Stochastic Scheduling Pricing and Dispatch

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Joint work with Golbon Zakeri, Andy Philpott.
With thanks to Geoff Pritchard.
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A problem: The cost of being deterministic is increasing

- Electricity pool markets dispatch participants deterministically.
- But wind not known apriori.
- Remedy: two markets. Forward and real-time.
- If wind & solar small or market hydro-dominated then the cost of being deterministic is small. Otherwise, it can be large.
- There is economic & political pressure to invest in wind & solar generation; the cost of being deterministic is increasing.
- If the forward market is deterministic, then wind causes pricing inconsistencies between the markets (Zavala et al, 2017).

A solution: A stochastic dispatch mechanism

Wong & Fuller (2007), Pritchard et al (2009), Zakeri et al (2017)

The day-ahead market clearing problem:

$$\begin{array}{lll} \text{Min} & \mathbb{E}_\omega[c^T X(\omega) + r_u^T U(\omega) + r_v^T V(\omega)] & \\ \text{s.t.} & \displaystyle\sum_{i \in T(n)} X_i(\omega) + \tau_n(F(\omega)) \geq D_n(\omega), & \forall \omega \in \Omega,\ [\mathbb{P}(\omega)\lambda_n(\omega)], \\ & x + U(\omega) - V(\omega) = X(\omega), & \forall \omega \in \Omega, \\ & F(\omega) \in \mathcal{F}, & \forall \omega \in \Omega, \\ & 0 \leq X(\omega) \leq G, & \forall \omega \in \Omega, \\ & 0 \leq U(\omega), V(\omega), & \forall \omega \in \Omega. \end{array}$$

- x is the forward setpoint. $X(\omega)$ is the dispatch in scenario ω.
- Ω is a sample of uncertainty.

What is this talk about? Three questions:

- What is the value of stochastic dispatch?
  - Khazaei et al (2014) estimate stochastic dispatch increases welfare by $2,160 per year in the NZEM.
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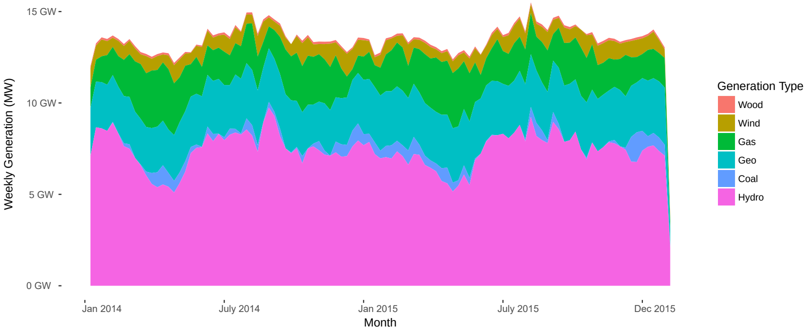
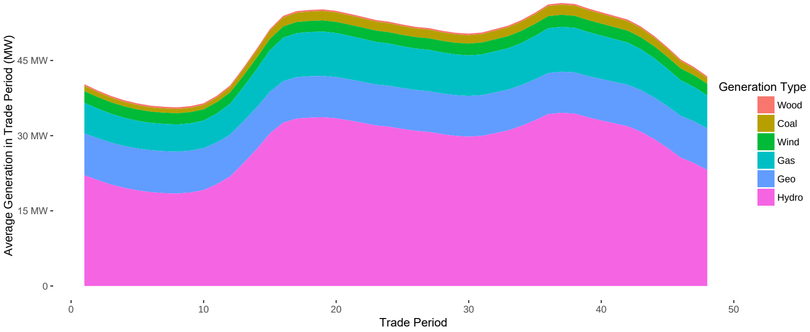
Composition of the NZEM in 2014 – 2015: By week



Hydro dominated (55%) with geothermal (21%), gas (15%), wind (5.7%), coal (2.6%), and wood (0.8%).

Composition of the NZEM in 2014 – 2015: By TP



We remove constraints on ramping and price reserves at zero. Increases hydro by 5% so underestimates savings.

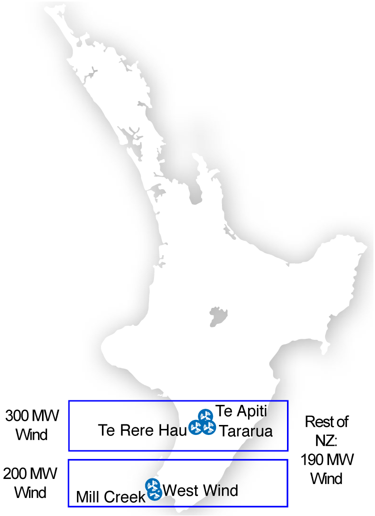
How to model wind with a probability distribution:

Pritchard (2011), Khazaei et al (2014), Cory-Wright & Zakeri (2017)

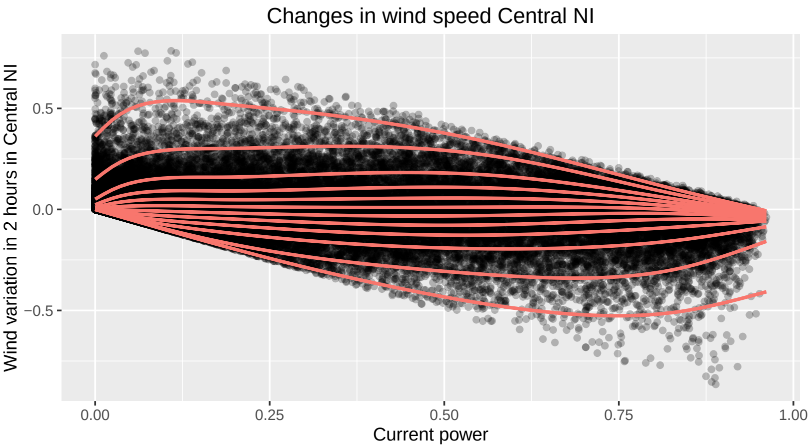
- Wind is drawn from a continuous distribution; use a sample.
- Scenarios drawn from quantiles of conditional distribution.
- Scenario splines generated from 2011 – 2013 historical data.

Scenario generation: Wind farms modelled

CNI, Wellington: assume conditionally independent.



Quantiles of the distribution of future uncertainty



How to estimate the marginal deviation costs:

Khazaei et al (2014), Cory-Wright & Zakeri (2017)

The costs of deviation are modelled by:

$$r_u = \frac{K}{\text{Generator Ramp Up Rate}},$$
$$r_v = \frac{K}{\text{Generator Ramp Down Rate}}.$$

$K = 10$ and $K = 100$ chosen so that thermal ($K = 10$) and hydro ($K = 100$) deviation costs match NZEM reserve prices.

Khazaei et al chose $K = 0.01$; our savings estimates will be higher.
Note: savings w.r.t. deterministic dispatch.

Parameter tuning

30540 TPs per experiment, takes 3 years with default CPLEX.
The following CPLEX parameters reduce the runtime to 3 months:

Parameter	Value	Meaning
names	no	Don't load names into CPLEX
lpmethod	4	Solve DE via Log Barrier
barcolnz	50	Manage cols with 50+ non-zero entries separately
barorder	3	Order rows via Nested Disection
scaind	1	Aggressively scale the problem matrix
objllim	0	Bound the objective from below with 0
parallelmode	−1	Use opportunistic parallel search
threads	4	Use all 4 cores

Cumulative payoffs $K = 10$

Type of TP	No TPs	95% CI Lower	95% CI Upper
Overall	35040	$63,671.97	$71,118.11
0% – 2.5% Wind	11280	$69,316.39	$76,522.04
2.5% – 5% Wind	12258	$49,446.38	$56,672.47
5% + Wind	11502	$73,321.71	$81,198.44
0% – 60% Hydro	12290	$91,555.62	$100,429.07
60% – 65% Hydro	10348	$57,082.71	$64,165.46
65% + Hydro	12402	$41,721.38	$47,685.45

Cumulative payoffs $K = 100$

Type of TP	No TPs	95% CI Lower	95% CI Upper
Overall	35040	$\$370,625.76$	$\$408,309.35$
$0\% - 2.5\%$ Wind	11280	$\$357,759.78$	$\$391,674.00$
$2.5\% - 5\%$ Wind	12258	$\$291,387.78$	$\$327,908.03$
$5\% +$ Wind	11502	$\$468,261.33$	$\$510,250.19$
$0\% - 60\%$ Hydro	12290	$\$519,906.59$	$\$566,029.24$
$60\% - 65\%$ Hydro	10348	$\$339,214.04$	$\$375,537.97$
$65\% +$ Hydro	12402	$\$250,583.89$	$\$278,329.44$

Key questions:

- What is the value of stochastic dispatch?
  - Between \$64,000 and \$408,000 per year in the NZEM.
  - Varies with the price of water and wind penetration.
- Who benefits from stochastic dispatch?
  - Are savings allocated to generators, consumers or both? Under what conditions?
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Participant payoffs $K = 10$

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In NZEM payoffs are:

Participant	Stochastic Larger 95% CI Savings/Yr		Deterministic Larger 95% CI Savings/Yr	
	Lower Limit	Upper Limit	Lower Limit	Upper Limit
Generators	−\$11.51 m	−\$10.22 m	+\$15.46 m	+\$16.66 m
Consumers	+\$10.51 m	+\$11.82 m	−\$16.94 m	−\$15.71 m
ISO	−\$0.303 m	−\$0.206 m	+\$0.304 m	+\$0.356 m
Net	+\$0.032 m	+\$0.060 m	+\$0.066 m	+\$0.093 m

Stochastic larger in 17429 TPs, deterministic larger in 17558 TPs.
Savings w.r.t. deterministic dispatch, not being out of pocket.

Generator payoffs $K = 10$ part 1

In 17429 TPs (49.7%) stochastic dispatch procured more generation. In a year of these TPs, generator losses are:

% Generator	95% CI Lower	95% CI Upper
Contact Energy	$-\$2,250,872.73$	$-\$1,997,026.47$
Genesis Energy	$-\$2,558,880.89$	$-\$2,255,615.11$
Meridian Energy	$-\$3,584,718.82$	$-\$3,176,249.18$
MRP	$-\$1,932,786.06$	$-\$1,707,169.14$
Norske Skog	$-\$117,469.65$	$-\$103,282.35$
Todd Energy	$-\$199,639.02$	$-\$172,836.18$
Trustpower	$-\$877,572.93$	$-\$778,417.47$

Profits w.r.t. deterministic dispatch, not being out of pocket.

Generator payoffs $K = 10$ part 2

In 17558 TPs (50.1%) deterministic dispatch procured more generation. In a year of these TPs, generator profits are:

% Generator	95% CI Lower	95% CI Upper
Contact Energy	$\$3,163,499.63$	$\$3,419,114.77$
Genesis Energy	$\$3,469,396.43$	$\$3,739,733.17$
Meridian Energy	$\$4,360,564.41$	$\$4,721,803.59$
MRP	$\$2,822,589.90$	$\$3,038,200.50$
Norske Skog	$\$172,856.08$	$\$186,654.32$
Todd Energy	$\$227,688.83$	$\$253,059.97$
Trustpower	$\$1,216,686.33$	$\$1,309,347.27$

Profits w.r.t. deterministic dispatch, not being out of pocket.

Analysis: Who benefits from stochastic dispatch?

In the NZEM?

- Increase (decrease) in generator (consumer) welfare an order of magnitude larger than increase in cumulative welfare.

In general?

- Componentwise, the forward dispatch is the $\frac{r_u}{r_u+r_v}$ quantile of the dist of second stage dispatches (Zakeri et al, 2017).
- Generators benefit if the cost of downward deviation is higher.
- Consumers benefit if the cost of upward deviation is higher.

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- Who benefits from stochastic dispatch?
  - Depends on size of forward dispatch w.r.t expected demand; marginal costs of deviation.
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Risk aversion without a market for risk

- There is no longer an equivalence between a competitive partial equilibria and a social optimum.
- Dispatch participants by solving a complimentarity problem.
- Kazempour and Pinson (2016) provide numerical evidence that generator risk-aversion causes supply to be withheld in the forward market.
- Without financial instruments, risk-aversion causes less generation to be procured in the forward market, expected nodal prices to increase and generators to benefit over consumers.

Risk aversion with a market for risk

Heath & Ku (2004), Ralph & Smeers (2015) , Philpott, Ferris, Wets (2016)

- Alternatively, we can complete a market for risk by introducing Arrow-Debreu securities. All participants within the system behave in the same manner as the least risk-averse participant in the market.
- Like using a market to decide the probability measure.
- Difficulties translating ADB securities out-of-sample; we consider the corresponding system optimization problem.
- System optimization problem is minimax; nature selects worst case probability measure from intersection of uncertainty sets.
- What happens to the payoffs?

System optimization with risk aversion: Numerical results

Increased generation procured compared to risk-neutral for first week of 2014; System endowed with the $\alpha - CV@R$ risk criterion:

α coeff	1.0	0.9	0.7	0.5	0.3	0.1
Max	397.01	335.43	187.11	101.41	60.04	21.77
3rd Qu.	175.22	125.82	77.92	49.54	29.51	9.78
Mean	137.28	103.37	63.13	38.22	21.80	7.20
Median	108.15	77.77	47.38	30.03	17.93	6.05
1st Qu.	78.35	59.16	35.31	22.48	13.30	4.37
Min	18.13	3.08	0.00	0.00	0.00	0.00

With financial instruments, as the system gets more risk-averse, it procures more generation, expected nodal prices decrease and consumers benefit.

This is similar to the result from Allaz & Villa (1993).

Who bears the efficiency losses from risk-aversion?

- Consumers, without a market for risk.
  - Possibly indistinguishable from market power.
- Generators, with a market for risk and no risk-neutral agent.
  - Easy to differentiate from market power.
  - A market decides the probability measure in-sample.
  - But interpreting ADB securities out-of-sample is challenging.

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- Who benefits from stochastic dispatch?
  - Depends on size of forward dispatch w.r.t expected demand; marginal costs of deviation.
- What if generators are risk-averse?
  - Without a market for risk, consumers lose out.
  - With a market for risk, generators lose out.

Results appear in the following papers:

- R. Cory-Wright, A. Philpott, and G. Zakeri. On payment mechanisms for electricity markets with uncertain supply. Submitted to Operations Research Letters.
- R. Cory-Wright and G. Zakeri. Who benefits from Stochastic Dispatch? Working paper.

- Stay tuned to epoc.org.nz.

Thank You!

Questions?

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