Zero-price Energy Offering by (Multiband) Robust Optimization

Fabio D'Andreagiovanni

Zuse Institute Berlin (ZIB)

Freie Universität Berlin

Technical University Berlin

DFG Research Center MATHEON
Mathematics for key technologies

ECMath
Einstein Center for Mathematics Berlin

National Research Council of Italy

IASI-CNR

FER – University of Zagreb, June 29th 2016

Presentation outline

- Energy Offering under Market Price Uncertainty for a Price-Taker (EnOff-PT)
- A review of a highly cited Robust Optimization approach for the EnOff-PT
- A new Robust Optimization approach for the EnOff-PT
- Computational results
- Can we do better by Multiband Robust Optimization?

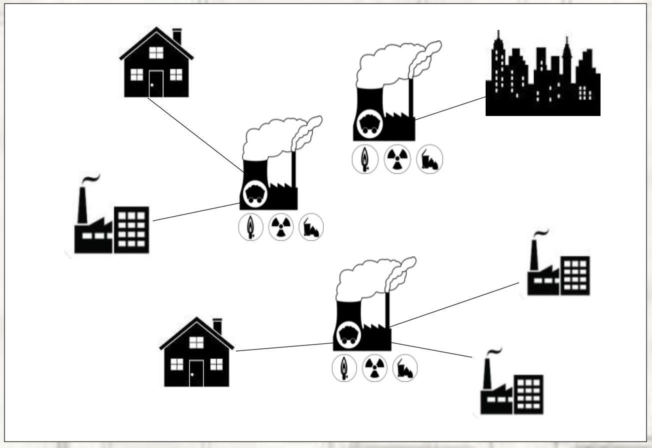
All the presented results are strongly based on discussions with experts from our industrial partners, namely:

QuanTek QUANTITATIVE TECHNOLOGY

A MAJOR EUROPEAN ELECTRIC UTILITY
CONFIDENTIAL

and are based on realistic data. The model and approach were validated by the Partners, as well.

The canonical Unit Commitment Problem (UC)



Given:

- a **set I of energy generation units**
- a planning horizon decomposed into a **set T of time periods**
- a demand for energy in each time period

We want to:

- choose the energy generated by each unit in each time period

So that:

- the total **cost** of production is **minimized**
- the **demand** in each time period is **satisfied**
- technical constraints of the units are satisfied (e.g., min up/down time, ramp limits)

A different perspective: Energy Offering (EnOff)

Given:

- a **set I of energy generation units**
- a planning horizon decomposed into a **set T of time periods**
- ~~a demand for energy in each time period~~ **THE ENERGY PRICE IN EACH PERIOD**

We want to:

- choose the energy ~~generated~~ **TO OFFER FOR** by each unit in each time period

So that:

- the total ~~**cost**~~ **PROFIT** of production is ~~**minimized**~~ **MAXIMIZED**
- ~~the **demand** in each time period is **satisfied**~~
- technical constraints of the units are satisfied (e.g., min up/down time, ramp limits)

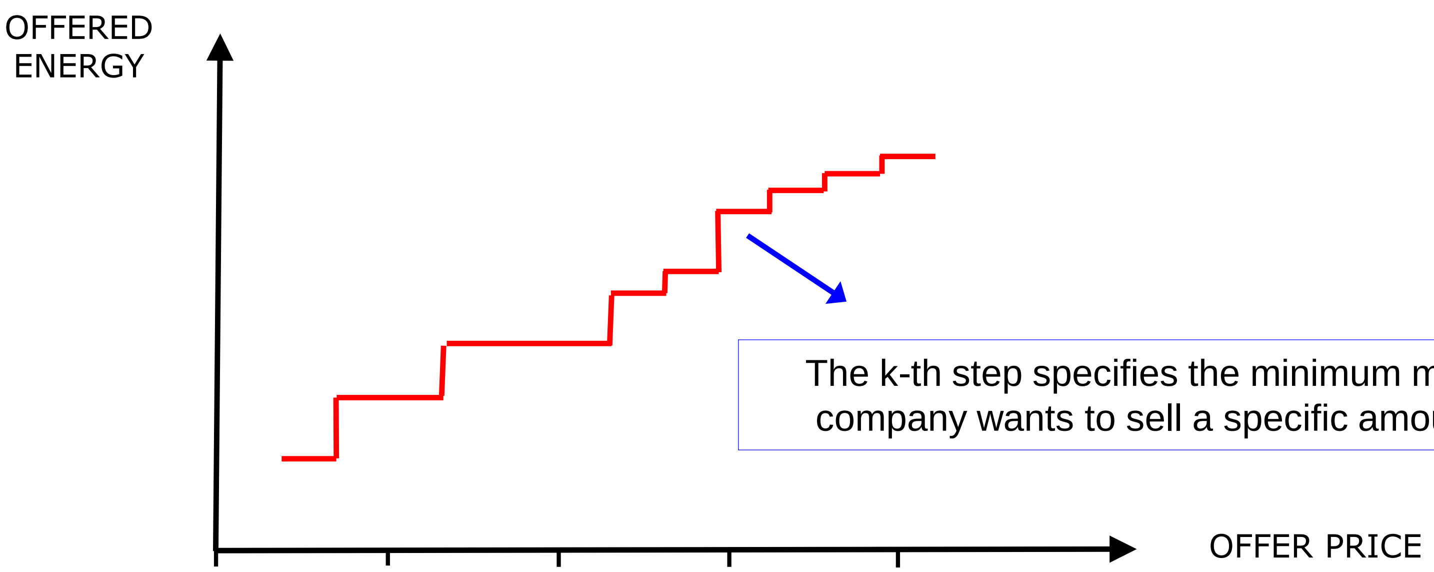
IN ESSENCE:

UNIT COMMITMENT	ENERGY OFFERING
MINIMIZE COSTS (deterministic)	**MAXIMIZE PROFIT (uncertain)**
SATISFY DEMAND	**DECIDE ENERGY VOLUMES TO OFFER**

Offering Curves

- A company submits energy selling offers by specifying an offering curve for each of its generation unit and for each time period

- The offering curve is **typically a (non-decreasing) step function**



- Market rules typically **admit only step functions with a small number of steps**

Energy Offering for a Price-Taker (EnOff-PT)

PRICE-TAKER → producer that does not influence **market price**
(limited energy production)

The multi-unit offering problem can be decomposed into single-unit problems

For each unit of the producer :

Given:

- a planning horizon decomposed into a **set T of time periods**
- **the market price in each time period t**

We want to:

- choose the energy to offer in each time period in the market

So that:

- the total profit is maximized
- technical constraints of the units are satisfied (e.g., min up/down time, ramp limits)

A natural formulation for the EnOff-PT

RELEVANT FEATURES OF A GENERATION UNIT

$P^{\min}$	$P^{\max}$	(MIN and MAX ENERGY OUTPUT)
$R^{\nearrow}$	$R^{\searrow}$	(RAMP-UP and RAMP-DOWN RATE)
P^{SU}	P^{SD}	(MAX ENERGY OUTPUT AT START UP and BEFORE SHUT-DOWN)
U	D	(MIN UP and DOWN TIME)

DECISION VARIABLES

$p_t \geq 0$	$t \in T$	(ENERGY OUTPUT)
$u_t \in \{0,1\}$	$t \in T$	(STATUS ON/OFF)
$v_t \in \{0,1\}$	$t \in T$	(SWITCH ON)
$w_t \in \{0,1\}$	$t \in T$	(SWITCH OFF)

$$\max \sum_{t \in T} [\lambda_t p_t - c_t(p_t)]$$

PROFIT MAXIMIZATION
(REVENUE MINUS COSTS OF GENERATION AND START)

$$P^{\min} u_t \leq p_t \leq P^{\max} u_t \qquad t \in T$$

VARIABLE POWER BOUND

$$p_t \leq p_{t-1} + R^{\nearrow} u_t + \left(P^{SU} - R^{\nearrow}\right) v_t \qquad t \in T$$

$$p_t \geq p_{t-1} - R^{\searrow} u_{t-1} + \left(R^{\searrow} - P^{SD}\right) w_t \qquad t \in T$$

RAMP-UP AND –DOWN LIMITS

$$\sum_{\tau=t-U+1}^{t} v_\tau \leq u_t \qquad t \in \{U+1, \ldots, |T|\}$$

$$\sum_{\tau=t-D+1}^{t} w_\tau \leq 1 - u_t \qquad t \in \{D+1, \ldots, |T|\}$$

MIN UP AND DOWN TIME
(STRONG VERSION)

$$w_t = v_t + u_{t-1} - u_t \qquad t \in T$$

LINKING OF VARIABLES

Price uncertainty in the EnOff-PT

Major challenge for the price-taker → the hourly prices are not kwown exactly when the problem is solved (MARKET PRICE UNCERTAINTY)

The price-taker could solve its commitment problem using estimates of prices that he trusts…

…BUT he would risk a lot!

price estimates (sensibly) higher than the real market price → OVERPRODUCTION → LOSSES

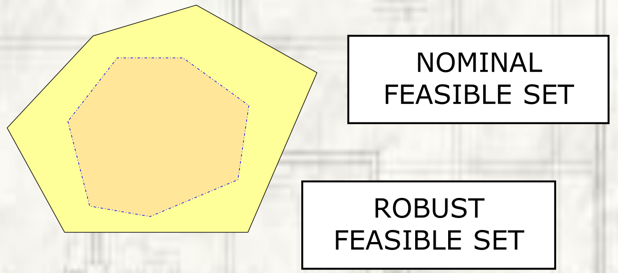
price estimates (sensibly) lower than the real market price → UNDERPRODUCTION → REDUCED PROFIT

We cannot neglect price uncertainty and we must tackle it!

WHAT CAN WE DO?

Robust Optimization

Data uncertainty is modelled as hard constraints that restrict the feasible set
[Ben-Tal, Nemirovski 98, El-Ghaoui et. al. 97]



NOMINAL PROBLEM → Coefficients are uncertain!!! → ROBUST COUNTERPART

$$\max \; c' \, x$$
$$A \, x \leq b$$
$$x \geq 0^n$$

$$a_{ij} = \bar{a}_{ij} + \delta_{ij}$$

ACTUAL VALUE / NOMINAL VALUE / DEVIATION

$$\max \quad c' \, x$$
$$\tilde{A} \, x \leq b \quad \tilde{A} \in \mathcal{A}$$
$$x \geq 0^n$$

- $\mathcal{A}$ should reflect the risk aversion of the decision maker
- protection entails the so-called Price of Robustness

The Bertsimas-Sim Γ-Robustness model (BS)

$$\max \sum_{j \in J} c_j\, x_j$$

$$\sum_{j \in J} a_{ij}\, x_j \leq b_i \qquad i \in I = \{1, \ldots, m\}$$

$$x_j \geq 0 \qquad j \in J = \{1, \ldots, n\}$$

Assumptions:

1) w.l.o.g. uncertainty just affects the coefficient matrix
2) the coefficients are independent random variables following an unknown **symmetric distribution over a symmetric range**

Deviation range: each coefficient a_{ij} assumes value in the symmetric range $a_{ij} \in [\bar{a}_{ij} - d_{ij}^{\max}, \bar{a}_{ij} + d_{ij}^{\max}]$

Row-wise uncertainty: for each constraint *i*, $\Gamma_i \in [0, n]$ specifies the max number of coefficients deviating from a_{ij}

ROBUST COUNTERPART (NON-LINEAR)

$$\max \sum_{j \in J} c_j x_j$$

$$\sum_{j \in J} \bar{a}_{ij} x_j + DEV(x, \Gamma_i) \leq b_i \qquad \forall i \in I$$

$$x_j \geq 0 \qquad \forall j \in J$$

ROBUST COUNTERPART [Bertsimas, Sim 04] (LINEAR AND COMPACT)

$$\max \sum_{j \in J} c_j x_j$$

$$\sum_{j \in J} \bar{a}_{ij} x_j + \Gamma_i w_i + \sum_{j \in J} z_{ij} \leq b_i \qquad \forall i \in I$$

$$w_i + z_{ij} \geq d_i^{\max} j x_j \qquad \forall i \in I, j \in J$$

$$z_{ij} \geq 0 \qquad \forall i \in I, j \in J$$

$$w_i \geq 0 \qquad \forall i \in I$$

$$x_j \geq 0 \qquad \forall j \in J$$

Γ-Robustness for the price-uncertain EnOff-PT

Remarks about the EnOff-PT:

- data uncertainty only affects the objective function (uncertain price coefficients)

Γ-Robust Counterpart:

Given:

- the **nominal price** in each period λ_t^{NOM}
- the **worst deviation of price** w.r.t. the nominal price in each hour d_t
- the **number** $\Gamma > 0$ of price deviations for which protection is required

The robust counterpart is:

$$\max \sum_{t \in T} \left[\lambda_t^{\text{NOM}} p_t - c_t(p_t)\right] - \Gamma z - \sum_{t \in T} q_t$$

$$z + q_t \geq d_t p_t \qquad t \in T$$

$$z \geq 0$$

$$q_t \geq 0 \qquad t \in T$$

(ADDITIONAL VARIABLES AND CONSTRAINTS FROM ROBUST DUALIZATION)

$$p_t \in P_t \qquad t \in T$$

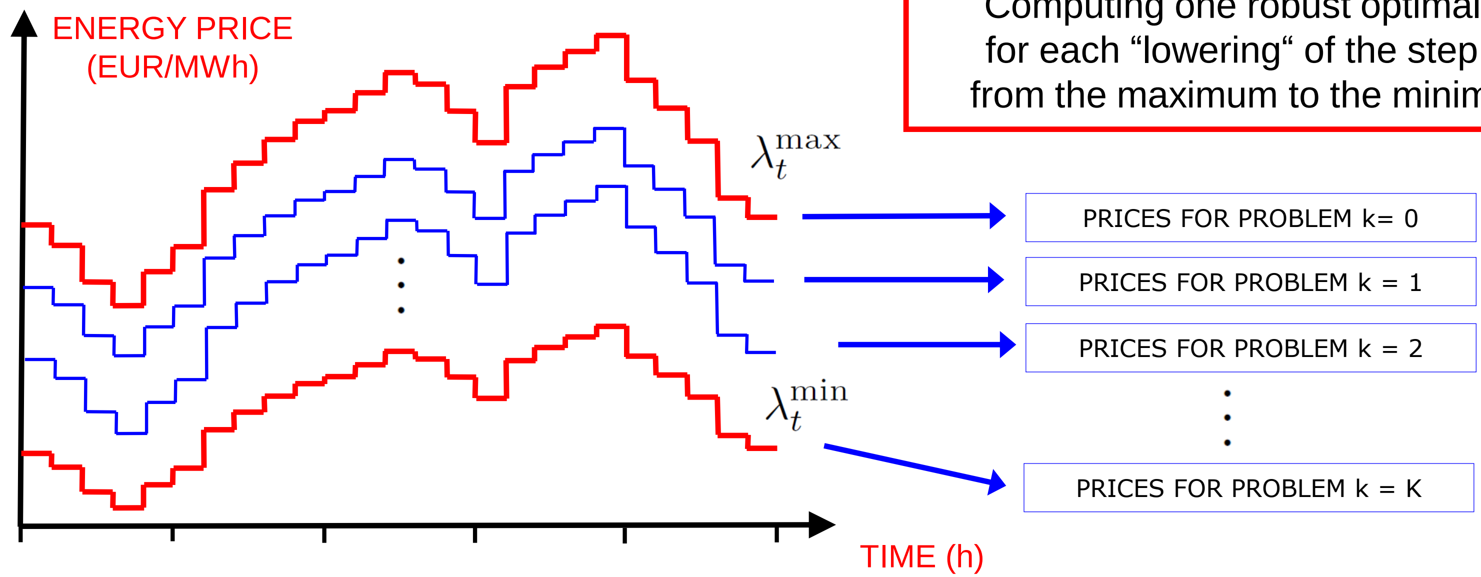
(FEASIBLE ENERGY PRODUCTION SET)

The Baringo-Conejo approach (1)

Highly cited work proposing a method for building energy offering curves for a price taker (2011)

Main steps:

- identify the **overall range of prices** in each period - maximum and miminum prices $\lambda_t^{\min}$ $\lambda_t^{\max}$
- define an **elementary price shortfall** $\delta \cdot (\lambda_t^{\max} - \lambda_t^{\min})$ with $0 < \delta < 1$
- Solve k = 0, 1, …, K Γ-Robust Counterpart where in each period
  - the **nominal price** is the **maximum price** of the range $\lambda_t^{\text{NOM}} = \lambda_t^{\max}$
  - the **worst deviation** is **k-times the elementary price shortfall** $d_t = k \cdot \delta \cdot (\lambda_t^{\max} - \lambda_t^{\min})$
  - Γ = **|T|** → FULL PROTECTION!



Computing one robust optimal solution for each "lowering" of the step function from the maximum to the minimum price

The Baringo-Conejo approach (2)

- For each step function k, we obtain a robust optimal solution
- The **robust optimal solutions are merged** to build one **energy offering curve** for each time period
- For each time period:

STEP FUNCTION k → MARKET PRICE k → OFFERED ENERGY k

- The offering curve built for each time period are submitted to the Energy Exchange

The Baringo-Conejo approach – our critique

The approach presents **several issues** that have **NOT** been **pointed out until our work**

ISSUE 1: definition of offering curves that break market rules

An offering curve is built considering a high number of intermediate prices between the maximum and minimum prices (100 prices in experimentals tests)

→ **Violation of the limit on the number of steps of a curve** imposed by market rules

ISSUE 2: risk of non-acceptance

The offering curves **risk to be NOT accepted** in the market (minimum price asked for selling) → **BIG LOSSES**

ISSUE 3: compromised optimality and feasibility

The **offering curves defined merging distinct optimal robust solutions** obtained for different assumptions on the prices

→ optimality of energy production is compromised!

→ accepted portion of curves may result infeasible (e.g., violation of ramp constraints)

ISSUE 4: unnecessarily complex robust counterpart

The approach imposes full protection (worst price in each period)

→ it is not necessary to define the Γ-Robustness counterpart of increased dimension

Our revised approach based on Γ-Robustness (1)

OUR OBJECTIVES:

- (dramatically) increasing the chances that our energy offers are accepted
- defining robust solutions following the real spirit of Γ-Robustness
  (full protection is bad!)

BASIC FEATURES OF OUR STRATEGY:

- we do not compete on price and **all our selling offers are at zero price**

  → our offers are automatically accepted (≤ market price!)

- from historical market price data, we derive
  - the **nominal value** equals the **average price** over the past observations
  - the **worst deviation** is identified by **excluding the worst M observations** in a way that **better fits the practice of power system professionals**

- **we exclude extreme unlikely price shortfalls** and we show that partial protection grants (much) higher profits

Our revised approach based on Γ-Robustness (2)

Given a set of past observations of the price for each time period:

- the **nominal value** equals the **average price** over the past observations
- the **worst deviation** is identified by **excluding the worst M observations**

We do not want to be too conservative!

⇒ Exclude protection against **extreme and unlikely shortfalls**

EXAMPLE:

Given past observations (10 previous days) for a given hour t: 38 44 45 47 48 51 51 52 56 57

- **Nominal value = average value** 48.9
- The worst deviation is defined excluding the worst 10% of observations → 38 excluded
  - **44** is the **worst relevant observation**
  - - 4.9 is the worst deviation

⚠ Approach discussed and validated with industrial partners ⚠

Computational tests

- Tests on **45 realistic instances**:
  - **15 power plants** located in **3 distinct Italian price-zone**
  - **24 time periods (= hours in one day)**
  - **3 percentages of exclusions** of worst price observations **(0, 10, 20 %)**

- Experiments on a Windows machine with Intel 2 Duo-3.16 GHz processor and 8 GB of RAM

- Robust model coded in C/C++ interfaced through Concert Technology with CPLEX 12.5.1

Historical data and test period construction:

- For each hour:
  - we consider the **prices observed** in the price zone **in a time window of 4 weeks**
  - from these prices, we derive the nominal value and the max deviation of the uncertain price

- We compute the robust optimal solution **for each Γ=0 (=no protection), 1, 2, …, 24 (= full protection)**

- We test the performance of the computed robust optimal solution in the **week following the 4 weeks of the construction set**

- The 4-week time window is shifted through the entire year with steps of 1 week providing **24 evaluation periods**

Computational results

Unit ID	%Excluded	Γ Best w.r.t. Γ = 0 Δπ(EUR)	Δπ%	Γ Best w.r.t. Γ = 24 Δπ(EUR)	Δπ%
U1	0	+ 40399	+ 5.75	+ 213730	+ 40.45
	10	+ 44350	+ 6.32	+ 183161	+ 32.54
	20	+ 41921	+ 5.97	+ 152608	+ 25.82
U2	0	+ 23394	+ 5.00	+ 333543	+ 212.07
	10	+ 46063	+ 9.85	+ 234371	+ 83.96
	20	+ 42071	+ 9.00	+ 218607	+ 75.15
U3	0	- 1383	- 0.02	+ 1984511	+ 47.59
	10	+ 88980	+ 1.44	+ 1031465	+ 19.78
	20	+ 105253	+ 1.70	+ 627146	+ 11.13
U4	0	+ 43246	+ 6.27	+ 255124	+ 53.50
	10	+ 57386	+ 8.33	+ 181356	+ 32.11
	20	+ 51614	+ 7.49	+ 148634	+ 25.12
U5	0	+ 15454	+ 3.57	+ 340567	+ 319.00
	10	+ 45327	+ 10.49	+ 240506	+ 101.61
	20	+ 45331	+ 10.49	+ 199406	+ 71.78
U6	0	+ 14273	+ 5.30	+ 2030185	+ 44.87
	10	+ 91766	+ 10.58	+ 1117143	+ 20.25
	20	+ 152707	+ 11.77	+ 675172	+ 11.22
U7	0	+ 307690	+ 5.73	+ 1312795	+ 30.13
	10	+ 268508	+ 5.00	+ 909989	+ 19.28
	20	+ 195207	+ 3.64	+ 792081	+ 16.62

Generation units of increasing capacity

DIFFERENCE OF TOTAL PROFIT
(IN EUR, SUM OF 24 TEST PERIODS)
best protection - no protection **best protection - full protection**

Unit ID	%Excluded	Γ Best w.r.t. Γ = 0 Δπ(EUR)	Δπ%	Γ Best w.r.t. Γ = 24 Δπ(EUR)	Δπ%
U8	0	+ 465184	+ 12.62	+ 1295788	+ 45.41
	10	+ 492568	+ 13.37	+ 1052152	+ 33.68
	20	+ 387575	+ 10.52	+ 888433	+ 27.91
U9	0	- 179096	- 0.54	+ 8606255	+ 35.47
	10	+ 249549	+ 0.75	+ 4586552	+ 15.97
	20	+ 253871	+ 0.76	+ 3008976	+ 9.93
U10	0	+ 579613	+ 11.70	+ 1711145	+ 44.78
	10	+ 662118	+ 13.36	+ 870430	+ 18.34
	20	+ 502539	+ 10.14	+ 594417	+ 12.22
U11	0	+ 612087	+ 19.62	+ 2471071	+ 196.02
	10	+ 465014	+ 14.90	+ 1270815	+ 54.92
	20	+ 534279	+ 17.12	+ 788373	+ 27.51
U12	0	+ 23935	+ 19.62	+ 12397479	+ 49.27
	10	+ 409219	+ 14.90	+ 4751121	+ 14.31
	20	+ 438452	+ 17.12	+ 3506377	+ 10.17
U13	0	+ 111221	+ 0.34	+ 8244775	+ 33.56
	10	+ 421916	+ 1.29	+ 8244775	+ 16.04
	20	+ 479952	+ 1.46	+ 1809060	+ 5.76
U14	0	+ 231532	+ 6.14	+ 2103904	+ 111.02
	10	+ 391966	+ 10.40	+ 1184916	+ 39.83
	20	+ 485693	+ 12.89	+ 494986	+ 13.17
U15	0	- 76685	- 0.21	+ 11622838	+ 49.54
	10	+ 524423	+ 1.49	+ 5459972	+ 18.06
	20	+ 442969	+ 1.25	+ 3175311	+ 9.79

In almost all cases we can:

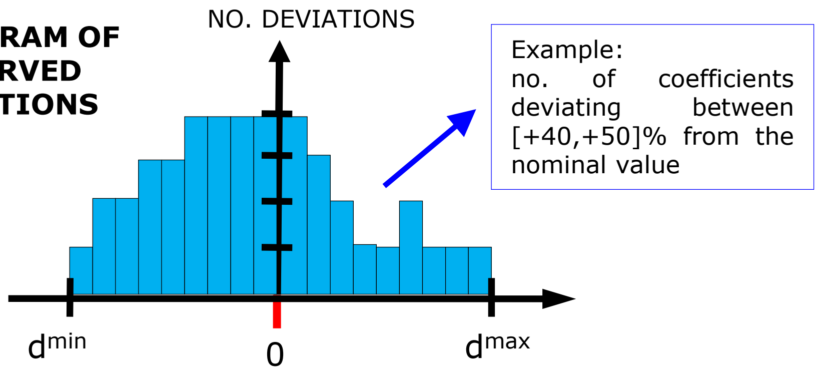
- **greatly increase the profit** w.r.t. a practice that we observed among professionals (average price)
- **dramatically increase the profit** w.r.t. full protection

Using the Bertsimas-Sim model (BS) in practice

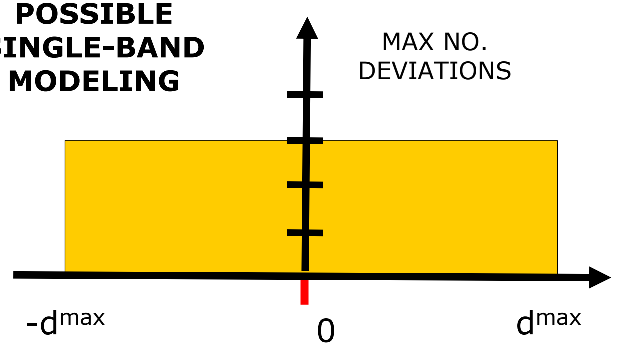
- In real-world problems, historical data about the deviations of the uncertain coefficients are commonly available
- The data can be easily used to build histograms representing the distribution of the deviations

? ARE WE REALLY ABLE TO EXPLOIT SUCH INFORMATION WITH THE BERTSIMAS-SIM MODEL ?

HISTOGRAM OF OBSERVED DEVIATIONS



POSSIBLE SINGLE-BAND MODELING



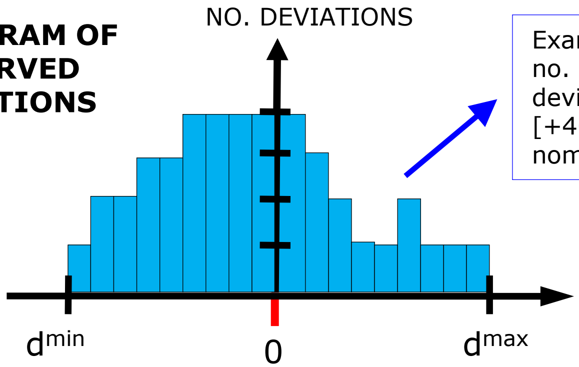
- The behaviour of the uncertainty internally to the deviation range is completely neglected (focus on the extreme deviations)
- According to our past experiences, practitioners would definitely prefer a more refined representation of the uncertainty

Multiband uncertainty (MB)

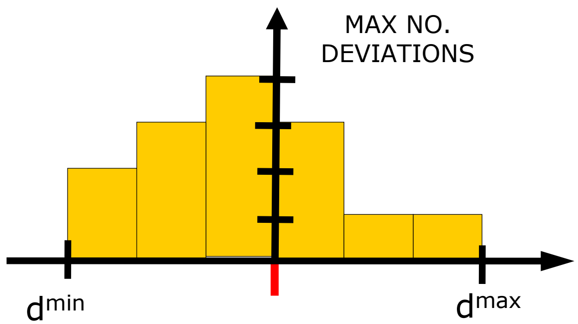
? WHAT CAN WE DO TO INCREASE OUR MODELING CAPACITY ?

ADOPT A MULTI-BAND UNCERTAINTY SET

HISTOGRAM OF OBSERVED DEVIATIONS



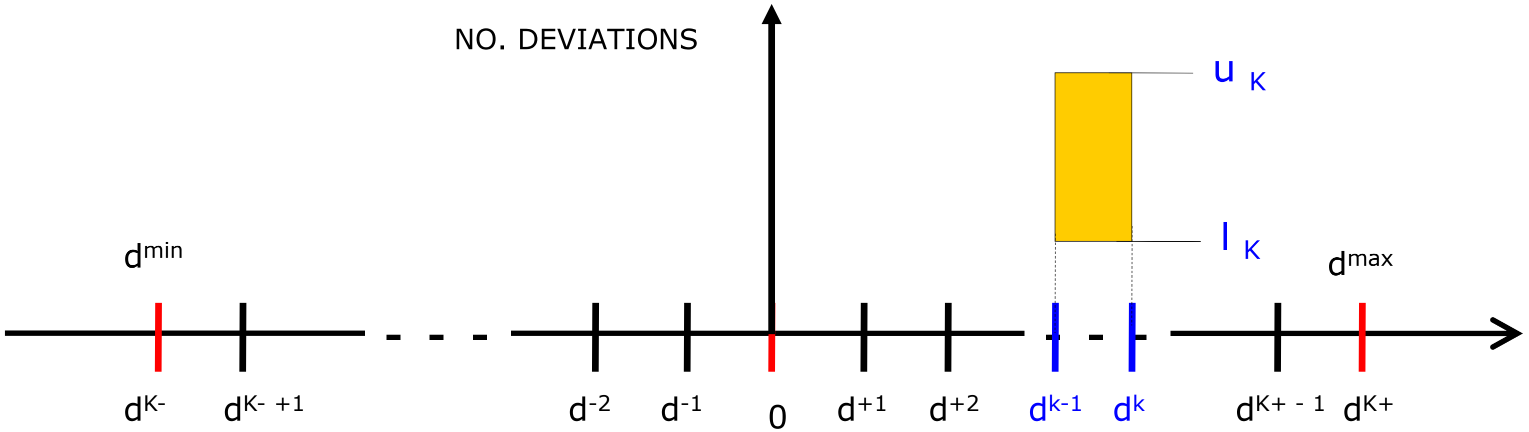
Example:
no. of coefficients deviating between [+40,+50]% from the nominal value



- strongly data-driven uncertainty set
- first proposed by Bienstock for Portfolio Optimization (2007)
- later extended to Network Design (Bienstock & D’Andreagiovanni 2009)
- a general theoretical study was missing! → OUR AIM HAS BEEN TO FILL SUCH GAP

Formalizing Multiband Uncertainty

Focus on the coefficients a_{ij} of each constraint i (row-wise uncertainty)



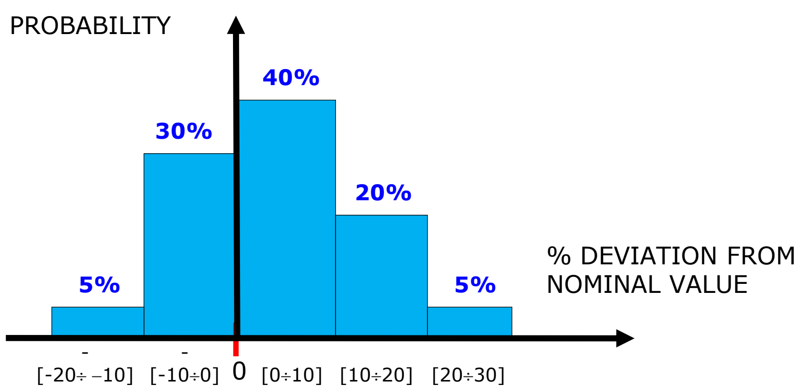
- K deviation values $-\infty < d_{ij}^{K-} < \cdots < d_{ij}^{0} = 0 < \cdots < d_{ij}^{K+} < +\infty$ for each coefficient a_{ij}
- K deviation bands such that each band k corresponds with range $(d_{ij}^{k-1}, d_{ij}^{k}]$
- Lower and upper bounds $0 \leq l_k \leq u_k \leq n$ on the number of coefficients deviating in each band k
- No upper bound on band k = 0, i.e. $u_0 = n$
- There exists a feasible assignment $\sum_{k \in K} l_k \leq n$

General example of construction

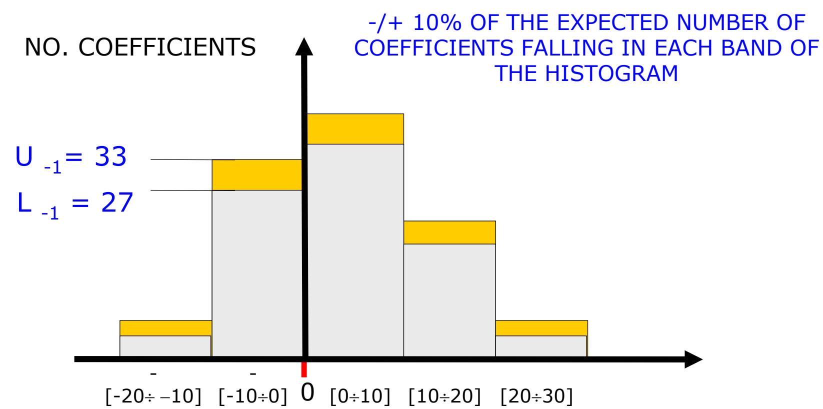
- Focus on the coefficients a_{ij} of each constraint i (row uncertainty)
- For each coefficient a_{ij}, we have a number of past observations $\hat{a}_{ij}$
- Compute the percentage deviation of an observation from the nominal value $\frac{\hat{a}_{ij} - \bar{a}_{ij}}{\bar{a}_{ij}} \cdot 100$
- Build the histogram representing the distribution of the percentage deviations for the considered constraint

Example

OBSERVED DISCRETE DISTRIBUTION (ALL COEFFICIENTS IN THE CONSTRAINT)



POSSIBLE MULTI-BAND SET FOR THE CONSTRAINT (assuming 100 coefficients in the constraint)



The max-deviation auxiliary problem under MB

MILP

NON-LINEAR ROBUST COUNTERPART

$$\max \sum_{j \in J} c_j x_j$$

$$\sum_{j \in J} \bar{a}_{ij} x_j \qquad \leq b_i \qquad \forall i \in I$$

$$x_j \geq 0 \qquad \forall j \in J$$

$$x_j \in \mathbb{Z}_+ \qquad \forall j \in J_{\mathbb{Z}} \subseteq J$$

DEV01

$$\max \sum_{j \in J} \sum_{k \in K} d_{ij}^k \, x_j \, y_{ij}^k$$

MAXIMIZATION OF TOTAL DEVIATION

$$l_k \leq \sum_{j \in J} y_{ij}^k \leq u_k \qquad k \in K$$

BOUNDS ON THE NO. OF COEFFICIENTS FALLING IN BAND k

$$\sum_{k \in K} y_{ij}^k \leq 1 \qquad j \in J$$

EACH COEFFICIENT FALLS IN AT MOST ONE BAND

$$y_{ij}^k \in \{0,1\} \qquad j \in J, k \in K$$

The Robust Counterpart under MB

PROPOSITION 1 (Büsing & D'Andreagiovanni 12)

The polytope associated with (DEV01) is integral.

- Proof based on showing that the coefficient matrix of (DEV01) is totally unimodular

THEOREM 1 (Büsing & D'Andreagiovanni 12)

The Robust Counterpart of (MILP) under multi-band uncertainty is equivalent to:

$$\max \sum_{j \in J} c_j \, x_j \qquad (RLP)$$

$$\sum_{j \in J} \bar{a}_{ij} \, x_j - \sum_{k \in K} l_k \, v_i^k + \sum_{k \in K} u_k \, w_i^k + \sum_{j \in J} z_i^j \leq b_i \qquad i \in I$$

$$-v_i^k + w_i^k + z_i^j \geq d_{ij}^k \, x_j \qquad i \in I, j \in J, k \in K$$

$$v_i^k, \; w_i^k \geq 0 \qquad i \in I, k \in K$$

$$z_i^j \geq 0 \qquad i \in I, j \in J$$

$$x_j \geq 0 \qquad j \in J$$

$$x_j \in \mathbb{Z}_+ \qquad j \in J_{\mathbb{Z}} \subseteq J$$

- Proof based on exploiting the integrality of (DEV01) and strong duality
- If the original problem is linear, then also the counterpart is linear

Separation of Multiband Robustness Cuts

GOAL: finding a robust optimal solution for multi-band set D through a cutting-plane algorithm

Separation problem

Given a solution $x \in \mathbb{R}_+^{n-\lambda} \times \mathbb{Z}_+^{\lambda}$, is this solution robust feasible for constraint *i* ?

$x \in \mathbb{R}_+^{n-\lambda} \times \mathbb{Z}_+^{\lambda}$ robust feasible for i $\Longleftrightarrow$ $\sum_{j \in J} \bar{a}_{ij} x_j + DEV_i(x, D) \leq b_i$

If this condition does not hold and y* is an optimal solution to (DEV01) then

$$\sum_{j \in J} \bar{a}_{ij} x_j + \sum_{j \in J} \sum_{k \in K} d_{ij}^k \, x_j \, y_{ij}^{*k} \leq b_i$$

is a valid inequality for the original formulation and cuts off *x* (robustness cut)

THEOREM 2 (Büsing & D'Andreagiovanni 12)

Separating a robustness cut corresponds with solving a min-cost flow problem

- Proof based on showing the 1:1 correspondence between integral flows and assignments y of (DEV01)

Multiband Robustness – further results

- Dominance among multiband uncertainty sets
- Special results for 0-1 Linear Programs
- (Strong) valid inequalities for Mixed Integer Linear Programs
- Uncertainty in right-hand-sides
- Probability bounds of constraint violation

Multiband Robustness for Energy Offering

MULTIBAND ROBUST COUNTERPART

$$
\begin{aligned}
\max \sum_{t \in T} [\lambda_t^{\max} p_t - c_t(p_t)] + \sum_{k \in K} \ell_k v_k - \sum_{k \in K} u_k w_k - \sum_{t \in T} q_t & \\
- v_k + w_k + q_t \geq d_t^k p_t & \qquad t \in T, k \in K \\
v_k \geq 0 & \qquad k \in K \\
w_k \geq 0 & \qquad k \in K \\
q_t \geq 0 & \qquad t \in T \\
p_t \in P_t & \qquad t \in T \, ,
\end{aligned}
$$

- Preliminary computational results for a system of 5 deviation bands

- Increase in profit of about 23% on average

Final Remarks

- We have addressed the **Energy Offering Problem for a price-taker considering price uncertainty**

- **We pointed out the limits of a highly-cited approach for solving the problem:**
  - risk of refusal of energy offers
  - infeasibility and sub-optimality of energy offers
  - excessive conservatism (full protection)

- We proposed an alternative approach that:
  - dramatically **reduces the risk of non-acceptance** of offers
  - **better fits the spirit of Robust Optimization**
  - grants in practice a **(very) good increase in profit** w.r.t. industry practice

FOR FURTHER DETAILS

F. D'Andreagiovanni ***** , G. Felici, F. Lacalandra,
*** First Author**
"Revisiting the use of Robust Optimization for optimal energy offering under price uncertainty"
Submitted for publication, available on ArXiV

ONGOING WORK

- Extension to realistic Price-Maker cases