-convex power units	Only non-convex power units
Possibility of inaction holds	Possibility of inaction does not hold
No network	**Network of 30 bidding zones**
11 load scenarios, 24 periods	**12 load scenarios** of 24 and 96 periods
Public data	Private data

* Knueven, B., Ostrowski, J., Watson, J.P., 2020. On mixed-integer programming formulations for the unit commitment problem. INFORMS J. Comput. 32, 857–876.
Krall, E., Higgins, M., O'Neill, R.P., 2012. Rto Unit Commitment Test System. Federal Energy Regulatory Commission, p. 98.

Some advantages of convex hull pricing

1 Marginal pricing leads to poor incentives for market participants

Table 2
Incentives of market agents on the CWE dataset depending on the price (average over 12 scenarios).

		MP	CHP	ELMP	MMWP	MMWP*	MMWP**
Dispatch Cost		5,489,000					
Av. Price [€/MWh]		42.8	43.4	47.3	27.7	23.8	52.6
Num. Suppl. with LOC		33.2%	35.9%	45.3%	83.6%	63.4%	64.3%
Av. LOC per Suppl.		3,528	278	1,285	141,834	29,326	27,066
LOC	Tot.	83,543	8,093	42,948	98,681,795	41,808,171	20,789,079
	Suppl.	83,543	6,810	39,006	8,746,513	1,350,259	1,250,017
	Net.	0	1,282	3,942	89,935,282	40,457,912	19,539,062
RS	Tot.	10,550	1,987	8,508	0	0	0
	Suppl.	10,550	1,987	8,508	0	0	0
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Av. LOC per Suppl.		3,528	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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Intuition: fixed "indivisible" costs (start-up, etc.) are not reflected the price signal

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2 CHP significantly improves the incentives of the market participants

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Significant improvement of **total** incentives (LOC) for the participants under CH

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Distribution of the LOC across participants: CHP improves significantly the average LOC born by individual agents

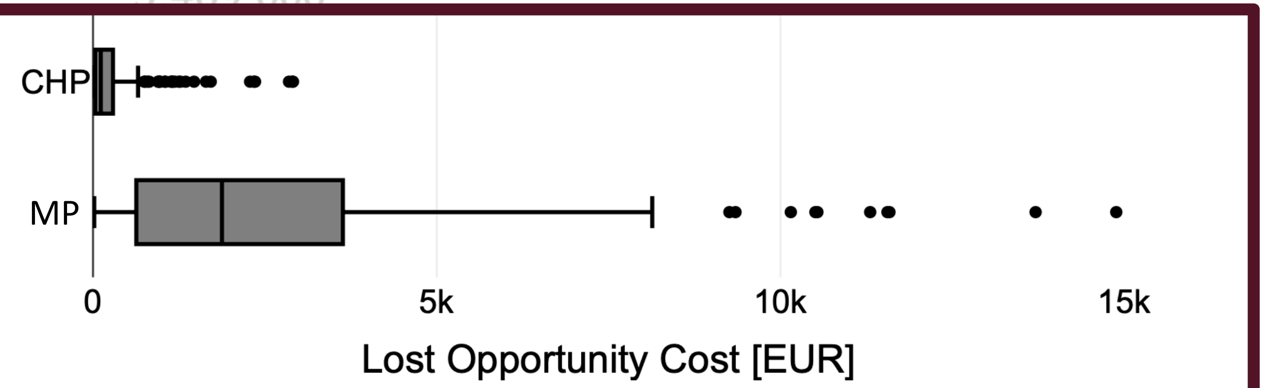

Figure 1: Distribution of the LOC accross suppliers for IP, CHP and ELMP (aggregate of all the CWE cases).

Some advantages of convex hull pricing

2 CHP significantly improves the incentives of the market participants

Table 1
Incentives of market agents on the FERC dataset depending on the price (average over 11 scenarios).

		MP	CHP	ELMP	MMWP	MMWP*	MMWP**
Dispatch Cost					29,780,000		
Av. Price [$/MWh]		28.8	28.7	28.8	56.3	26.8	28.9
Num. Suppl. with LOC		3.4%	1.8%	7.5%	79.2%	24.7%	9.5%
Av. LOC per Suppl.		628	19	37	148,232	4,577	94
LOC	Tot.	37,576	323	2,801	130,147,114	1,176,050	14,217
	Conv.	0	67	94	1,978,501	5,268	79
	Non-Conv.	37,576	257	2,707	128,168,613	1,170,782	14,137
RS	Tot.	669	19	206	0	0	0
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Significant improvement of **total** incentives (LOC) for the participants under CH

Some advantages of convex hull pricing

3 With CHP, the LOC are bounded : they do not grow with market size

Table 6
Results of CHP and IP pricing on FERC datasets (load profile `2015-08-01_lw`) depending on the market size. The initial 50-unit market is multiplied by a factor ranging from 2 to 20.

Market Size			Convex Hull Pricing		Marginal Pricing	
Number of Plants	Av. Hourly Load (MW)	Tot. Cost ($)	LOC ($)	LOC (% Tot. Cost)	LOC ($)	LOC (% Tot. Cost)
50	4,900	1,820,308	11,222	0.62%	276,383	15.18%
100	9,800	3,631,286	13,114	0.36%	538,713	14.84%
150	14,700	5,444,099	16,841	0.31%	805,370	14.79%
200	19,600	7,245,546	9,202	0.13%	1,060,574	14.64%
250	24,500	9,052,185	6,756	0.07%	1,320,763	14.59%
300	29,400	10,857,007	2,492	0.02%	1,579,297	14.55%
350	34,300	12,666,418	2,817	0.02%	1,842,613	14.55%
400	39,200	14,475,824	3,136	0.02%	2,105,629	14.55%
450	44,100	16,290,191	8,417	0.05%	2,373,870	14.57%
500	49,000	18,099,571	8,711	0.05%	2,636,708	14.57%
1000	98,000	36,183,999	2,280	0.01%	5,258,840	14.53%

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- With marginal pricing, the LOC grows with the market size
- With CHP not

Some advantages of convex hull pricing

4 Minimizing the LOC also leads to moderate RS

Table 2
Incentives of market agents on the CWE dataset depending on the price (average over 12 scenarios).

		MP	CHP	ELMP	MMWP	MMWP*	MMWP**
Dispatch Cost					5,489,000		
Av. Price [€/MWh]		42.8	43.4	47.3	27.7	23.8	52.6
Num. Suppl. with LOC		33.2%	35.9%	[illegible]	[illegible]	[illegible]	[illegible]
Av. LOC per Suppl.		3,528	278	[illegible]	[illegible]	[illegible]	[illegible]
LOC	Tot.	83,543	8,093	[illegible]	[illegible]	[illegible]	[illegible]
	Suppl.	83,543	6,810	[illegible]	[illegible]	[illegible]	[illegible]
	Net.	0	1,282	3,942	[illegible]	40,457,912	19,539,062
RS	Tot.	10,550	1,987	8,508	0	0	0
	Suppl.	10,550	1,987	8,508	0	0	0
	Net.	0	0	0	0	0	0

this is because RS <= LOC
→ RS = incentive to self-schedule at 0

Some advantages of convex hull pricing

5 Minimizing the RS, on the other hand, exacerbates the LOC significantly

Table 1
Incentives of market agents on the FERC dataset depending on the price (average over 11 scenarios).

		MP	CHP	ELMP	MMWP	MMWP*	MMWP**
Dispatch Cost					29,780,0[illegible]		
Av. Price [$/MWh]		28.8	28.7	28.8	[illegible]	[illegible]	[illegible]
Num. Suppl. with LOC		3.4%	1.8%	7.5%	[illegible]	[illegible]	[illegible]
Av. LOC per Suppl.		628	19	37	1[illegible]	[illegible]	[illegible]
LOC	Tot.	37,576	323	2,801	130[illegible]	[illegible]	[illegible]
	Conv.	0	67	94	1,[illegible]	[illegible]	[illegible]
	Non-Conv.	37,576	257	2,707	128,[illegible]	[illegible]	[illegible]
RS	Tot.	669	19	206	0	0	0
	Conv.	0	0	3	0	0	0
	Non-Conv.	669	19	203	0	0	0

Minimizing RS:
- Mild requirement
- Many ways to do it (not one single unambiguous pricing outcome)

Some advantages of convex hull pricing

5 Minimizing the RS, on the other hand, exacerbates the LOC significantly

Table 1
Incentives of market agents on the FERC dataset depending on the price (average over 11 scenarios).

		MP	CHP	ELMP	MMWP	MMWP*	MMWP**
Dispatch Cost					29,780,000		
Av. Price [$/MWh]		28.8	28.7	28.8	56.3	26.8	28.9
Num. Suppl. with LOC		3.4%	1.8%	[illegible]	[illegible]	[illegible]	9.5%
Av. LOC per Suppl.		628	19	[illegible]	[illegible]	[illegible]	94
LOC	Tot.	37,576	323	[illegible]	[illegible]	[illegible]	14,217
	Conv.	0	67	[illegible]	[illegible]	[illegible]	79
	Non-Conv.	37,576	257	2,707	128,168,613	[illegible]	14,137
RS	Tot.	669	19	206	0	0	0
	Conv.	0	0	3	0	0	0
	Non-Conv.	669	19	203	0	0	0

Minimizing RS leads to 0 RS in these cases

Some advantages of convex hull pricing

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Incentives of market agents on the FERC dataset depending on the price (average over 11 scenarios).

		MP	CHP	ELMP	MMWP	MMWP*	MMWP**
Dispatch Cost					29,780,000		
Av. Price [$/MWh]		28.8	28.7	28.8	56.3	26.8	28.9
Num. Suppl. with LOC		3.4%	1.8%	7.5%	79.2%	24.7%	9.5%
Av. LOC per Suppl.		628	19	37	148,232	4,577	94
LOC	Tot.	37,576	323	[illegible]	[illegible]	[illegible]	14,217
	Conv.	0	67	[illegible]	[illegible]	[illegible]	79
	Non-Conv.	37,576	257	[illegible]	[illegible]	[illegible]	14,137
RS	Tot.	669	19	[illegible]	[illegible]	[illegible]	0
	Conv.	0	0	3	0	0	0
	Non-Conv.	669	19	203	0	0	0

But it exacerbate the LOC

Some advantages of convex hull pricing

5 Minimizing the RS, on the other hand, exacerbates the LOC significantly

Table 2
Incentives of market agents on the CWE dataset depending on the price (average over 12 scenarios).

		MP	CHP	ELMP	MMWP	MMWP*	MMWP**
Dispatch Cost					5,489,000		
Av. Price [€/MWh]		42.8	43.4	[illegible]	[illegible]	[illegible]	52.6
Num. Suppl. with LOC		33.2%	35.9%	[illegible]	[illegible]	[illegible]	64.3%
Av. LOC per Suppl.		3,528	278	[illegible]	[illegible]	[illegible]	27,066
LOC	Tot.	83,543	8,093	[illegible]	[illegible]	[illegible]	20,789,079
	Suppl.	83,543	6,810	[illegible]	[illegible]	[illegible]	1,250,017
	Net.	0	1,282	3,942	89,935,282	40,457,912	19,539,062
RS	Tot.	10,550	1,987	8,508	0	0	0
	Suppl.	10,550	1,987	8,508	0	0	0
	Net.	0	0	0	0	0	0

In presence of network constraint, this becomes dramatic

Plan

Motivations

- Theoretical
- Policy relevance: both in US and EU markets

Theoretical framework

- Formalize the problem
- Solution to the problem — pricing schemes: marginal pricing, convex hull pricing…

Numerical simulations

- Numerical analysis on auction datasets
- Cross comparison of different pricing schemes
- Some advantages of convex hull pricing

Conclusion

Conclusion

- Pricing the non-convexities in electricity auctions is a **long-lasting debate**
  - In the **US**: heterogeneous and changing policies
  - Recent discussions in **Europe** to reform the market pricing rule

- **Marginal pricing** could be an upgrade as compared to the current pricing rule: improvement in both **welfare** and **scalability**…

- But **Convex hull pricing comes with many benefits**
  - Significantly improves the incentives of the market participants
  - Ensures revenue shortfall remain contained
  - Guarantee that the LOC become relatively small when the market size increases

- While **minimizing the revenue shortfall**—or “make-whole payments”—may sound like a reasonable, target, it may also result in unbearable (and unbounded) lost opportunity costs

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Thank you!

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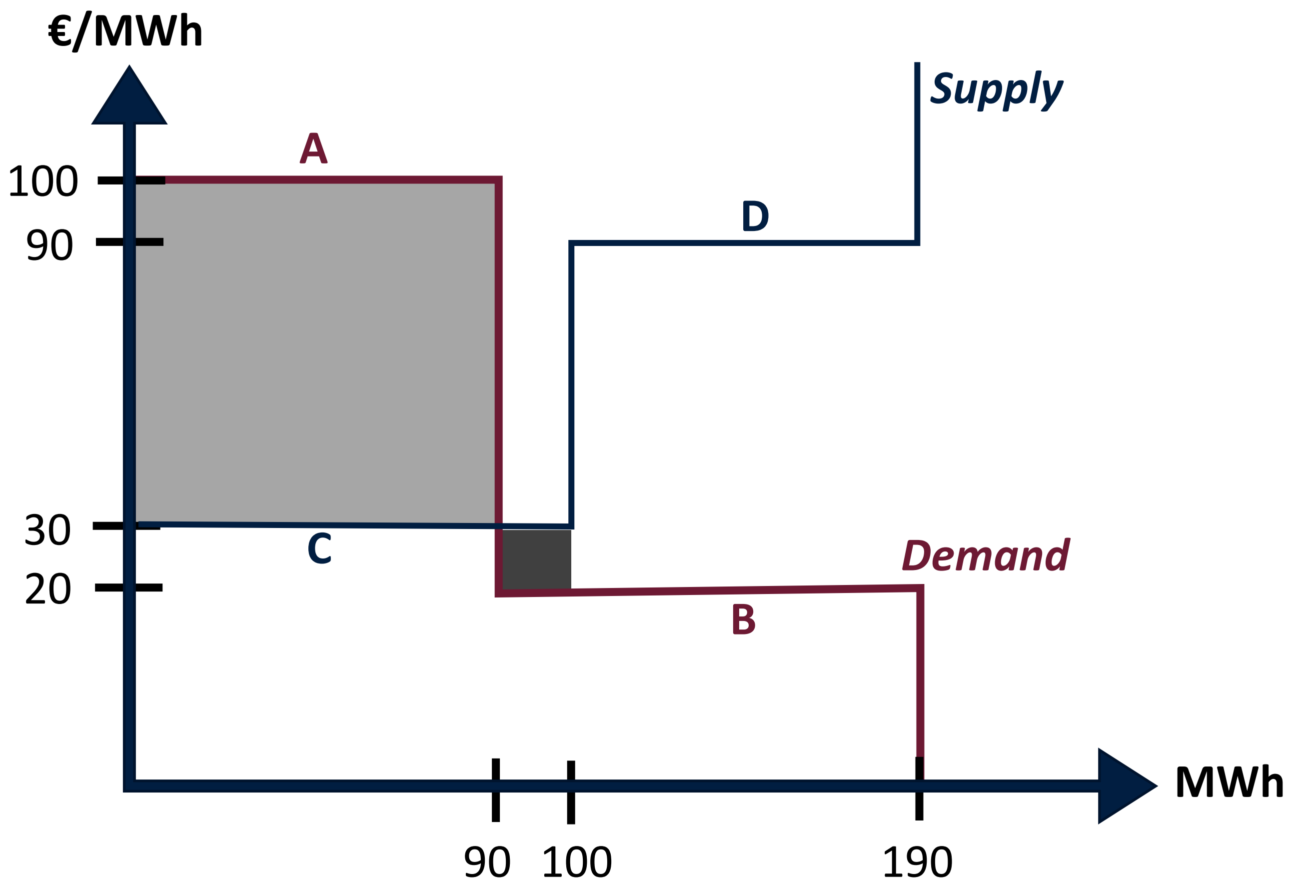
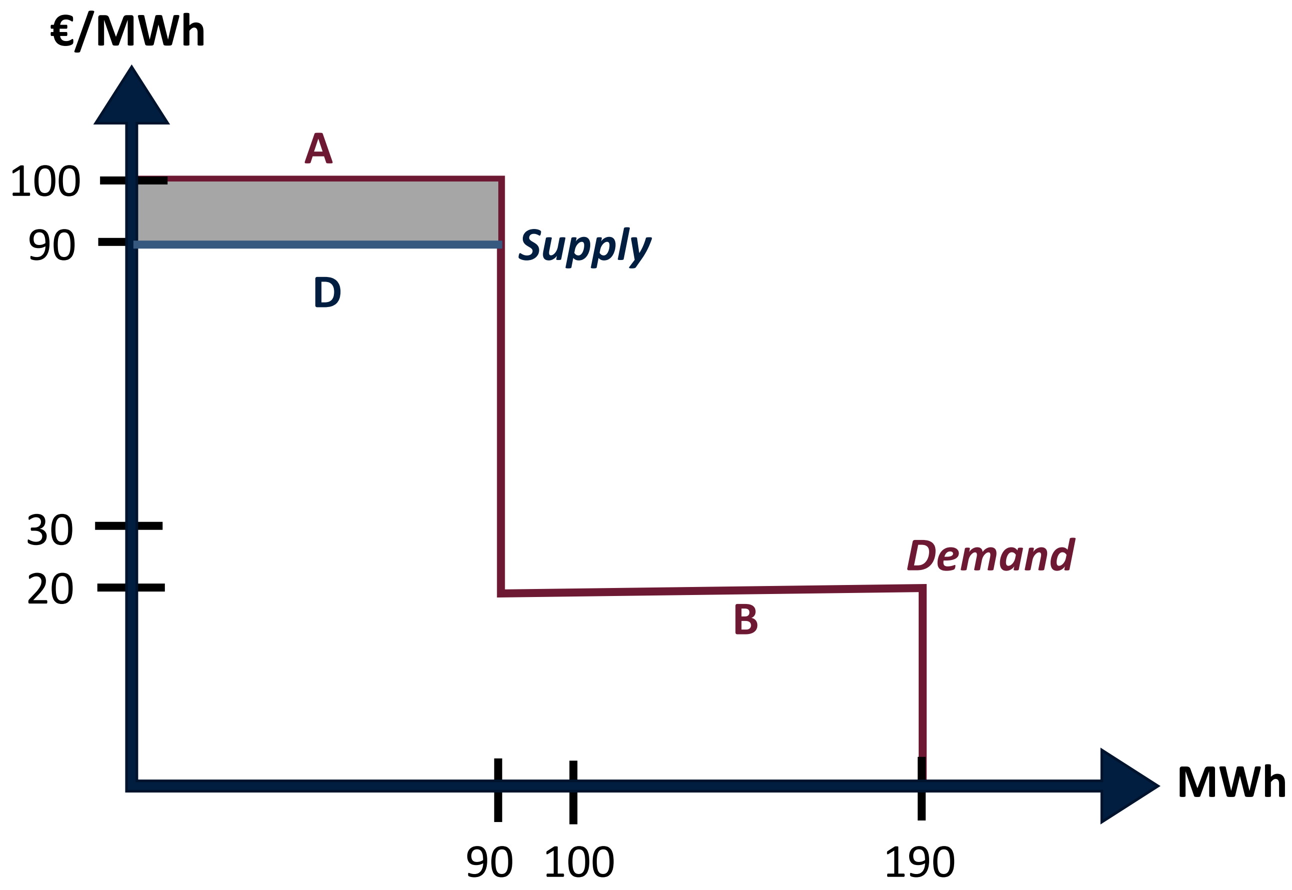
UCLouvain

Current European pricing rule



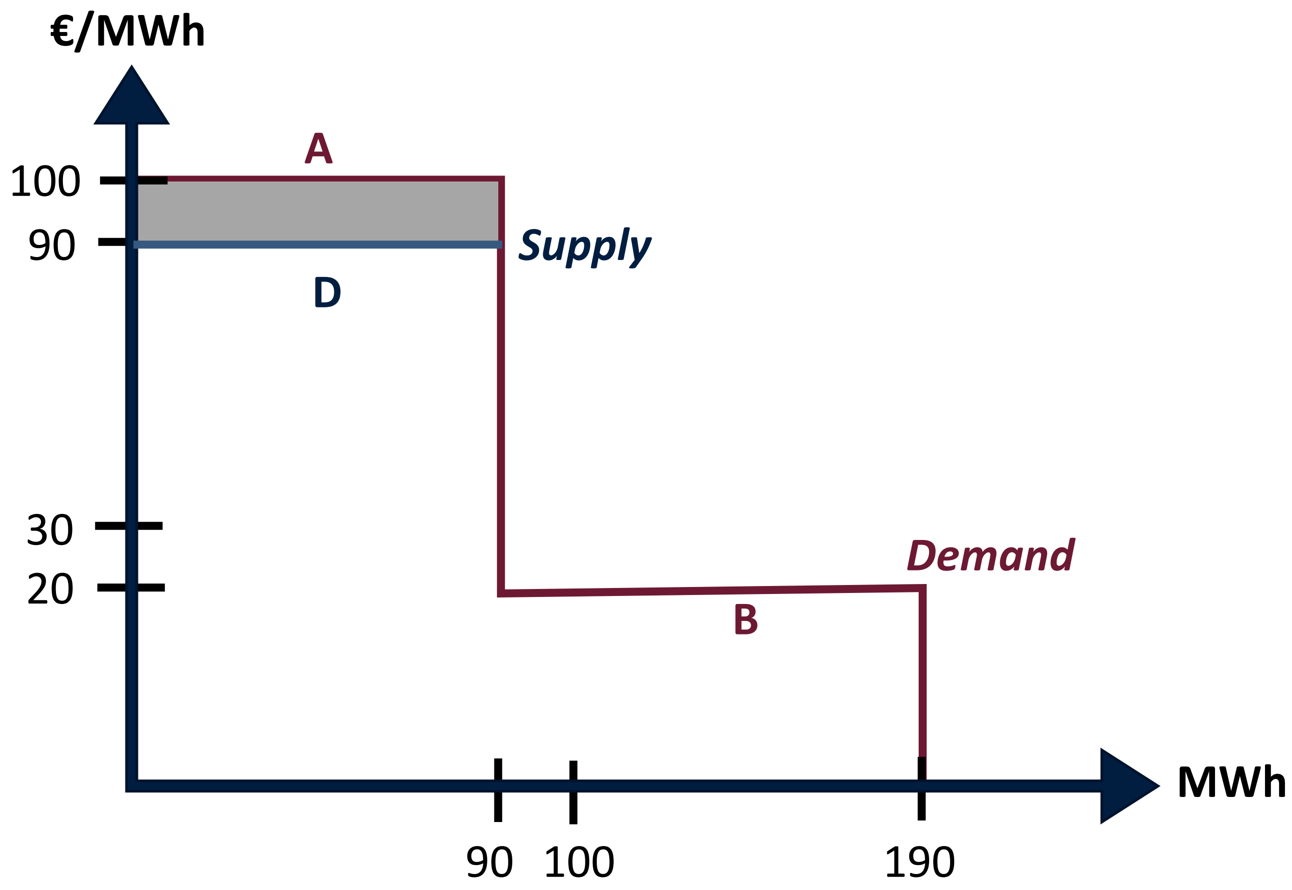
- Efficient solution: clear **A, C** and a fraction of **B**

Current European pricing rule



- Efficient solution: clear **A, C** and a fraction of **B**
- **Current European SDAC rule:**
  - Reject block **C**, clear **A** & **D**
  - Price: 90€/MWh

Current European pricing rule



- Efficient solution: clear **A, C** and a fraction of **B**

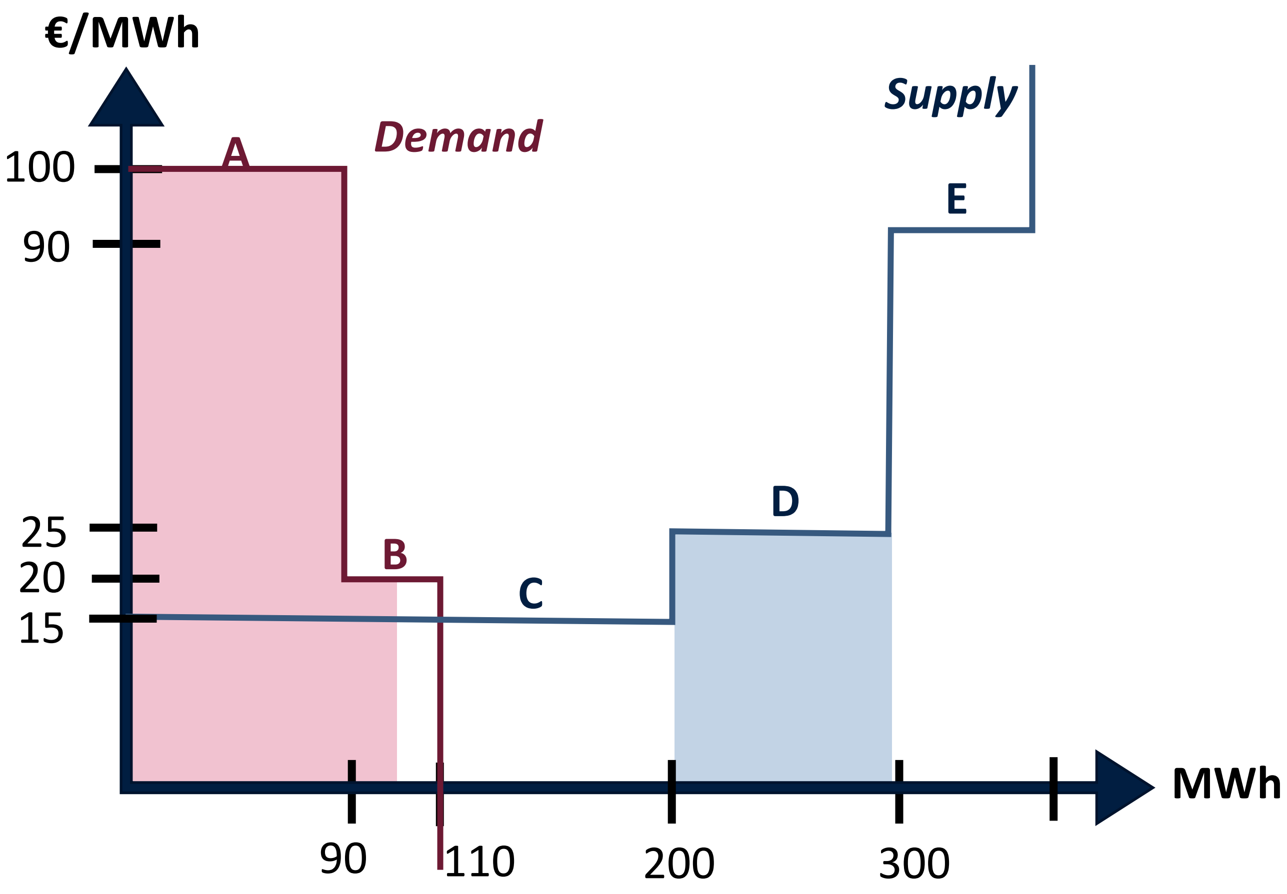
- **Current European SDAC rule:**
  - Reject block **C**, clear **A** & **D**
  - Price: 90€/MWh

- 3 main **issues**
  - Inefficiencies
  - Not an equilibrium
  - Computational scalability issues

Some advantages of convex hull pricing

2 Advantages of minimizing the LOC over the RS

CHP vs MMWP



- **C** & **D** are *indivisible* (all-or-nothing)
- Welfare optimum : clear **A**, **D** and 10MW of **B**

- It is **impossible to find a uniform price that eliminate revenue shortfalls for all market participant in a two-sided auction**
- Here:

  p>=25 to ensure 0 RS for D

  p<=20 to ensure 0 RS for B

→ **Some discrimination is in any case needed with elastic load**

- If load is **inelastic** (this is the case in the numerical simulations): ***any* price that is high enough ensures zero RS…** → **significant indeterminacy**

Some advantages of convex hull pricing

1 Significant improvements of incentives for the market' participants

Table 1
Incentives of market agents on the FERC dataset dependi[illegible]

		IP	CHP	ELMP	[illegible]	[illegible]	[illegible]
Dispatch Cost					29[illegible]	[illegible]	[illegible]
Av. Price [$/MWh]		28.8	28.7	28.8	[illegible]	[illegible]	[illegible]
Num. Suppl. with LOC		3.4%	1.8%	7.5%	[illegible]	[illegible]	[illegible]
Av. LOC per Suppl.		628	19	37	[illegible]	[illegible]	[illegible]
LOC	Tot.	37,576	323	2,801	130,147[illegible]	[illegible]	14,217
	Conv.	0	67	94	1,978,501	5,268	79
	Non-Conv.	37,576	257	2,707	128,168,613	1,170,782	14,137
RS (in LOC)	Tot.	669	19	206	0	0	0
	Conv.	0	0	3	0	0	0
	Non-Conv.	669	19	203	0	0	0
FO	Tot.	36,907	304	2,596	130,147,114	1,176,050	14,217
	Conv.	0	66	91	1,978,501	5,268	79
	Non-Conv.	36,907	238	2,505	128,168,613	1,170,782	14,137

Nonetheless, let's stress that it does not mean that each participant is better off under CHP: some could be better off under IP.

Proposition: under IP pricing, all convex participants have zero LOC.

Some advantages of convex hull pricing

1 Significant improvements of incentives for the market’ participants

Table 2
Incentives of market agents on the CWE dataset depending on th

		IP	CHP	ELMP			
Dispatch Cost					5,48		
Av. Price [€/MWh]		42.8	43.4	47.3			
Num. Suppl. with LOC		33.2%	35.9%	45.3%			
Av. LOC per Suppl.		3,528	278	1,285			
LOC	Tot.	83,543	8,093	42,948	9		
	Suppl.	83,543	6,810	39,006	8,746,51	,259	1,250,017
	Net.	0	1,282	3,942	89,935,282	40,457,912	19,539,062
RS (in LOC)	Tot.	10,550	1,987	8,508	0	0	0
	Suppl.	10,550	1,987	8,508	0	0	0
	Net.	0	0	0	0	0	0
FO	Tot.	72,993	6,106	34,440	98,681,795	41,808,171	20,789,079
	Suppl.	72,993	4,823	30,499	8,746,513	1,350,259	1,250,017
	Net.	0	1,282	3,942	89,935,282	40,457,912	19,539,062
RS (not in LOC)	Tot.	897,653	877,040	730,234	0	0	0
	Suppl.	897,653	877,040	730,234	0	0	0
	Net.	0	0	0	0	0	0

The network is a “convex participant”

Proposition: under IP pricing, all convex participants have zero LOC.

Some advantages of convex hull pricing

4 Consistency between LOC-minimization and welfare-maximization

CHP vs IP

Proposition: under CHP or ELMP, the relationship between optimality gap and LOC is monotone

Proposition: under IP or MMWP, the relationship between optimality gap and LOC is *not* monotone

Table 5
Sensitivity of lost opportunity cost to the primal optimality gap, depending on the price. The simulations are performed on CWE dataset (Spring WD 24). All figures are in €.

Opt. gap	Tot. Cost	IP LOC	ELMP LOC	CHP LOC	MMWP LOC	MMWP* LOC	MMWP** LOC
0.1%	5,213,357	115,043	43,346	12,611	127,174,509	46,374,970	25,487,688
0.09%	5,212,947	101,212	42,937	12,201	128,078,572	46,380,214	25,477,625
0.08%	5,212,121	194,521	42,111	11,375	128,503,837	46,534,306	25,374,010
0.07%	5,212,121	194,521	42,111	11,375	128,503,837	46,534,306	25,374,010
0.06%	5,211,690	129,455	41,680	10,944	129,671,679	46,505,121	25,366,511
0.05%	5,211,057	119,929	41,047	10,312	129,665,324	46,286,384	25,414,900
0.04%	5,210,885	119,579	40,875	10,140	129,855,305	46,366,246	25,411,805
0.03%	5,210,743	119,360	40,733	9,997	127,937,157	46,371,886	25,411,662
0.02%	5,210,685	119,351	40,675	9,940	127,677,227	46,360,290	25,411,605
0.01%	5,210,685	119,351	40,675	9,940	127,677,227	46,360,290	25,411,605

Some advantages of convex hull pricing

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0.09%	5,212,947	101,212	42,937	12,201	128,078,572	46,380,214	25,477,625
0.08%	5,212,121	194,521	42,111	11,375	128,503,837	46,534,306	25,374,010
0.07%	5,212,121	194,521	[illegible]	11,375	128,503,837	46,534,306	25,374,010
0.06%	5,211,690	129,455	[illegible]	[illegible]	[illegible]	[illegible]	25,366,511
0.05%	5,211,057	119,929	[illegible]	[illegible]	[illegible]	[illegible]	25,414,900
0.04%	5,210,885	119,579	[illegible]	[illegible]	[illegible]	[illegible]	25,411,805
0.03%	5,210,743	119,360	[illegible]	[illegible]	[illegible]	[illegible]	25,411,662
0.02%	5,210,685	119,351	40,675	9,940	127,677,227	46,360,290	25,411,605
0.01%	5,210,685	119,351	40,675	9,940	127,677,227	46,360,290	25,411,605

Going from **0.09%** to **0.08%** reduces the costs by **826€**…
…but it increases the LOC by **93,309€**. **Which solution should be preferred?**