Competition and Cooperation Among Wind Farms

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CMU Electricity Conference

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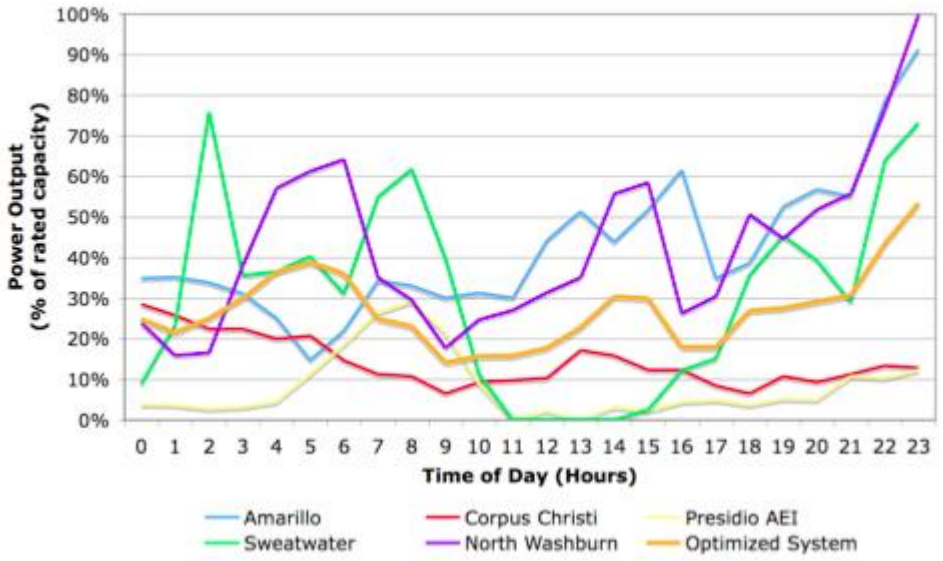
Wind Power

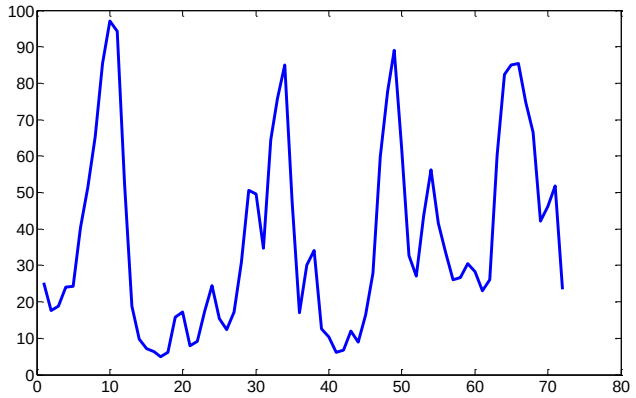
- Significant increase in wind power
- 30% renewable by 2030 in CA, 50% by 2050
- Taken as negative load
- Must participate in the market if subsides end

Uncertainty limits wind participation

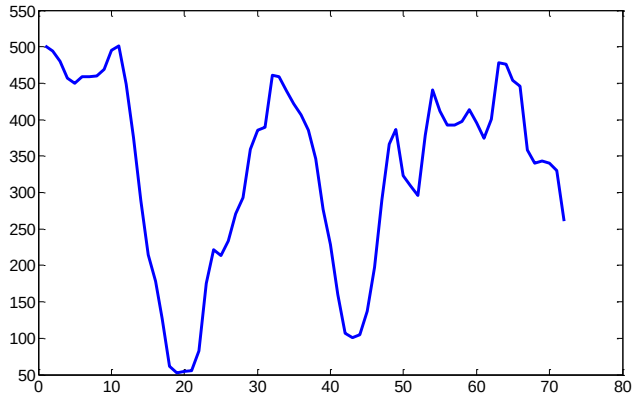


Overcoming Randomness

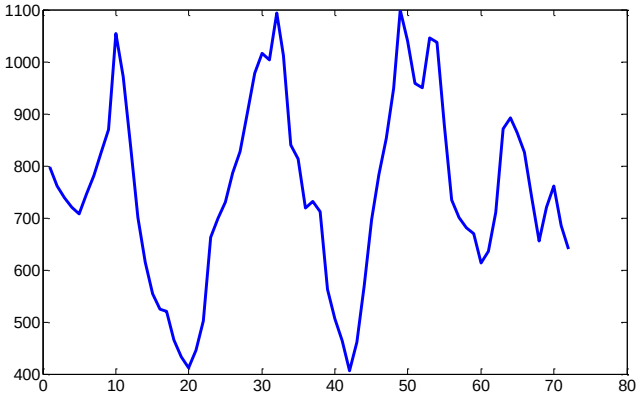
- Spatial diversity: coalitions



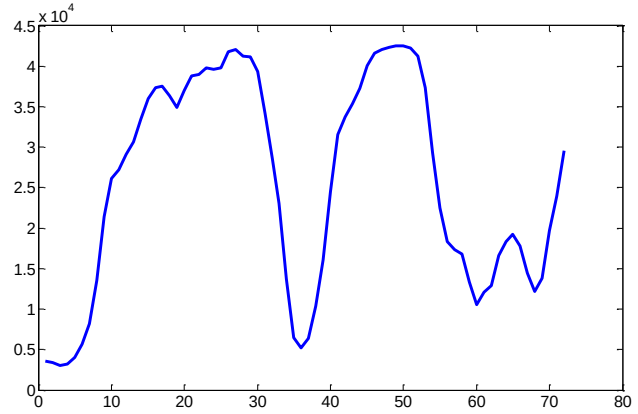
1 Wind Farm



5 Wind Farm



10 Wind Farm



50 Wind Farm

Overcoming Randomness

- Spatial diversity: coalitions
- What about market power?

  CA Energy Crisis

PALOS VERDES PENINSULA NEWS — SATURDAY, MARCH 13, 2004

ENERGY NEWS

Tapes Show Enron Arranged Plant Shutdown

Two years ago, U.S. Navy personnel and their families assigned to the Atsugi Navy base, home of the U.S.S. Kittyhawk, were treated to a rare experience when Terry Fleming and his local Irish/American band, Innisfree, traveled to the base to entertain them on St. Patrick's Day. Fleming and the other five members of Innisfree were delighted and honored to be able to go to Japan and lift the spirits, if only for a few hours, of the Navy personnel and their families.

For the third year in a row, Fleming — a local insurance broker in Rolling Hills by day and an entertainer by night — and the band travel to entertain the Navy men, women and families at various bases throughout Japan.

Fleming, the leader of the band on accordion and harmonica, actually is the only member of the band from Ireland. Other members include lead singer Julie Delaney, a civil engineer in Newport Beach; Terry Doyle, guitar, a news director with CBS news; Denis Doyle, Celtic harpist, a professor at Glendale College; Kevin Weed, keyboards and bagpipes, music teacher and assistant director of the Orange County Symphony; and Mike Tiffany, bass, a computer engineer. The band has been playing the length and breath of California for the past 25 years. They have played at pubs, wakes, weddings, birthdays and on occasions where there was little excuse for throwing a party.

Fleming says it was by coincidence the band got the opportunity to travel to Japan. Another band was unable to travel at the last minute and so he and his band were offered the opportunity to go in their place.

With some trepidation they made their first trip and with the overwhelming response they received at Atsugi, any fears they had were quickly allayed. On a damp St. Patrick's Day, hundreds of families, clad in many shades of green, whooped it up, sang their hearts out and danced up a storm. As the evening wore on, many in the audience were emboldened to try their hand or foot at the Irish gig, with much encouragement from the band.

Even though far from home, the Atsugi base — situated a few hours south of Tokyo — felt like home away from home, with its lush green rolling landscape and its multitude of cherry blossom trees. "Yet," Fleming says, "one was struck by the commitment and dedication of our men and women in uniform as they played their part in protecting and serving in an ever challenging and hostile world."

A couple of the families even took time out from their busy schedule to host Terry and the band members. They treated them to a guided tour of the base and accompanied them on a few exciting trips off the base, visiting beautiful ancient temples, monuments and revered giant Buddas.

On a visit to downtown Tokyo, the band came across what they assumed was a very rare sight, a place called "Scruffy Murphy," an Irish pub located in the heart of a bristling downtown. Upon checking the establishment out, they discovered a real authentic Irish Pub with excellent Guinness and good pub grub. It also happened to be open mic night, so the band members took over the stage and entertained the locals for a few fun-filled hours. It turned out that it was just one of many establishments in the city.

A special bond developed between the band members and these families and already exchange visits have occurred when the same families were on leave in the United States.

For more information about the band, log on to www.Innisfreemusic.com.

Norris Center for the Performing Arts, 27570 Crossfield Drive in RHE, on Saturday, March 20 at 2 and 4 p.m. Tickets are $38 for adults and $19 for students for the evening performance and $30 for adults and $15 for students at the matinee performance. For reservations, call 544-0403.

• UPCOMING — The Palos Verdes Peninsula Unified School District and Friends of School Music host the 15th Palos Verdes Elementary Choral Festival on March 23, 24 and 25 at the Norris Center for the Performing Arts, 27570 Crossfield Drive in RHE. All shows begin at 7:30 p.m. For tickets, call the Norris box office at 544-0403.

• ONGOING — The Distinctive Edge, 29050 S. Western Ave., Suite 113 in RPV, continues "Third Time's a Charm," an exhibit of 3-D collages by artist Steve Jacobsen, though March 30. For gallery hours, call 833-3613.

• ONGOING — "Natural Treasures" exhibition contin-

Overcoming Randomness

- Spatial diversity: coalitions
- What about market power?

- Gil & Lin,PJM, Trans. Power Systems, 2013
  - 10% of wind can reduce the day-ahead price by half

Overcoming Randomness

- Spatial diversity: coalitions
- What about market power?

Contribution:

- Tradeoff between uncertainty and market power

- Optimal size of coalitions

Market Setup

- Two-stage market

- N wind farms with output

$$W_1, \ldots, W_N$$

- Day-ahead profit for farm i

$$\pi_i(\widehat{W}_i) = \overbrace{p(\widehat{W}_1, \ldots, \widehat{W}_N)\,\widehat{W}_i}^{\text{Revenue}} - \overbrace{qE[(\widehat{W}_i - W_i)^+]}^{\text{Penalty}}$$

Bid — Day-ahead Price — Real-time Shortfall

Market Setup

- Two-stage market

- N wind farms with output

$$W_1, \ldots, W_N$$

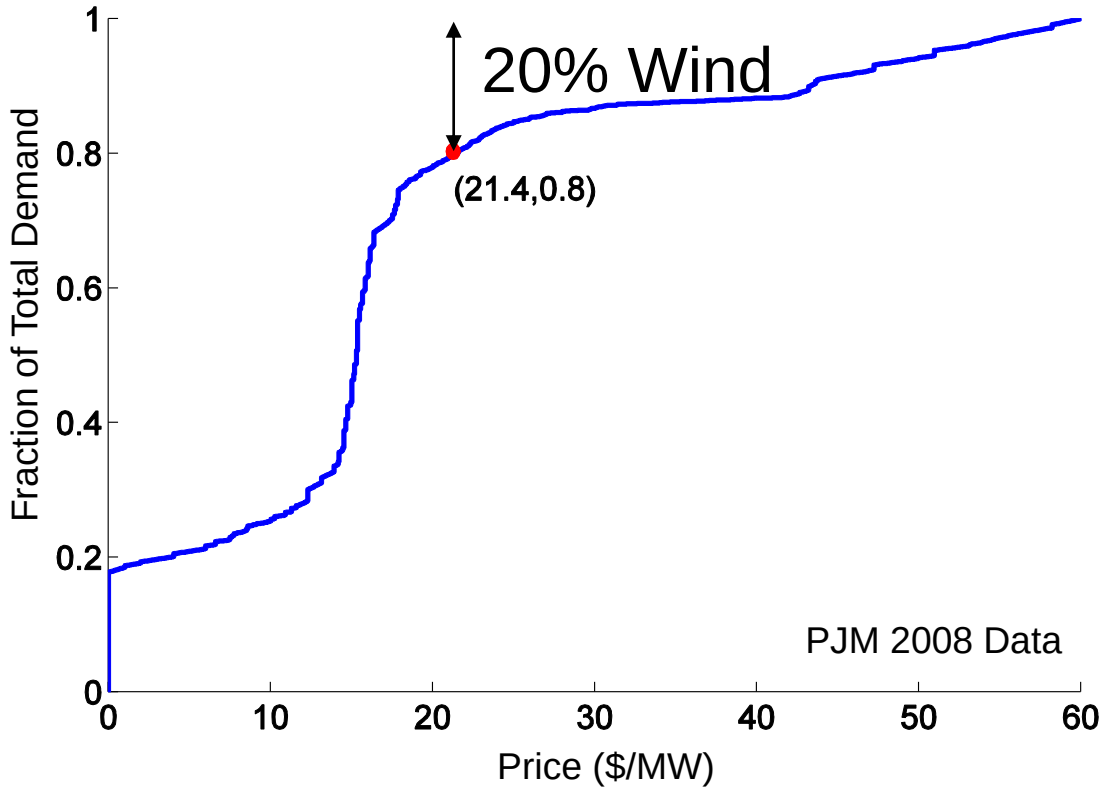
- Day-ahead profit for farm i

$$\pi_i(\widehat{W}_i) = p(\widehat{W}_1, \ldots, \widehat{W}_N)\,\widehat{W}_i - qE[(\widehat{W}_i - W_i)^+]$$

Bid — Day-ahead Price — Real-time Shortfall

Aggregate Price Curve

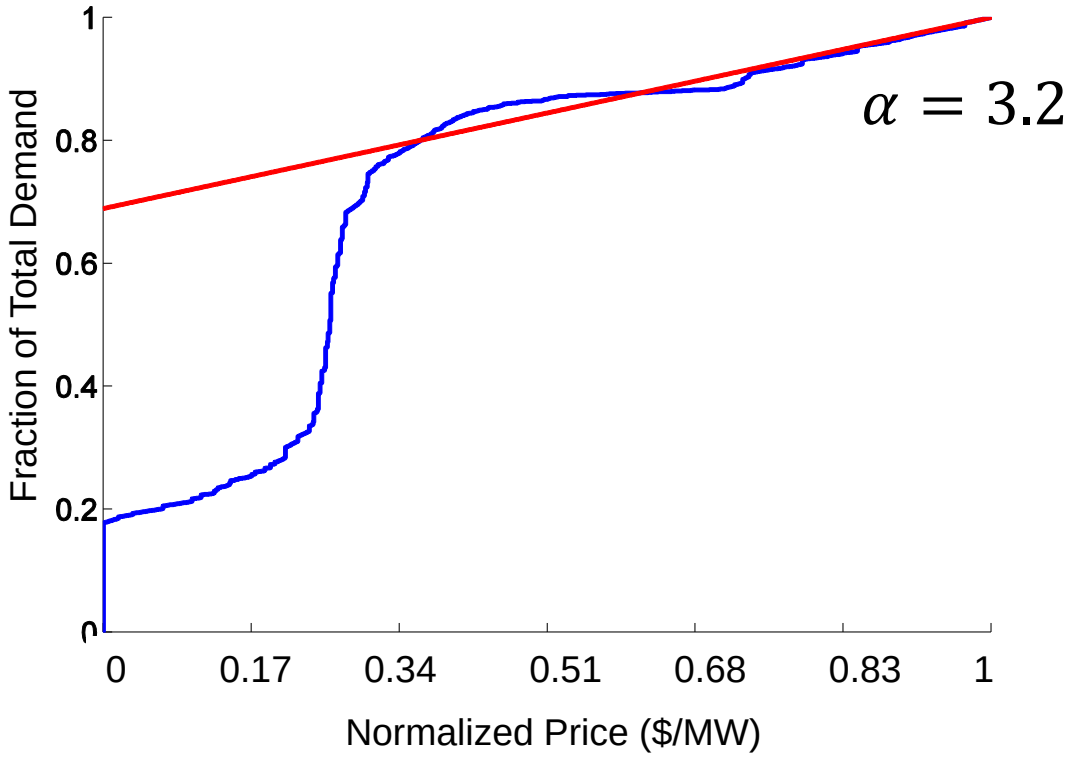
- Two kinds of generators: Traditional and Wind
- Wind farms bid quantity
- Aggregate price curve for traditional generators



Linear Approximation

- Price as function of wind

$$p\left(\widehat{W}_1, \ldots, \widehat{W}_N\right) = 1 - \alpha \sum_{i=1}^{N} \widehat{W}_i$$



Independent Wind Farms

- Wind farms are i.i.d.
- Large N regime, $\alpha = 3.2$
- Grand coalition

$$\max \left(1 - \alpha \widehat{W}\right)\widehat{W} - qE[(\sum W_i - \widehat{W})^+]$$

- Optimal solution: $\widehat{W}^* \leq \frac{1}{2\alpha} = 15\%$
- Withholding because of market power

Independent Wind Farms

- Wind farms are i.i.d.
- Large N regime, $\alpha = 3.2$
- Grand coalition$\leq \frac{1}{2\alpha} = 15\%$
- Individual competition

$$\max \left(1 - \alpha \sum \widehat{W}_i\right) \widehat{W}_i - qE[(W_i - \widehat{W}_i)^+]$$

- Optimal solution: total bid $\leq 15\%$
- Withholding because of uncertainty

Independent Wind Farms

- Wind farms are i.i.d.
- Large N regime, $\alpha = 3.2$
- Grand coalition $\leq \frac{1}{2\alpha} = 15\%$
- Individual competition $\leq \frac{1}{2\alpha} = 15\%$

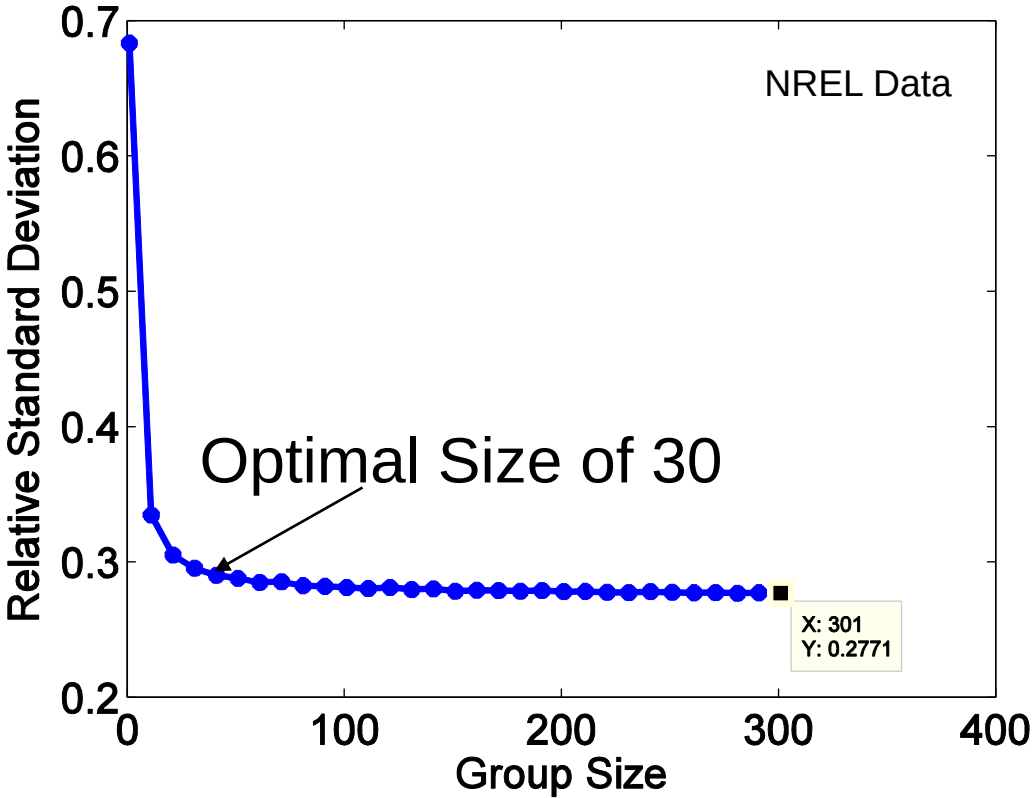
- Intermediate size

Group size of $\sqrt{N}$ achieves a penetration level of $\frac{1}{\alpha} = 30\%$

- Socially optimal

Correlated Wind Farms

- Identical but not independent
- Can still achieve $\frac{1}{\alpha}$
- Solve an optimization to find the optimal group size



Conclusion

- Tradeoff between market power and uncertainty
- Optimal size of coalitions
- Future directions: more detailed models