GO Competition Challenge 3 Solution Analysis

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GO Competition Challenge 3 Team

Grid Optimization Competition Challenge 3 Problem Formulation

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- https://gocompetition.energy.gov/
- https://gocompetition.energy.gov/sites/default/files/C3PF_20220216.pdf
- https://github.com/GOCompetition/C3DataUtilities

Overview

- Problem description
- Solution evaluation
- Specific questions about solver performance and solution characteristics, including some we have not gotten far on yet
  - Supply-demand equilibrium analysis
  - Comparing different solutions
  - Relative influence of different objective terms
  - Influence of security contingencies
  - Topology switching
  - Run time analysis
  - Pricing
  - Importance of flexible load
  - UC-AC decomposition

GO Competition Challenge 3 problem overview

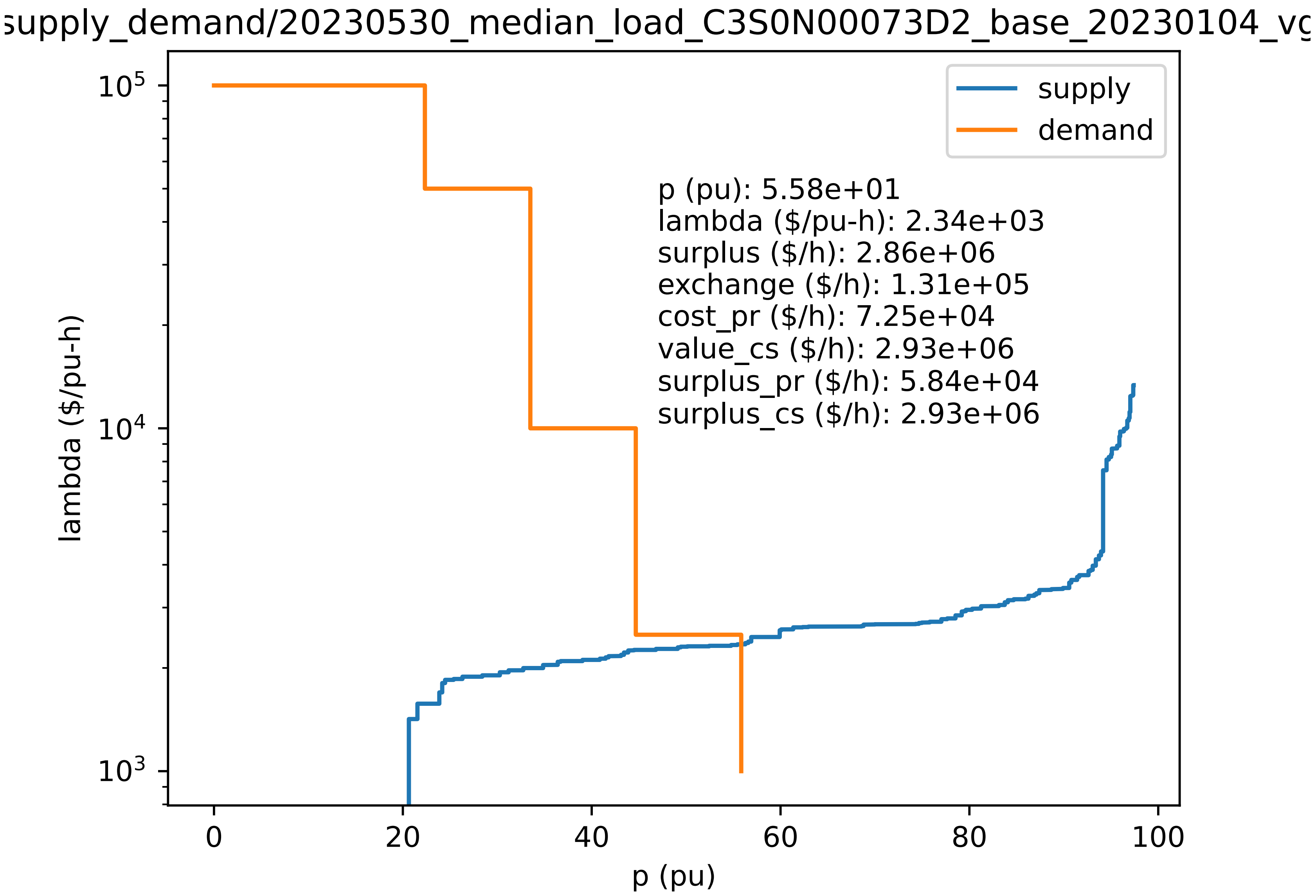
- Multi-period unit commitment
  - Division 1 – 6 hour look ahead
  - Division 2 – 48 hours, like DA market
  - Division 3 – 1 week, e.g. to plan for severe weather events
- AC – account for the need to startup a generator specifically for voltage support
- Flexible load – characterized by a bid curve and all the modeling features of generators
- Single branch outage security contingencies
  - Post-contingency power flow modeled as linear with real power only (basically DC)
- Full set of reserve products
  - Ramping reserve, increasingly important for management of wind and solar
  - Reactive power reserve, to cover what we miss by using a DC post-contingency model
- Topology switching
- Run time analysis

Solution evaluation

- Hard constraints
  - E.g. gen/load Pmax, ramping, integrality, voltage limits
- Soft constraints
  - Real and reactive power balance
  - Line limits
  - Multi-interval single device energy limits
  - Post-contingency line limits – used idea from HIPPO SFT to keep evaluation fast in the possible presence of topology switching (JH et al., “Fast Simultaneous Feasibility Test for Security Constrained Unit Commitment” https://ieeexplore.ieee.org/document/10094291)
- Market surplus objective = consumer value – producer cost – penalties
- Evaluation output (summary.json)
  - Feasibility
  - Objective value
  - ~400 other metrics
  - Run time

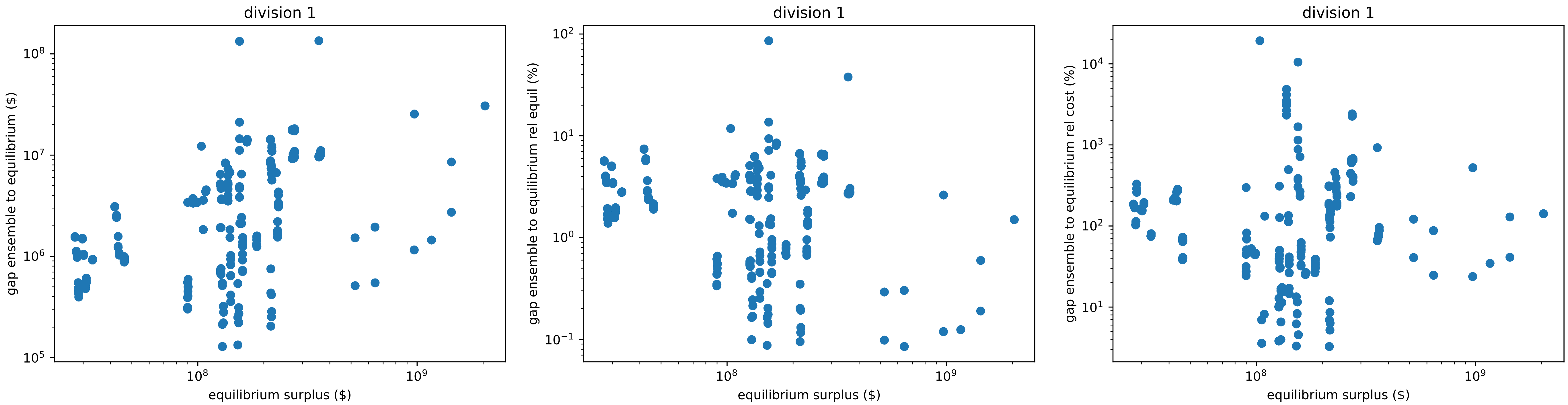
Supply-demand analysis

- In each time interval, form a supply curve and a demand curve from the Pmax and cost/value curves of all the generators and loads in the system
- Then compute an equilibrium price and quantity, the total generator cost and load value, and market surplus
- Essentially, this is an approximation of the real problem, ignoring unit commitment, ramping, line limits, voltage, etc.
- In many cases it is a relaxation, but in general it is not, due to line losses and negative cost generators
- Load value is much larger than the generator cost



Supply-demand analysis
Quality of approximation

- The approximation provided by supply-demand analysis is OK
- It behaves likes a relaxation: We have not observed any cases where it is less than the ensemble objective
- A few scenarios with particularly large gaps are probably due to manufactured switching cases
- Most of the time the gap is 10% or less
- If you consider the gap relative to the producer cost, then it is much worse, often about 100% to 1000%, but this might be the right way to analyze this gap

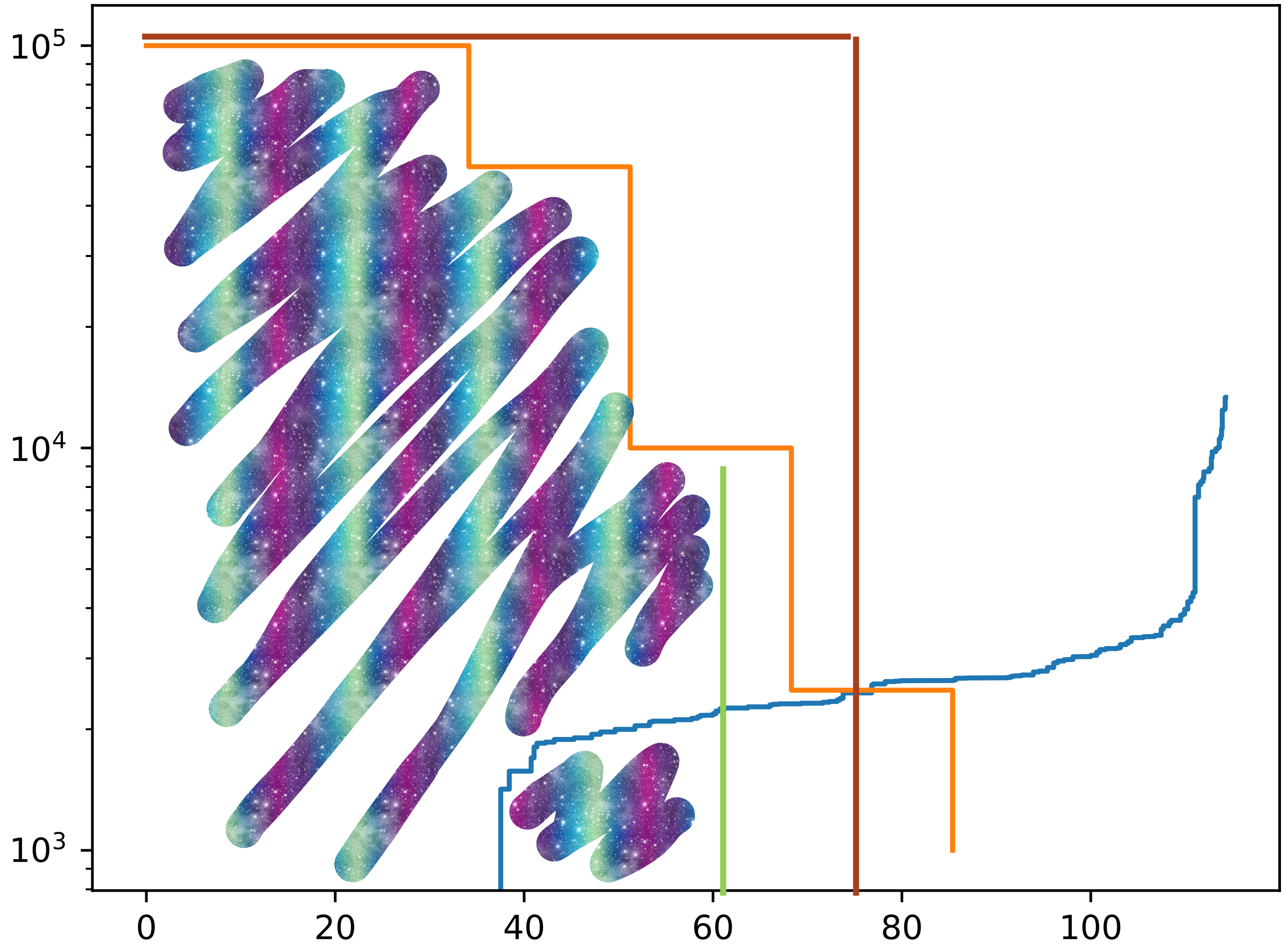


Relative comparison of two solutions in conditions of valuable flexible load

- When comparing two solutions of an optimization problem, we often describe the improvement of one over the other in terms of a relative gap:

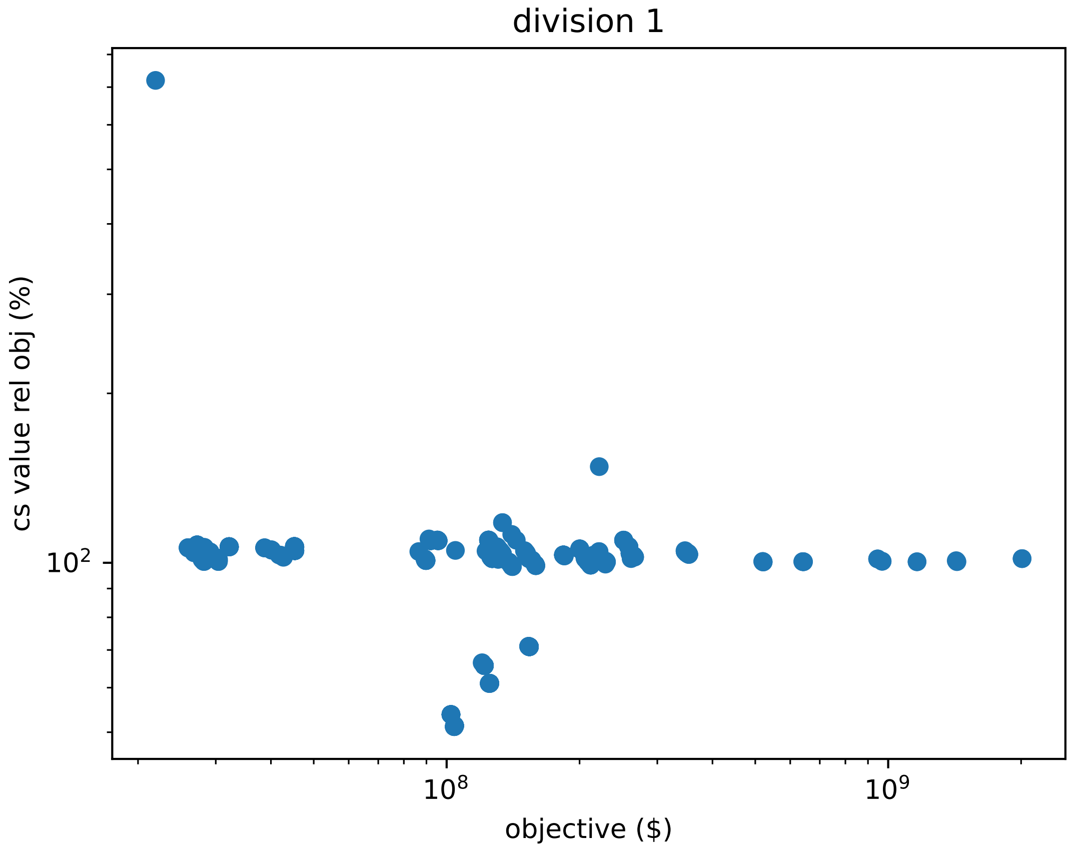
$$\frac{z_1 - z_2}{z^*}$$

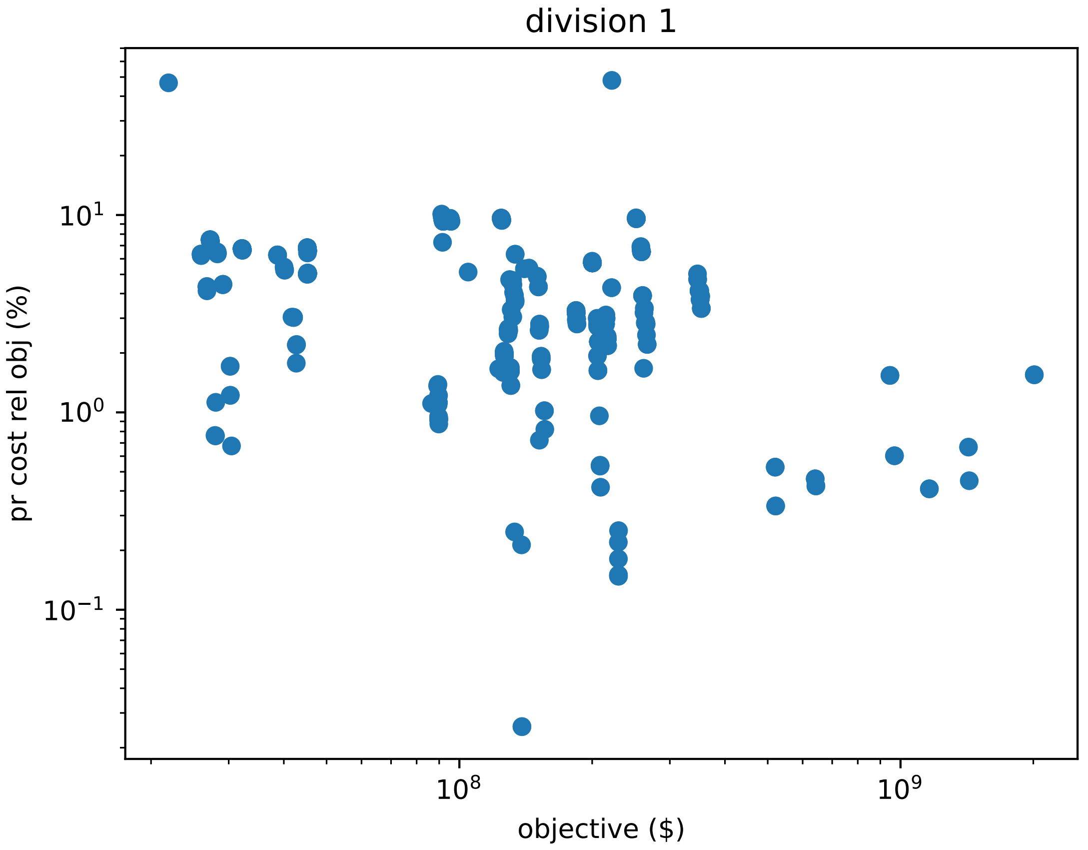
- What do we use for the denominator z^*?
- As long as z_1 and z_2 are not too different, either one can serve as z^*.
- But, if there is implicitly a large constant term in both solution objectives, then the denominator is too large – it makes significant differences appear insignificant.
- With the load value term so much larger than the generator cost term, I believe much of the load value acts as a large constant term
- We can fix this by using just the generator cost as the denominator
- And this is consistent with the normalization used in current UC practice, where flexible load is less common



Significance of generator cost and load value

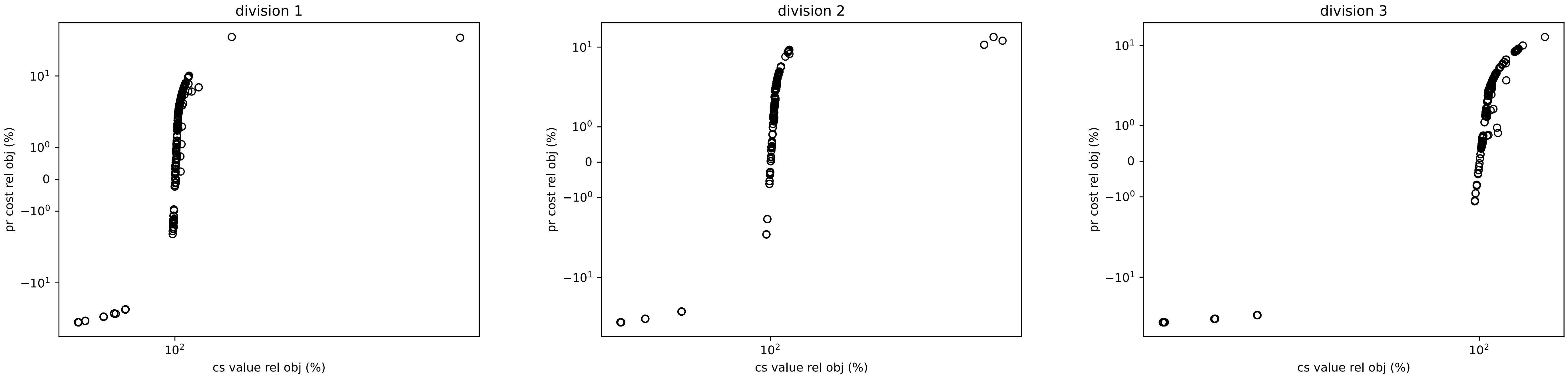
- Load value and generator cost were by far the most significant factors in the overall objective in the ensemble solutions
- Load value was typically about 100%
- Generator cost typically 1% to 10%





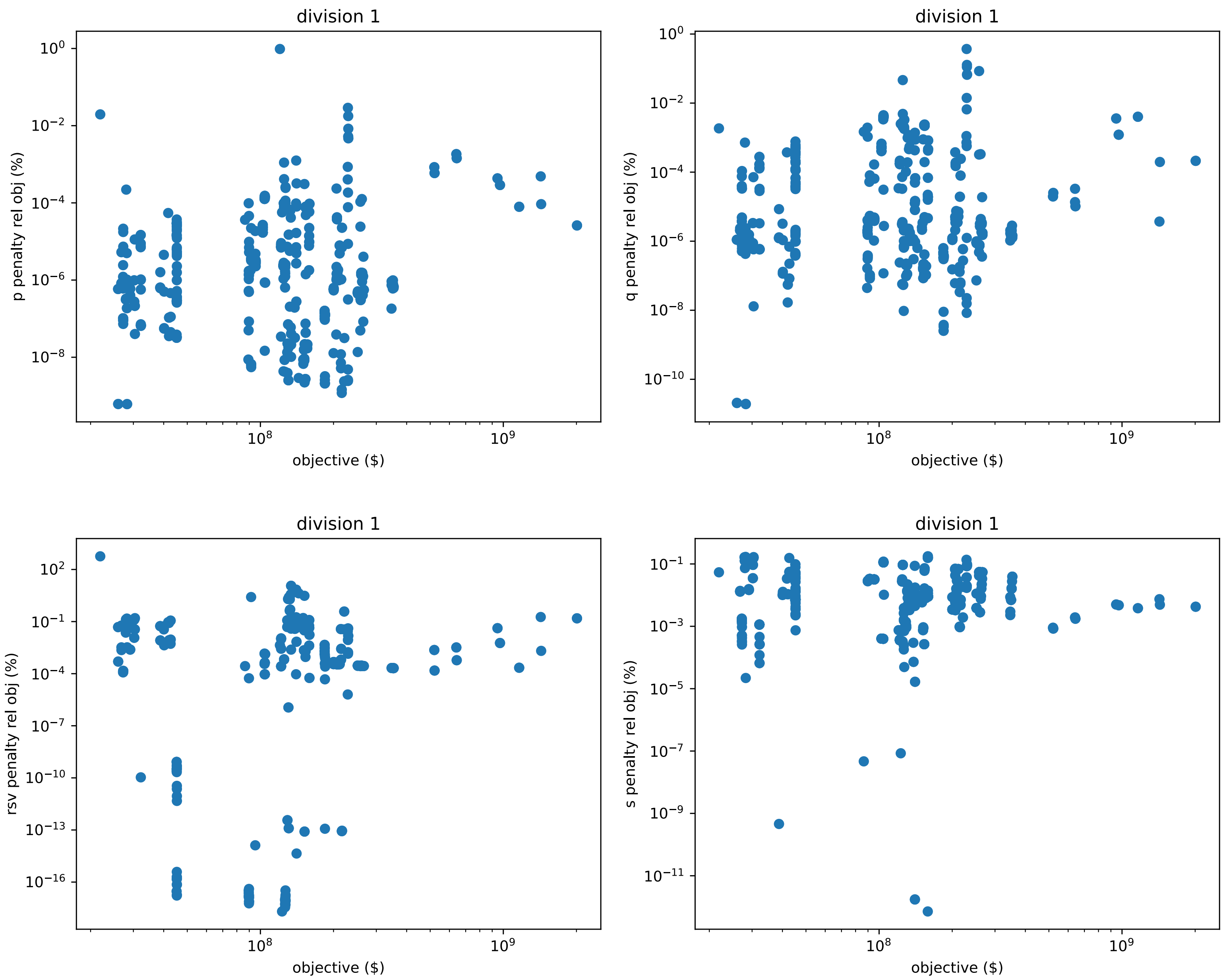
Generator cost and load value highly correlated in ensemble solutions

- Generator (producer) cost is typically between -10% and 10% of the total objective
- Load (consumer) value is typically between 90% and 110% of the total objective
- Gains in load value come at the expense of generator cost



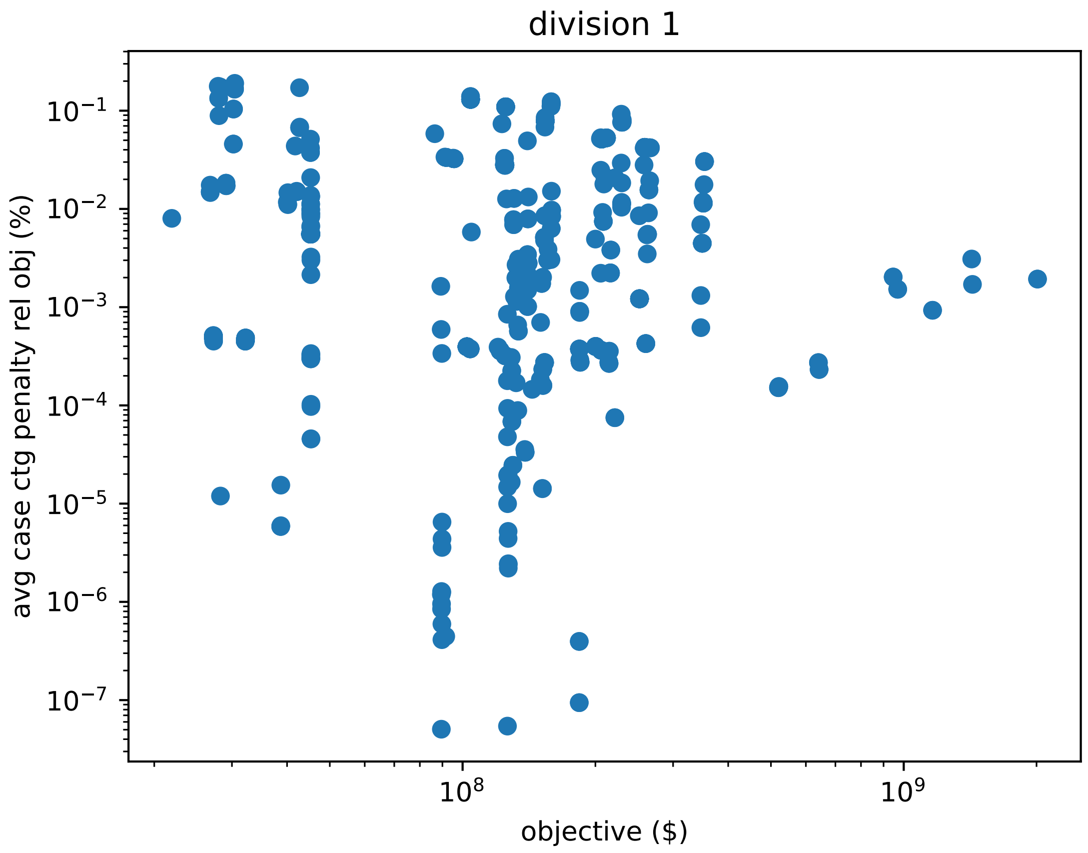
Significance of penalties on imbalance of real and reactive power and reserves and on line overload

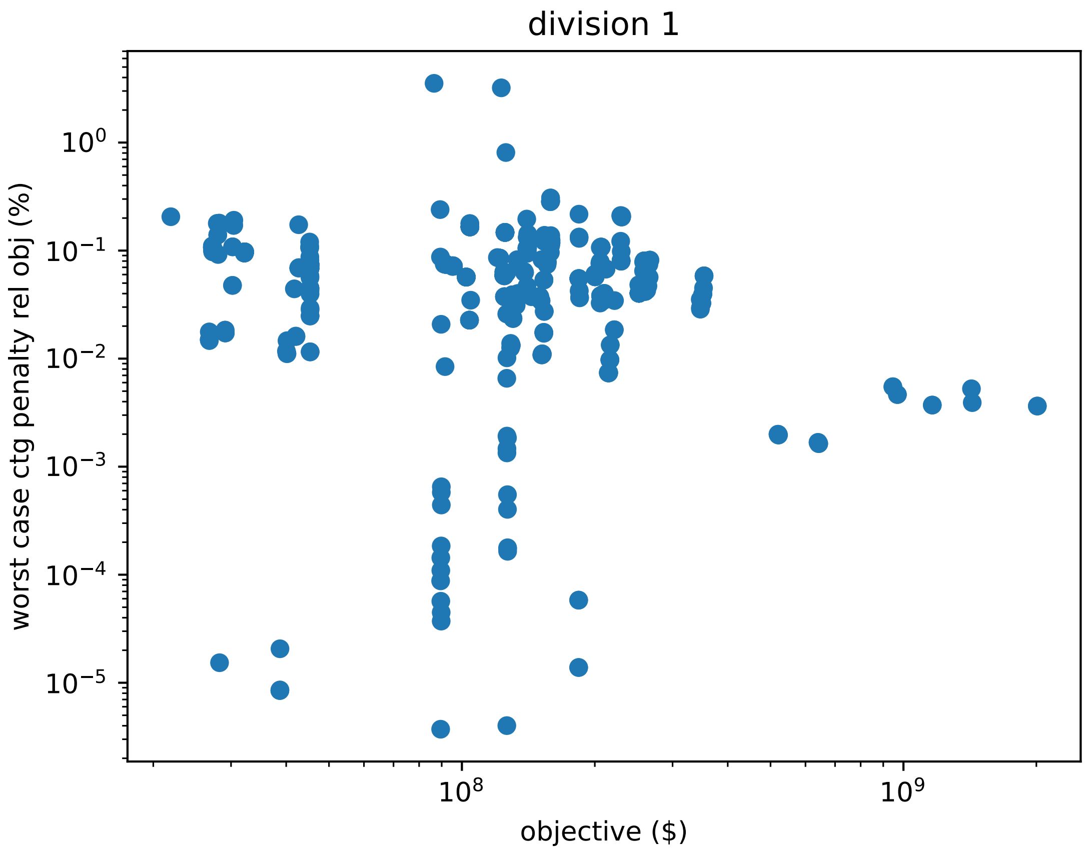
- Penalties on real and reactive power imbalance and on line overloads in the base case were not significant, generally < 1%, typically much less
- It appears that the ensemble solutions were highly accurate with respect to the physical constraints of power balance and also the engineering constraints of line flow
- Reserve imbalance penalties were more significant, often around 1% to 10%



Significance of post-contingency penalties

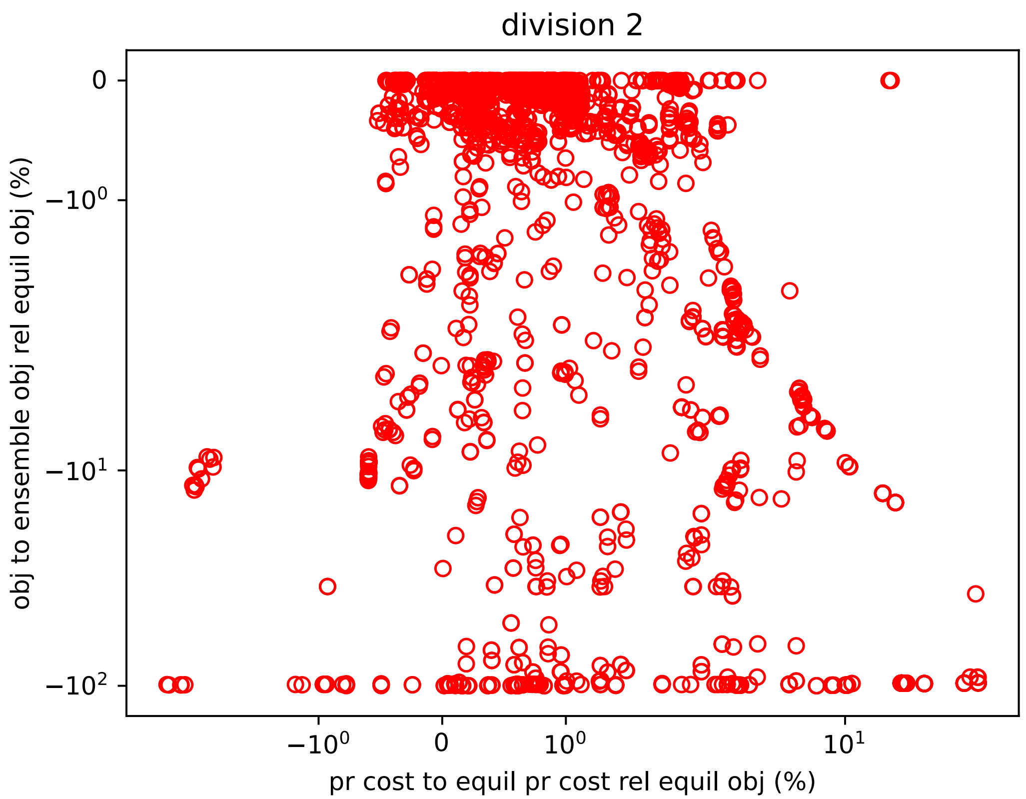
- The post-contingency penalties were only marginally significant
- The worst case penalty was somewhat more significant than the average case penalty, as expected, and was on the order of a few percent in some scenarios

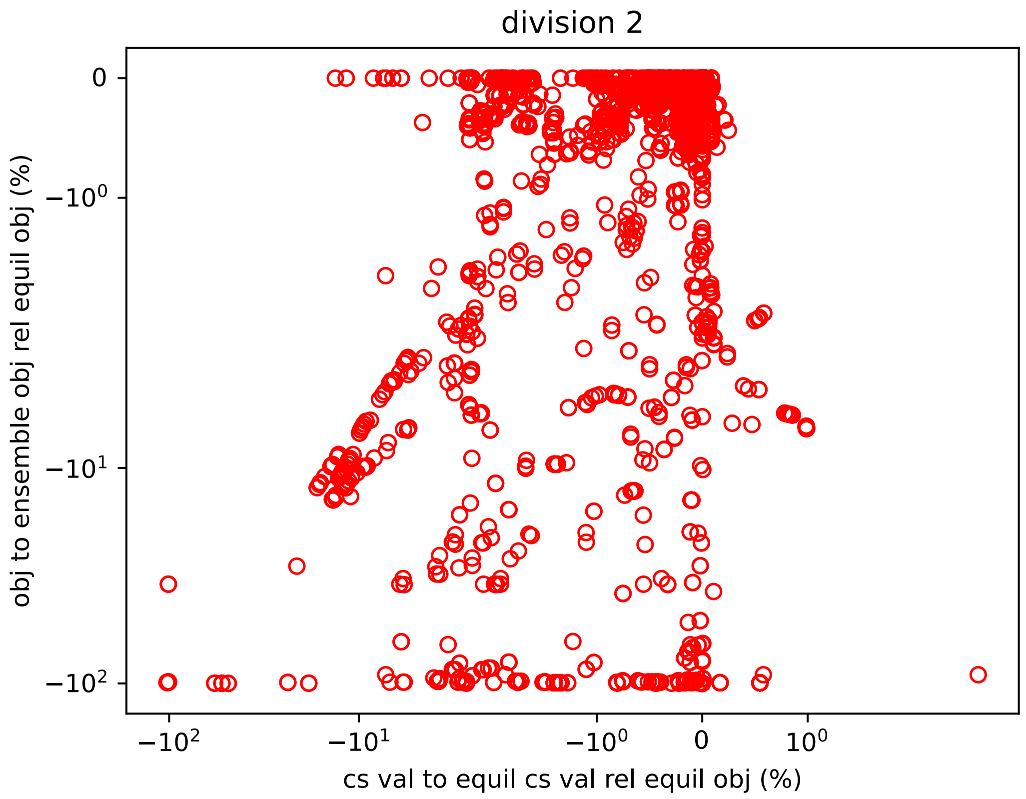




Influences on variation in objective – all solutions, not just the ensemble

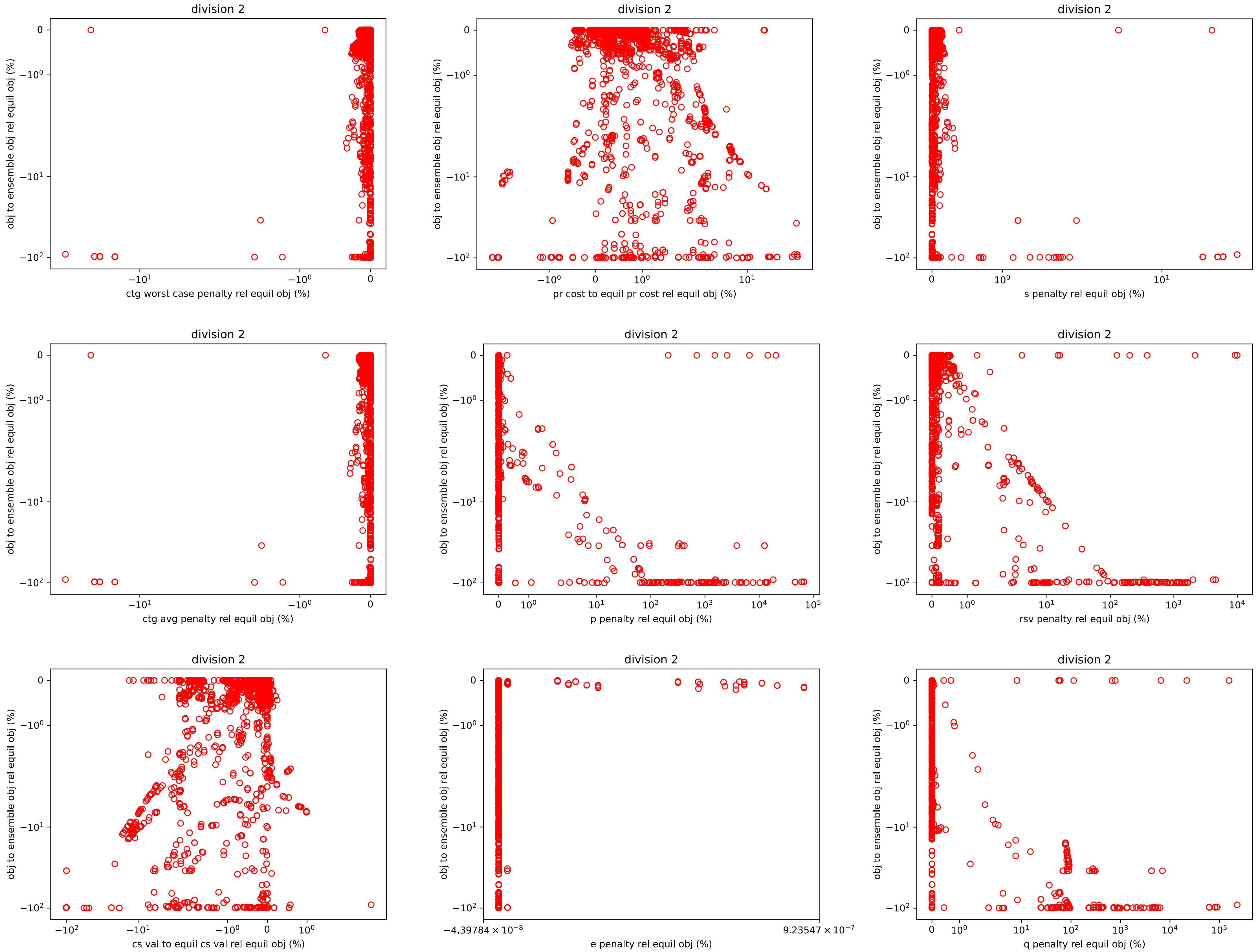
- Gauging variation in objective (y axis) as determined by variation in producer cost (x axis, top figure) and variation in consumer value (x axis, bottom figure)
- Normalization of each quantity X by reference values: (X – X*) / X^
- X is the value in a particular run (solver, scenario)
- X* is a reference level
- X^ is a reference scale
- It appears that there is some bunching of solutions near the optimal consumer value, and not much bunching near the optimal producer cost, but this effect is rather subtle.
- Can we actually say:
  - The variation in producer cost is greater than the variation in consumer value and contributes more to the variation in objective value.
- Need to check out penalties and try to confirm this observation quantitatively.





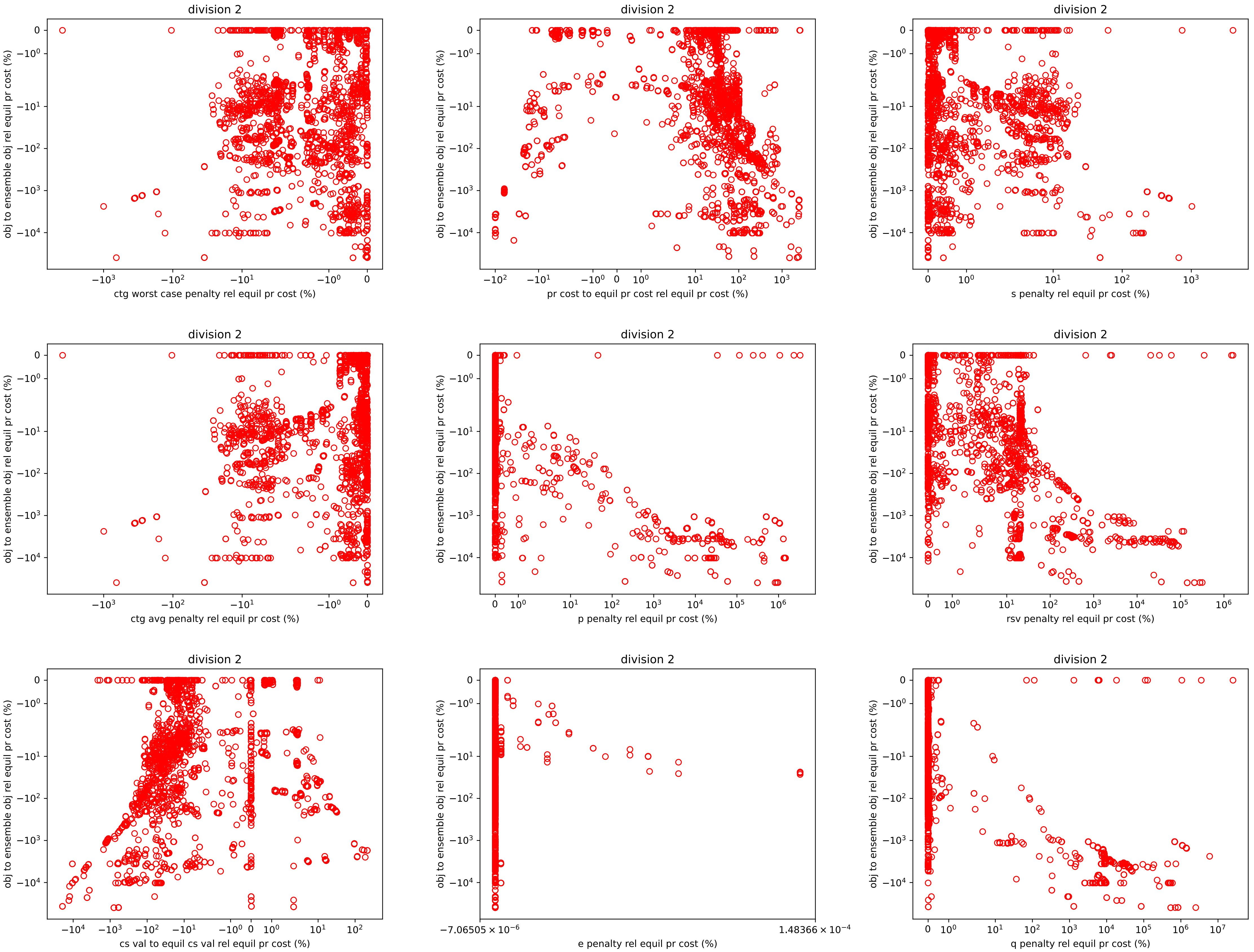
Influences on variation in objective

- Reference scale X^ is the equilibrium objective value



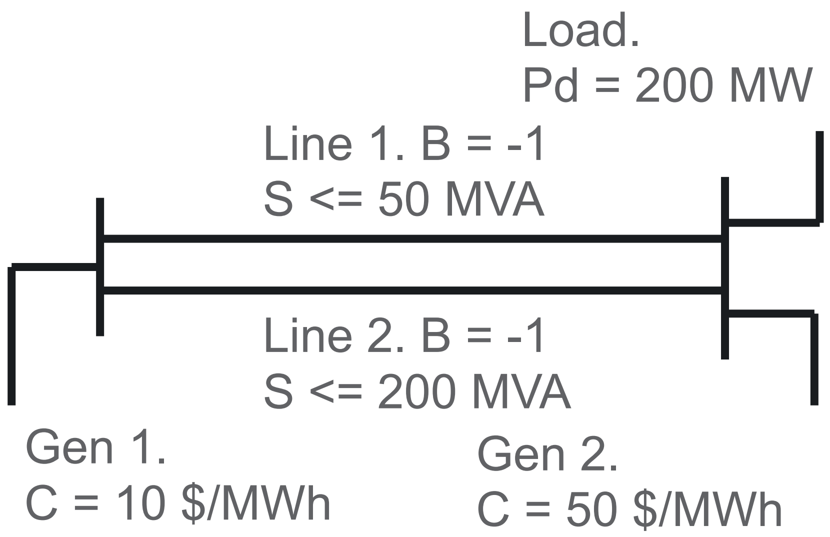
Influences on variation in objective

- Reference scale X^ is the equilibrium producer cost

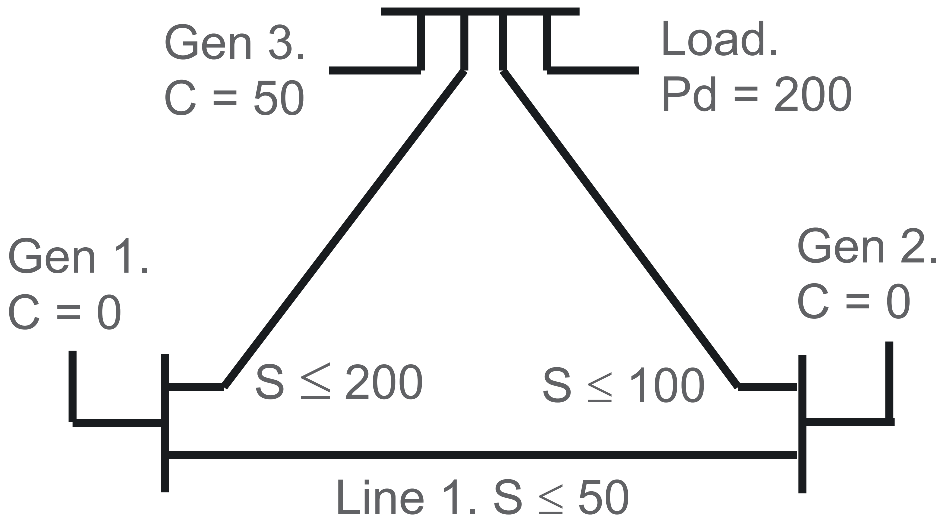


Topology Switching

- Standard DC example
  - Cheaper if we open low capacity line 1
- Why would we be in this situation?
  - Why is line 1 closed initially?
  - (n-1)-security
  - Diversity of operating conditions – wind, solar, flexible load.
- Further DC example
  - Optimal line 1 status depends on wind availability scenario
- How frequent are conditions like this?



Line 1	Closed	Open
Pg1	100	200
Pg2	100	0
C	6000	2000



Scen	1	1	2	2
Pmax1	200	200	0	0
Pmax2	0	0	200	200
Line 1	1	0	1	0
Pg3	50	0	50	100
C	2500	0	2500	5000

Methods of modifying a problem to make switching valuable

- Add a large open line in parallel with an existing line connecting a leaf node
  - Beneficial to close it (switch into service)
- Add a small closed line in parallel with an existing line
  - Beneficial to open it
- Add a small closed line in parallel with a pair of incident lines
  - Beneficial to open it
- Add a small open line in parallel with an existing line
  - Beneficial to keep it open
  - Algorithms that just close every line at the start of the model horizon will miss this

Creating a set of problems demonstrating value of switching

- Start with original problem P0
  - Solve with benchmark solver for solution X0
  - Evaluate solution – Z0
- Create modified problem P1 with presumably ideal topology in starting state
  - Solve with benchmark solver with no switching allowed for solution X1
  - Evaluate solution – Z1
- Create modified problem P2 with presumably non-ideal topology
  - Solve with benchmark with no switching allowed for solution X2
  - Evaluate solution – Z2
- Consider X1 as a solution to P2 with switching allowed
  - Evaluate – Z3
- Z3 – Z2 is the additional value created by allowing switching

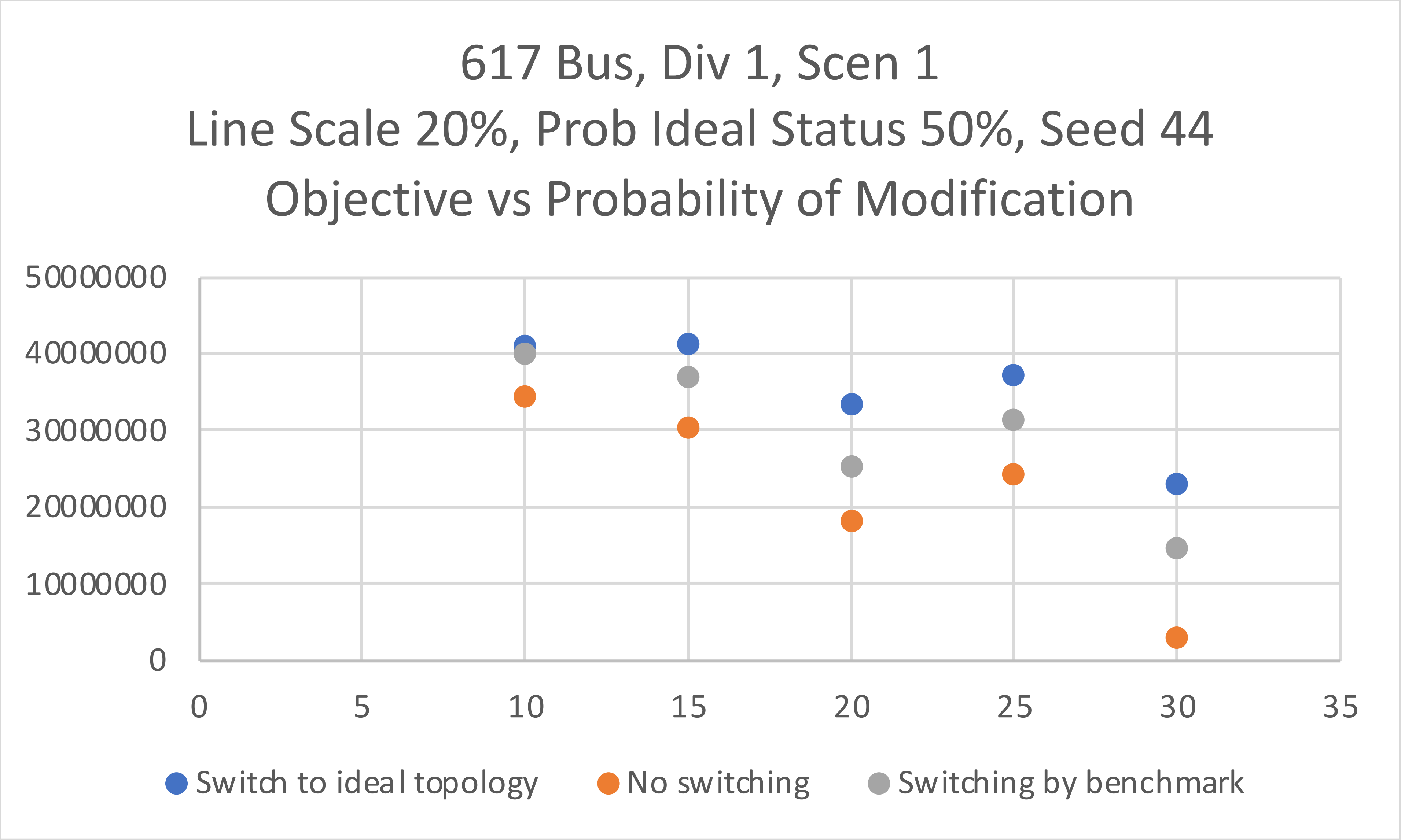
Value of switching in scenarios designed to highlight switching

- Modified 73 bus division 2 scenarios and 617 bus division 1 scenarios
- Varied the number of lines modified and the sizes of lines added
- Obtained modified scenarios demonstrating more or less value of switching

network	z_no_sw_allowed	z_yes_sw_allowed	no sw loss abs	no sw loss pct	z_sw_opt	opt loss abs	opt loss pct
C3E3N00617D1	34349360	40915590	6566230	16	39898295	1017295	2
C3E3N00617D1	30456450	41373876	10917426	26	36930040	4443836	11
C3E3N00617D1	18087631	33374254	15286623	46	25351734	8022520	24
C3E3N00617D1	24318942	37154170	12835228	35	31355758	5798412	16
C3E3N00617D1	11795038	21477245	9682207	45	20937141	540104	3
C3E3N00617D1	3118820	23088910	19970090	86	14698118	8390792	36
C3S0N00073D2	47039780	58931285	11891505	20	42226350	16704935	28
C3S0N00073D2	46626851	58930885	12304034	21	41457445	17473440	30
C3S0N00073D2	24358533	58930585	34572052	59	10072563	48858022	83
C3S0N00073D2	26566146	58931085	32364939	55	11300982	47630103	81
C3S0N00073D2	24212779	58930585	34717806	59	953999	57976586	98
C3S0N00073D2	56221797	58930885	2709088	5	55361458	3569427	6
C3S0N00073D2	49852648	58930585	9077937	15	46271681	12658904	21
C3S0N00073D2	49495530	58930585	9435055	16	46757325	12173260	21
C3S0N00073D2	57754552	58931285	1176733	2	57727613	1203672	2
C3S0N00073D2	57801114	58930885	1129771	2	57765829	1165056	2
C3S0N00073D2	56851990	58930585	2078595	4	55917541	3013044	5
C3S0N00073D2	56735576	58931085	2195509	4	56370859	2560226	4
C3S0N00073D2	56668049	58930585	2262536	4	56173196	2757389	5
C3S0N00073D2	58274130	58930585	656455	1	56084671	2845914	5
C3S0N00073D2	58024449	58930585	906136	2	51909135	7021450	12
C3S0N00073D2	56830422	58930585	2100163	4	36556126	22374459	38
C3S0N00073D2	58522652	58931285	408633	1	58522532	408753	1
C3S0N00073D2	58563148	58931085	367937	1	58546710	384375	1

Value of switching depends on extent of modification

- Adding more new lines
  - decreases the overall objective of the problem and
  - makes switching more beneficial



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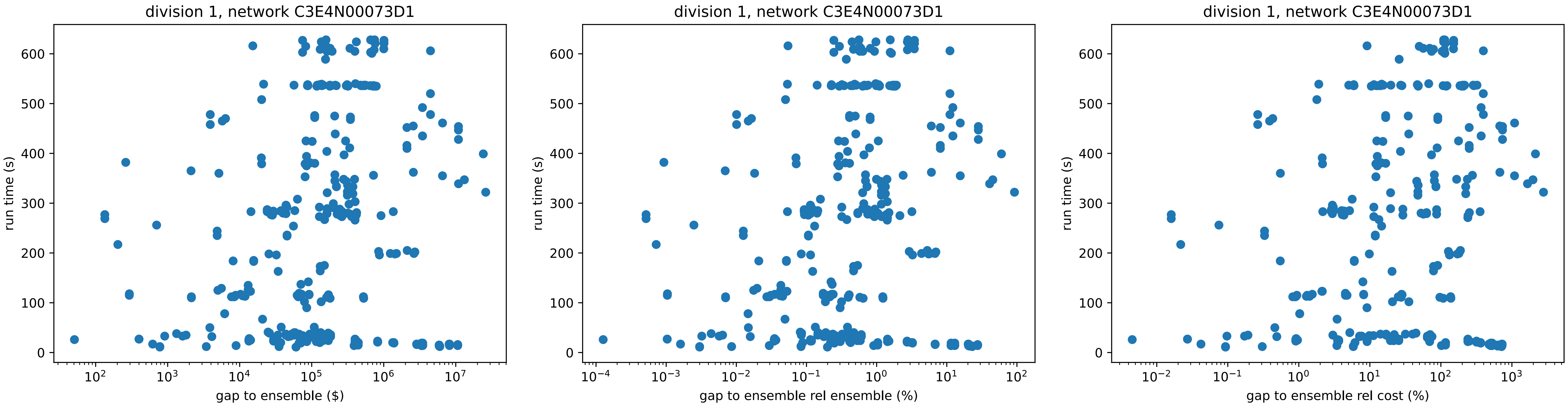
Competitor switching results

division	network	scenario	team	obj switching	obj no switching	obj improve switching	obj_improve_switching_rel	obj_improve_switching_rel_problem_cost_p	total switching	close at start	open at start	close after start	open after start
2	C3E4N00073D2	997		58,572,098	4,977,134	53,594,964	91.50%	9317.67%	31	0	4	5	5
2	C3E4N00073D2	992		58,572,085	5,006,892	53,565,193	91.45%	9312.50%	31	0	4	5	5
2	C3E4N00073D2	996		58,595,574	8,385,488	50,210,086	85.69%	8729.20%	29	0	4	4	4
2	C3E4N00073D2	991		58,596,339	8,571,370	50,024,969	85.37%	8697.02%	29	0	4	4	4
1	C3E4N04224D1	25		91,618,796	15,285,835	76,332,961	83.32%	1092.73%	8	8	0	0	0
2	C3E4N00073D2	313		78,853,610	47,041,750	31,811,860	40.34%	729.67%	0				
2	C3E4N02000D2	86		426,547,405	259,502,128	167,045,276	39.16%	484.40%	0	0	0	0	0
2	C3E4N00073D2	917		52,401,518	52,235,639	165,878	0.32%	28.84%	20	2	2	8	5
1	C3E4N04224D1	22		89,322,190	89,164,272	157,918	0.18%	2.26%	8	8	0	0	0
2	C3E4N00073D2	911		58,640,244	58,537,366	102,878	0.18%	17.89%	6	0	6	0	0
2	C3E4N04224D2	26		526,426,337	525,519,203	907,134	0.17%	2.18%	8	8	0	0	0
2	C3E4N00073D2	912		58,639,266	58,539,409	99,856	0.17%	17.36%	6	0	6	0	0
2	C3E4N00073D2	922		58,570,364	58,475,754	94,610	0.16%	16.45%	22	8	5	5	2

- Many instances of large improvements from no switching allowed to switching allowed
- Even the improvements that look small relative to the total objective are large relative to the generator cost
- Some improvements happened despite no switching occurring
- Some improvements occurred with switching only by closing all lines at the start of the horizon
- Some improvements occurred with “real” switching – i.e. either opening some lines at the start of the horizon or any kind of switching after the start

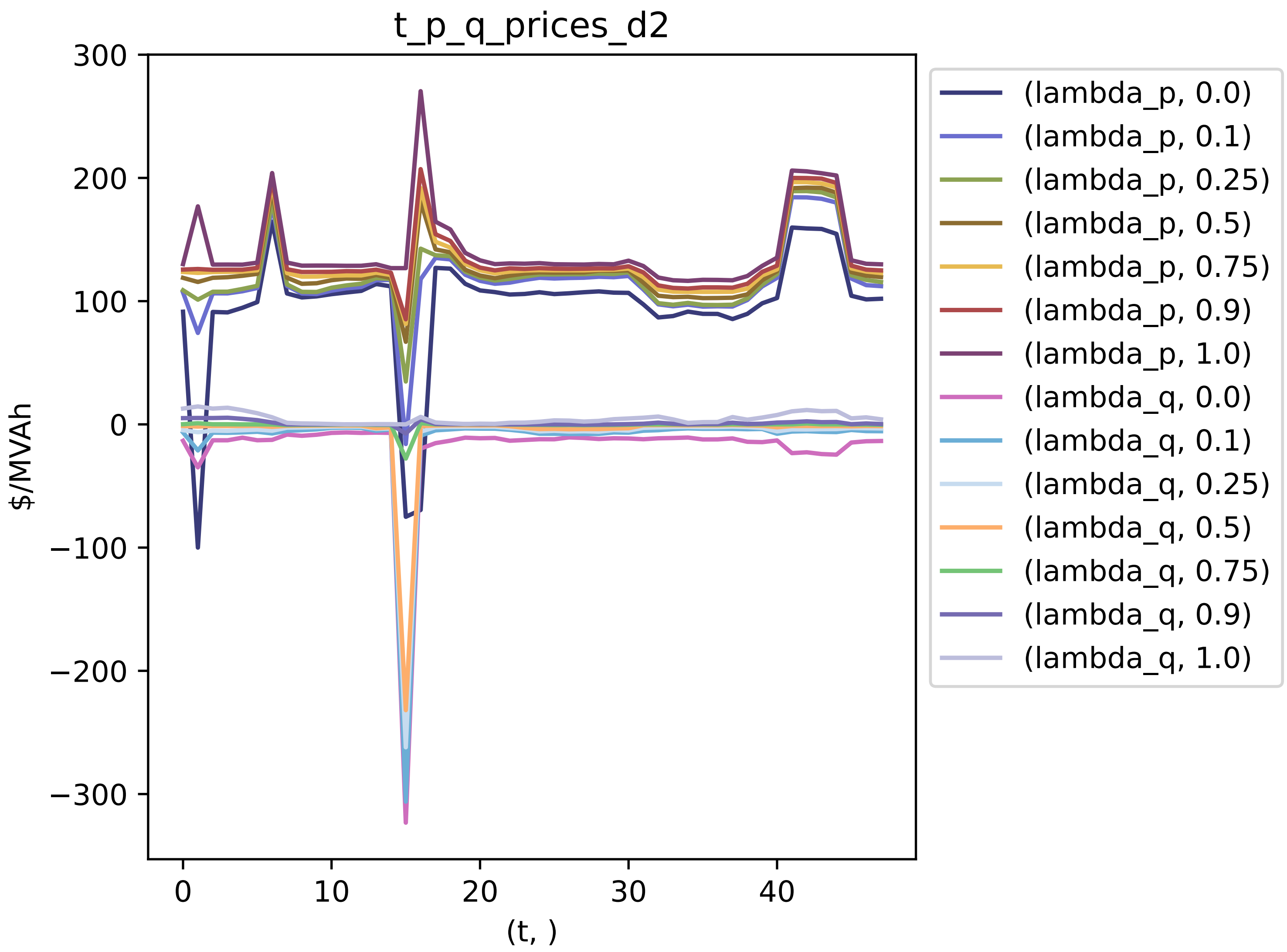
Run time

- Explore tradeoff between run time and solution quality
- Which solvers were particularly fast without sacrificing quality?
- Need a quality cutoff



Real and reactive power prices

- Using the benchmark solver on a D
  73 bus scenario
- The solver obtains Lagrange multipliers from the NLP solver IPOPT at a KKT point
- These can be transformed into price for real and reactive power ($/MWh and $/Mvar-h) at each bus in each interval
- Plot, over time, selected quantiles c the bus-indexed multipliers
- Much more to do
  - Other pricing methods
  - Incorporate reserves and ramping in pricing



Importance of flexible load

- Generate fixed load scenario from a given flexible load scenario
- A difficulty with this in Challenge 2 was that the events did not have any scenarios with fixed loads, so when we tried this analysis after the events, the solvers did not handle fixed loads well
- In Challenge 3, some of the scenarios in the events did have fixed loads

UC-AC decomposition

- Can we take the UC algorithm of one solver and combine it with the ACOPF algorithm of another solver?
- Currently we are experimenting with using the benchmark solver for the AC phase and using competitor solvers for the UC
- Next try the benchmark for the UC with competitors for AC
- Seems like an easy way to improve on a solver that is pretty good at UC or AC but not as good at the other task

References

- GO Competition web pages
  - https://gocompetition.energy.gov/
  - https://gocompetition.energy.gov/challenges/challenge-3
- Problem data checker and solution evaluator code
  - https://github.com/GOCompetition/C3DataUtilities
  - https://github.com/Smart-DS/GO-3-data-model
  - https://pypi.org/project/GO-3-data-model/
- Data format and problem formulation documents
  - https://gocompetition.energy.gov/sites/default/files/Challenge3_Problem_Formulation_20230515.pdf
  - https://gocompetition.energy.gov/sites/default/files/Challenge3_Data_Format_20230124.pdf
- Datasets
  - https://gocompetition.energy.gov/challenges/600650/datasets

- Papers

  - Y Chen, F Pan, J Holzer, A Veeramany, Z Wu, "On Improving Efficiency of Electricity Market Clearing Software with A Concurrent High Performance Computer Based Security Constrained Unit Commitment Solver," *PESGM* 2021, https://ieeexplore.ieee.org/abstract/document/9638040
  - F Safdarian et al., "Grid Optimization Competition on Synthetic and Industrial Power Systems," *NAPS* 2022, https://ieeexplore.ieee.org/document/10012138
  - JT Holzer, YChen, Z Wu, F Pan, A Veeramany, "Fast Simultaneous Feasibility Test for Security Constrained Unit Commitment," *IEEE TPWRS* 2023, https://ieeexplore.ieee.org/document/10094291
  - I Aravena et al, "Recent Developments in Security-Constrained AC Optimal Power Flow: Overview of Challenge 1 in the ARPA-E Grid Optimization Competition," *Operations Research* 2023, https://pubsonline.informs.org/doi/abs/10.1287/opre.2022.0315

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Thank you