Wind Generation in the US

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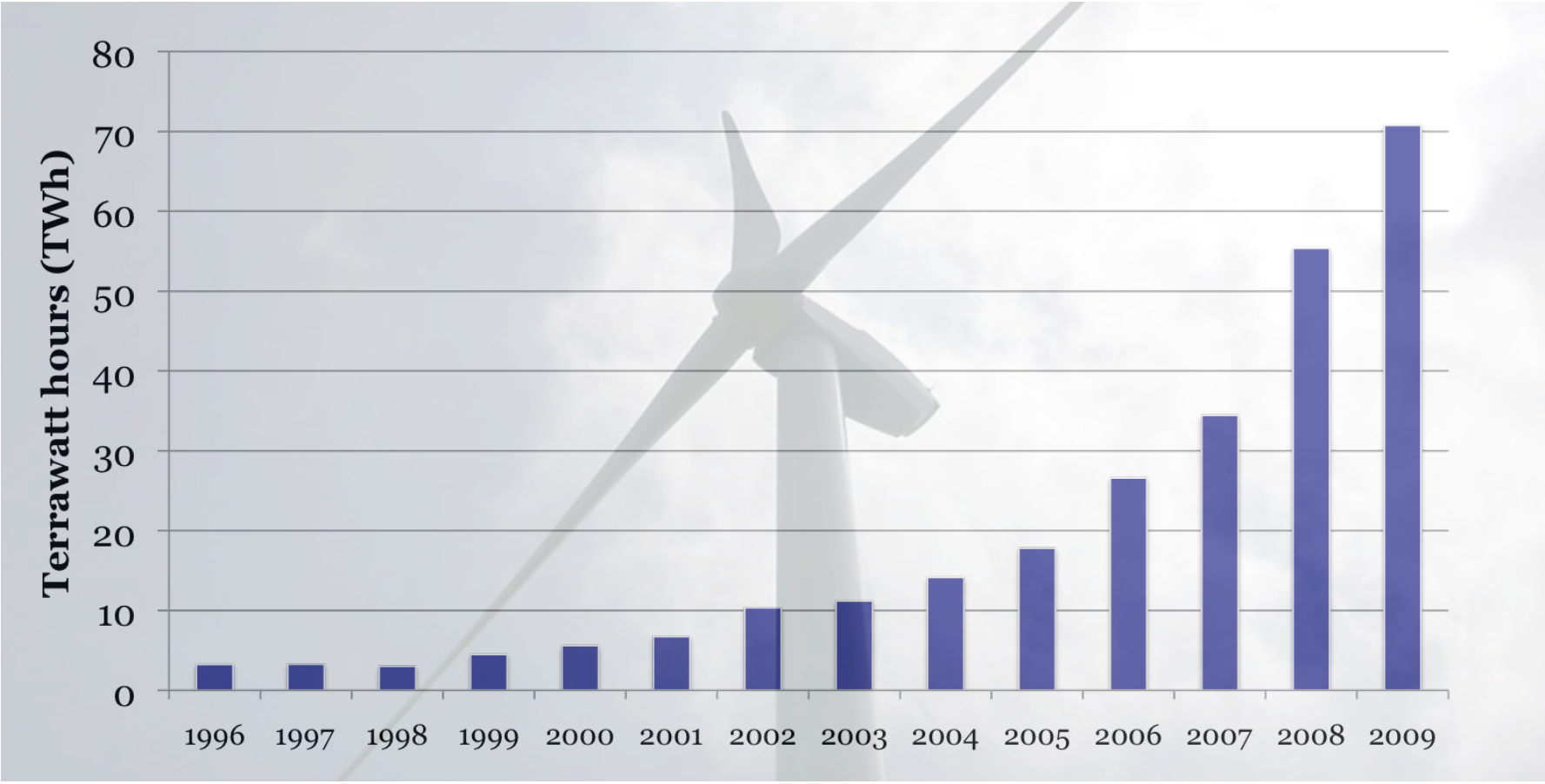
Key issues

- Is the recent rapid growth in wind generation in the US likely to be maintained?
- How has the growth in wind generation affected system operation?
- What is an appropriate “capacity allowance” for wind generation?
- What types of plants is wind generation likely to displace?
- How might increased wind generation affect the demand for other energy sources?
- This talk will focus on the ERCOT experience – the paper also examines MISO data

US wind generating output



Sources: Data – Energy Information Administration, Image – La Chaussé www.windpower.net

Rules, regulations and policies for renewable energy

	Personal tax	Corporate tax	Sales tax	Property tax	Rebates	Grants	Loans	Industry recruiting	Bonds	Production incentives
Federal	3	4				3	5	1		1
State	37	36	35	54	77	43	81	36		15
Local			1	11	12	5	16	1	3	
Utility					346	7	64			39
Private					1	4	7			3

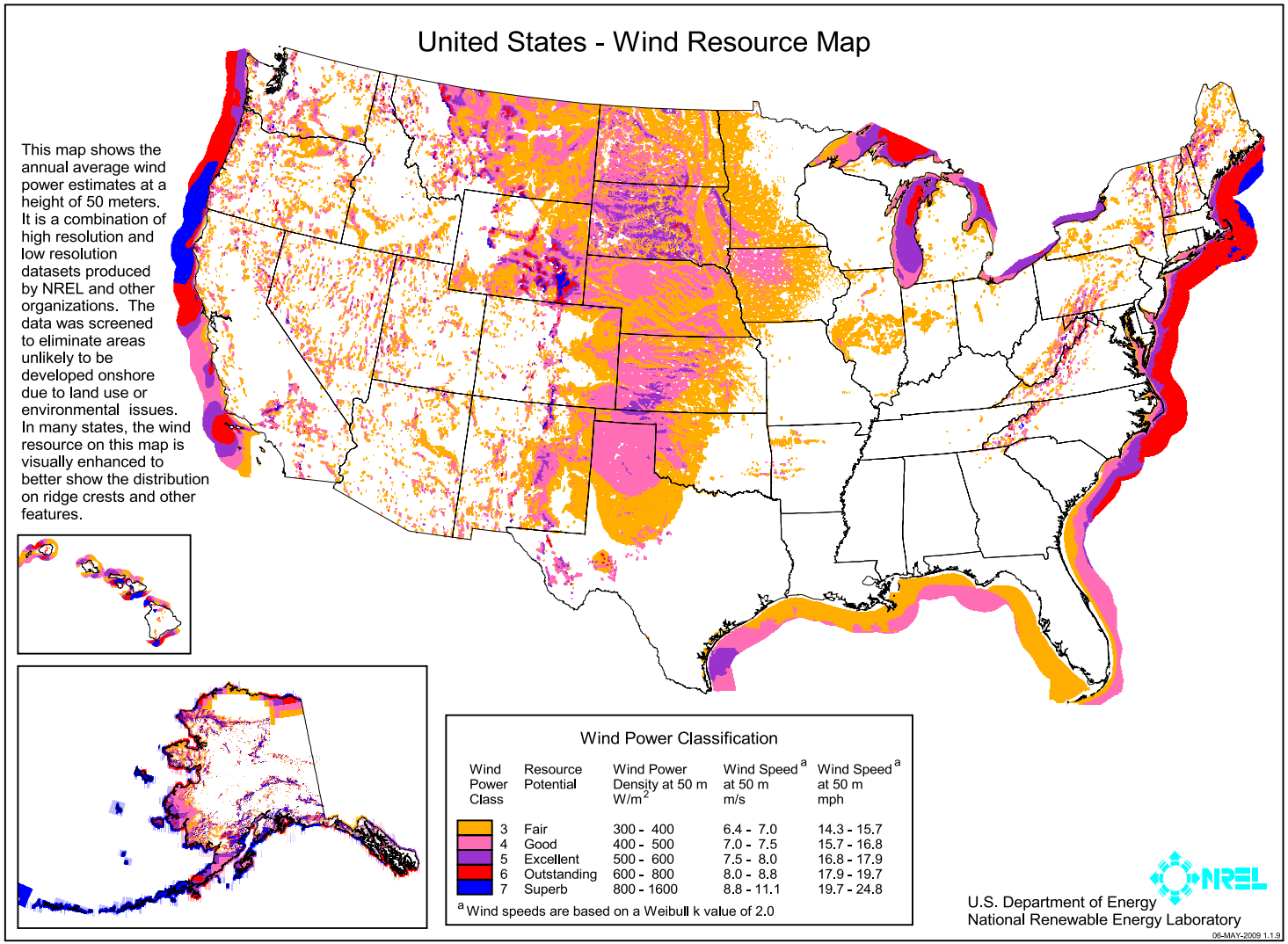
	Surcharge to support rebates	Renewable portfolio standard	Net metering	Renewable inter-connection standard	Laws safe-guarding access to wind, solar resources	Utilities required to offer a green power option
Federal				1		
State	20	38	44	43	44	9
Local	1	2	1		14	
Utility	2	3	18			

Source: Energy Information Administration, DSIRE database

EIA technology cost estimates

	Technology	Size (MW)	Total overnight cost ($2008/kW)	Variable O&M ($2008/MWh)	Fixed O&M ($2008/kW)	2009 Heat rate (BTU/kWh)
	Wind onshore	50	1,966	0	30.98	9,884
	Wind offshore	100	3,937	0	86.92	9,884
	Solar Thermal	100	5,132	0	58.05	9,884
"Renewable"	Photovoltaic	5	6,171	0	11.94	9,884
	Geothermal	50	1,749	0	168.33	32,969
	Landfill gas	30	2,599	0.01	116.8	13,648
	Biomass	80	3,849	6.86	65.89	9,451
	Scrubbed coal new	600	2,223	4.69	28.15	9,200
	Combined cycle	250	984	2.11	12.76	7,196
	Advanced combined cycle	400	968	2.04	11.96	6,752
"Non-renewable"	Combustion turbine	160	685	3.65	12.38	10,788
	Advanced combustion turbine	230	648	3.24	10.77	9,289
	Advanced nuclear	1350	3,820	0.51	92.04	10,488
	Fuel cells	10	5,478	49	5.78	7,930

US wind resources



Generating capacity (MW) by state (2007)

	AK	AL	AR	AZ	CA	CO	CT	DC	DE	FL	GA	HI	IA	ID	IL	IN	KS
All capacity	2163	33230	16462	28730	68522	13735	8561	868	3525	63145	39767	2674	13389	3518	48654	30050	12200
Wind capacity	3	0	0	0	2318	1065	0	0	0	0	0	64	1170	75	740	0	363
Wind percent	0.139	0.000	0.000	0.000	3.383	7.754	0.000	0.000	0.000	0.000	0.000	2.393	8.739	2.132	1.521	0.000	2.975

	KY	LA	MA	MD	ME	MI	MN	MO	MS	MT	NC	ND	NE	NH	NJ	NM	NV
All capacity	23351	30158	15299	13442	4522	33037	13984	22195	18184	5658	29654	5346	7422	4494	20154	7934	11526
Wind capacity	0	0	2	0	42	2	1139	57	0	165	0	383	71	0	8	494	425
Wind percent	0.000	0.000	0.013	0.000	0.929	0.006	8.145	0.257	0.000	2.916	0.000	7.164	0.957	0.000	0.040	6.226	3.687

	NY	OH	OK	OR	PA	RI	SC	SD	TN	TX	UT	VA	VT	WA	WI	WV	WY
All capacity	42769	36707	21901	13802	49176	2022	25078	3127	22962	111098	7521	25270	1090	28720	16976	16986	7036
Wind capacity	0	7	689	886	293	0	0	43	29	4490	0	0	6	1163	53	66	287
Wind percent	0.000	0.019	3.146	6.419	0.596	0.000	0.000	1.375	0.126	4.041	0.000	0.000	0.550	4.049	0.312	0.389	4.079

Source: EPA State Historical Tables

Generating capacity (MW) by state (2008)

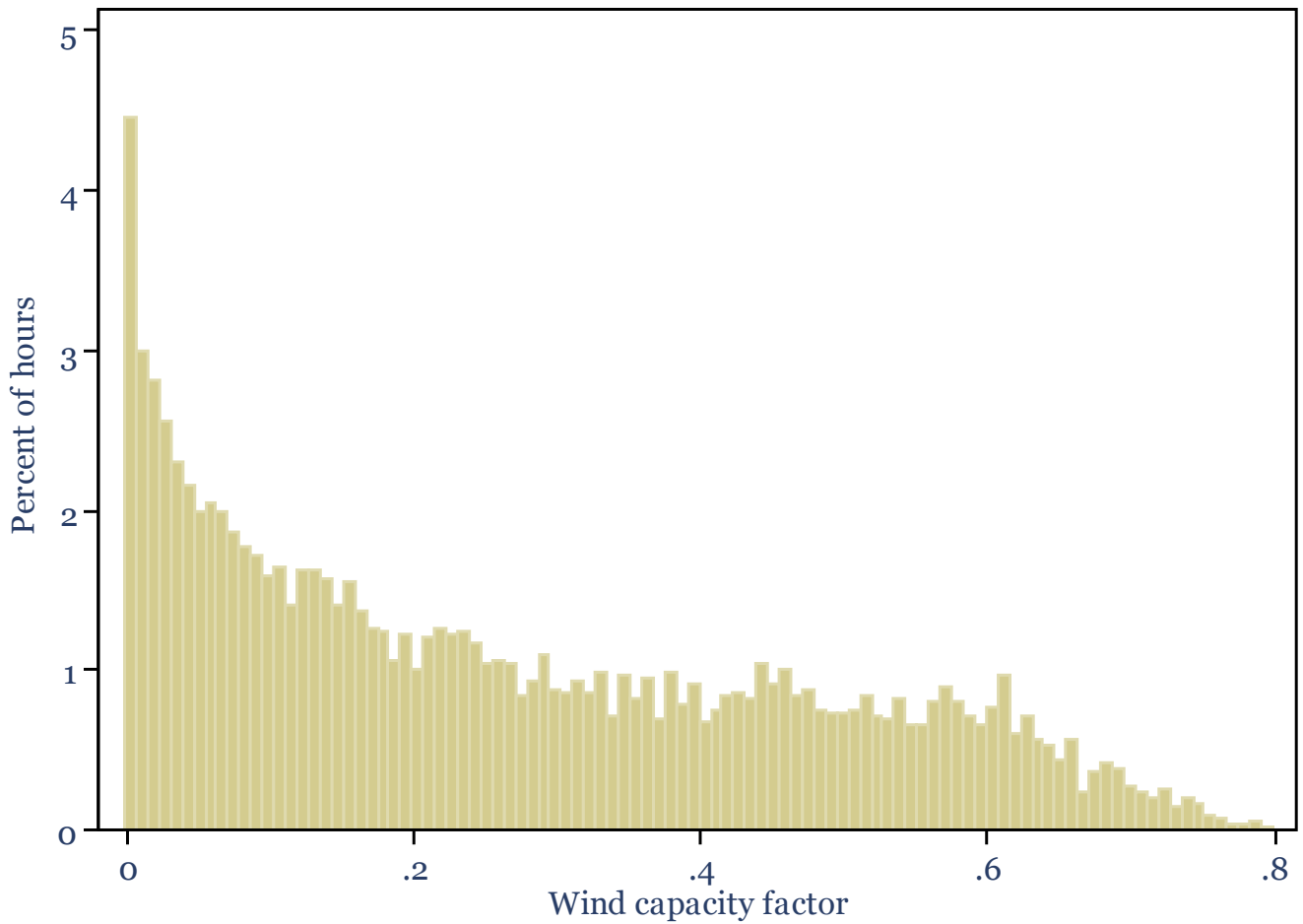
	AK	AL	AR	AZ	CA	CO	CT	DC	DE	FL	GA	HI	IA	ID	IL	IN	KS
All capacity	2190	33936	16461	29034	68695	14178	8604	850	3525	63318	39641	2675	14842	3751	48980	30133	13037
Wind capacity	3	0	0	0	2371	1065	0	0	0	0	0	64	2661	117	962	131	812
Wind percent	0.137	0	0	0	3.451	7.512	0	0	0	0	0	2.393	17.929	3.119	1.964	0.435	6.228

	KY	LA	MA	MD	ME	MI	MN	MO	MS	MT	NC	ND	NE	NH	NJ	NM	NV
All capacity	23617	30153	15225	13548	4529	33164	15678	22320	17826	5756	29647	5804	7421	4518	20136	8794	13024
Wind capacity	0	0	2	0	47	124	1481	163	0	271	0	841	71	24	8	496	0
Wind percent	0	0	0.013	0	1.038	0.374	9.446	0.73	0	4.708	0	14.49	0.957	0.531	0.04	5.64	0

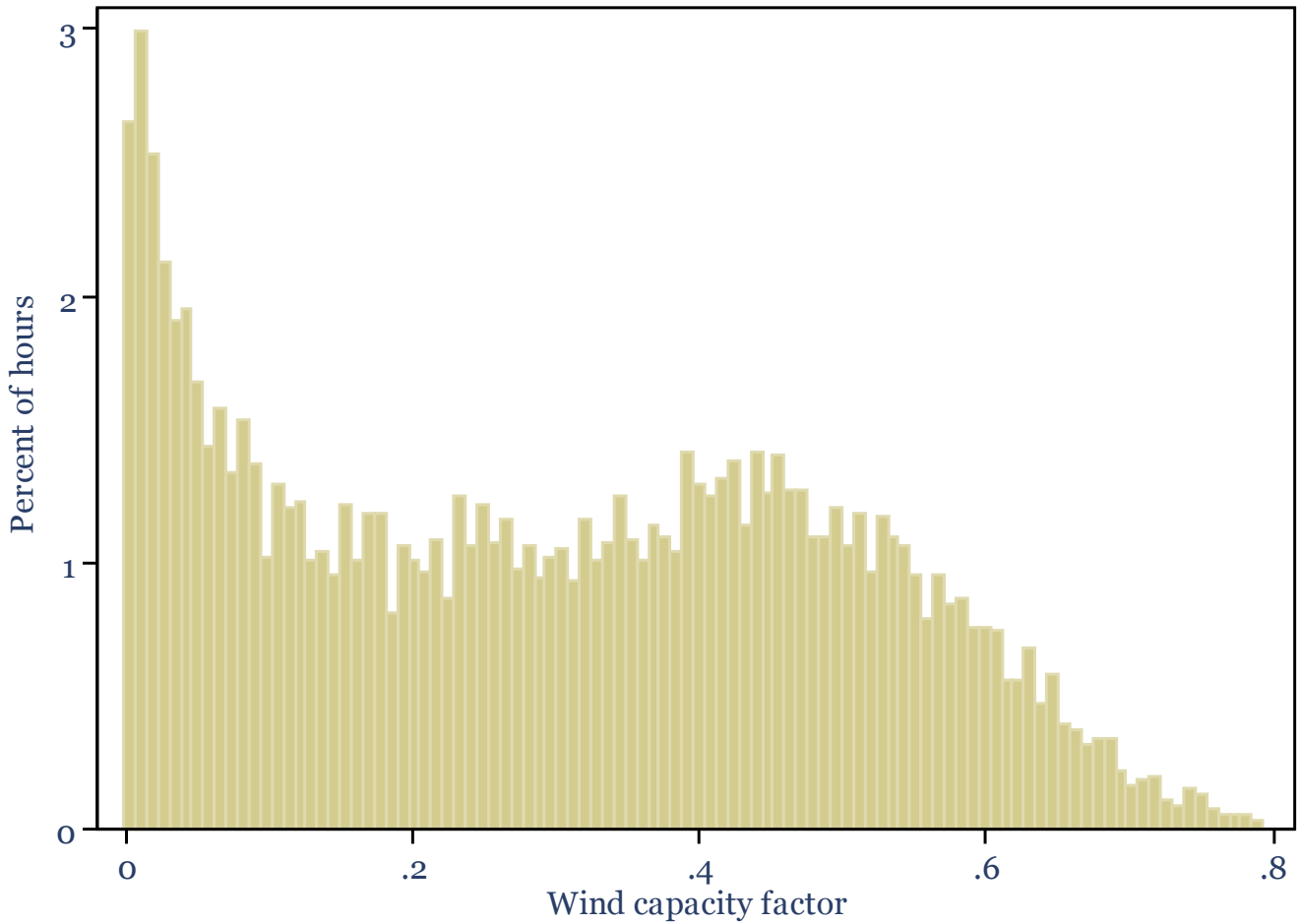
	NY	OH	OK	OR	PA	RI	SC	SD	TN	TX	UT	VA	VT	WA	WI	WV	WY
All capacity	42248	36442	22266	13910	49374	2020	25698	3374	22997	113688	7555	25642	1108	29912	18472	17250	7524
Wind capacity	707	7	708	1068	361	0	0	193	29	7431	19	0	6	1366	365	330	680
Wind percent	1.673	0.019	3.18	7.678	0.731	0	0	5.72	0.126	6.536	0.251	0	0.542	4.567	1.976	1.913	9.038

Source: EPA State Historical Tables

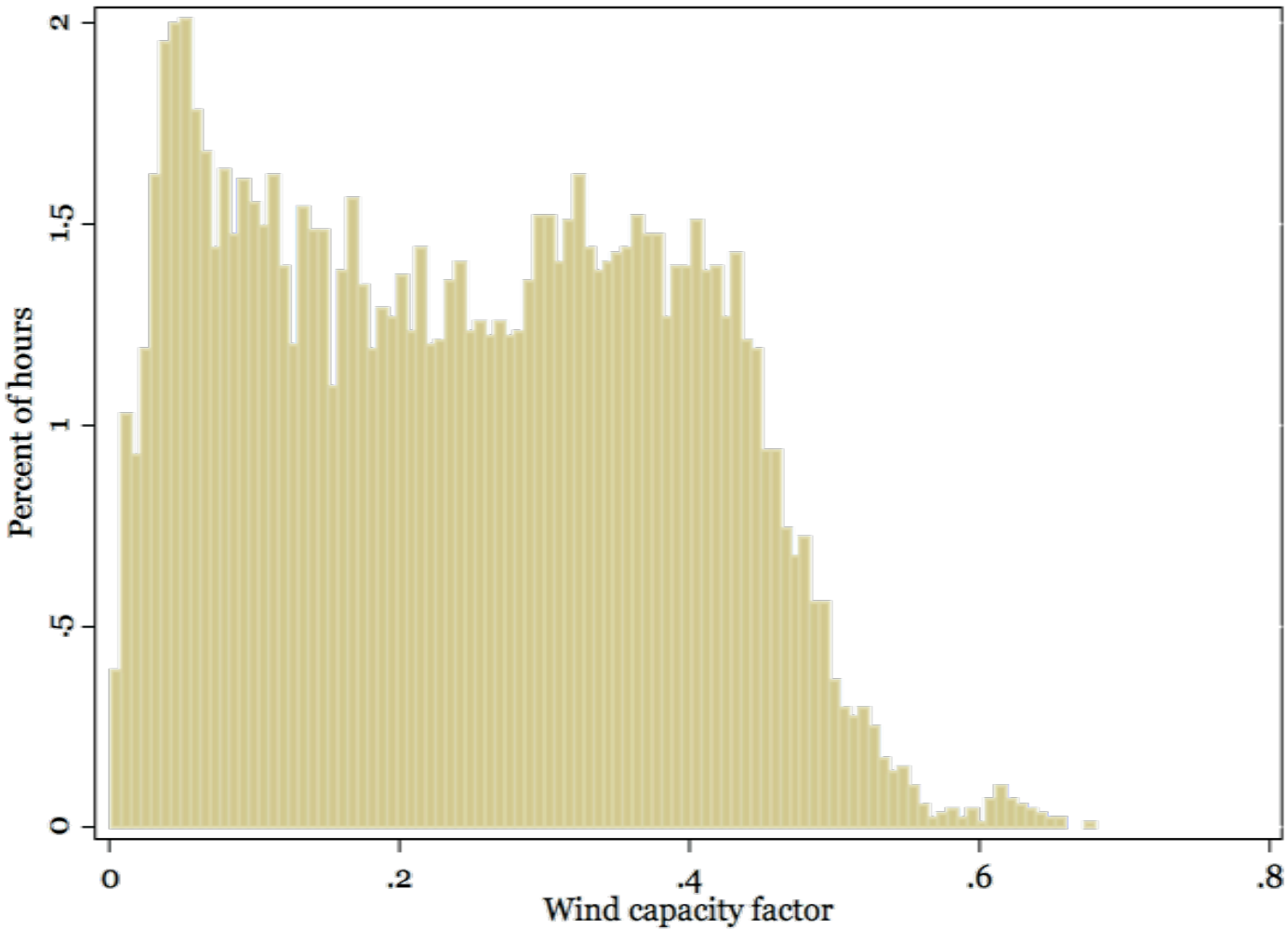
ERCOT wind capacity utilization 2007



ERCOT wind capacity utilization 2008



ERCOT wind capacity utilization 2009



Wind capacity utilization in ERCOT

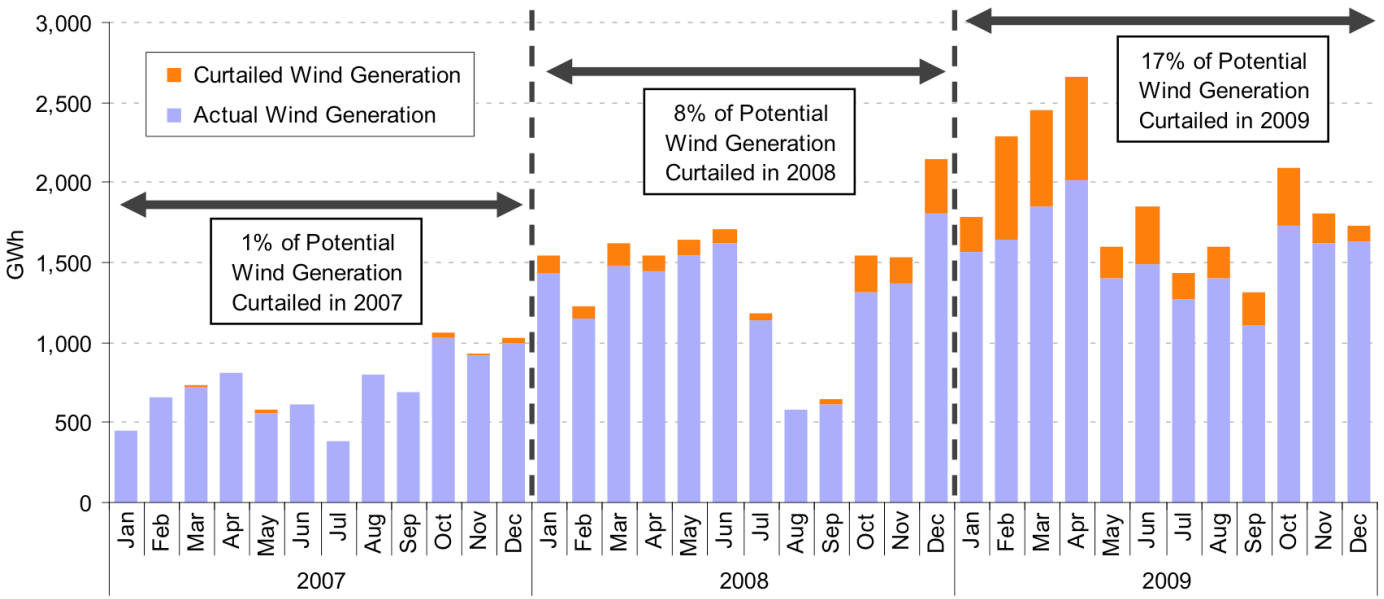
- Analysis based on hourly data from ERCOT for 2007, 2008, 2009
- Summary statistics:

	Mean	Standard deviation	Min	Percentiles 1	5	10	25	50	75	90	95	99	Max
2007	.2630	.2075	-.0013	-.0003	.0078	.0215	.0777	.2175	.4319	.5791	.6350	.7208	.7989
2008	.2966	.2019	-.0016	.0018	.0122	.0286	.1076	.2925	.4613	.5717	.6267	.7103	.7932
2009	.2445	.1441	.0016	0.0122	.0348	.0518	.1147	.2414	.3641	.4368	.4713	.5400	.6793

- Note reduced standard deviation and range in 2009
- *t*-test for mean utilization in 2009 < mean utilization in 2007: 6.85
- *t*-test for mean utilization in 2009 < mean utilization in 2008: 19.68

Curtailment reduced utilization in 2009 relative to 2008

- Augmenting wind output by 8% in 2008 and 17% in 2008, average capacity utilizations would rise to about 0.32 in 2008 and 0.286 in 2009
- This is still a decline of more than 10.6% and likely significant

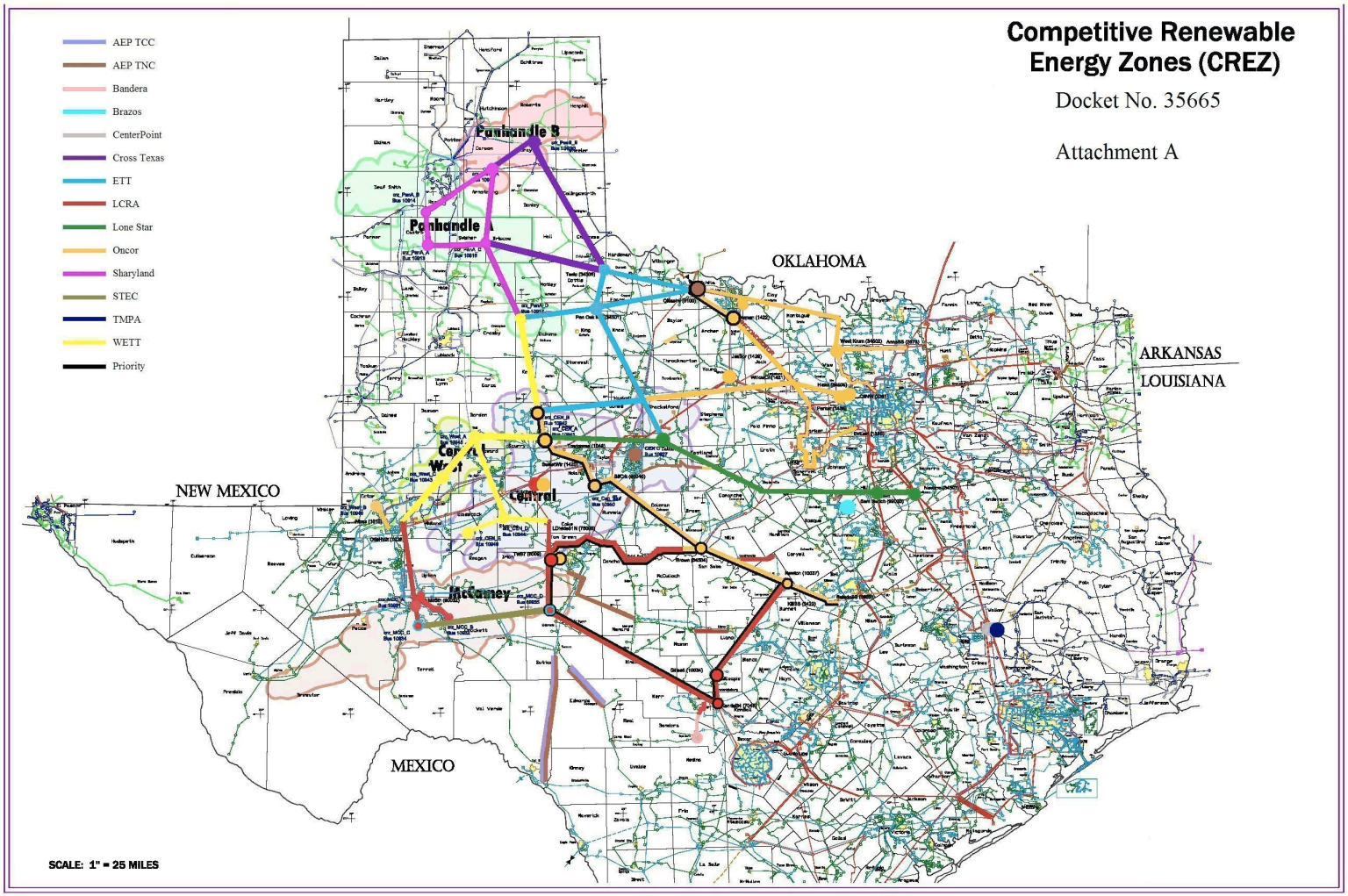


Source: Wiser and Bolinger (2009) based on personal communication from ERCOT

Other reasons for the utilization decline in 2009

- Average wind speed declined in 2009 relative to 2008, but the hourly standard deviations should allow for "normal variation" in wind speeds
  - Can slower wind speeds in 2009 account for a *statistically significant* reduction?
- Economics would predict that the best available sites would be developed first
  - Although new transmission lines, for example, could open up superior sites, on average we might expect the quality of developed sites to decline over time
  - Within ERCOT the average wind speed at the locations of new wind farms declined on average from 2007Q2:2009Q4
  - Coefficient in a regression of average assessed wind speed on quarter was –0.061 with an estimated standard error of 0.022

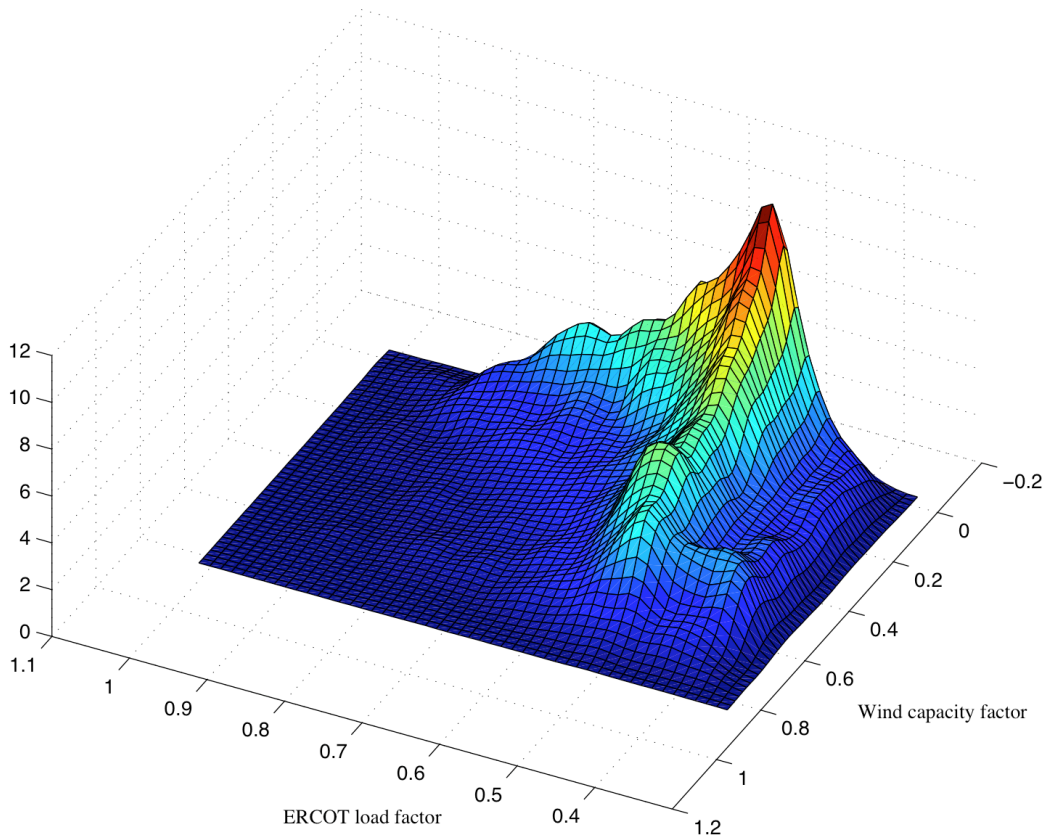
Proposed transmission upgrades in Texas



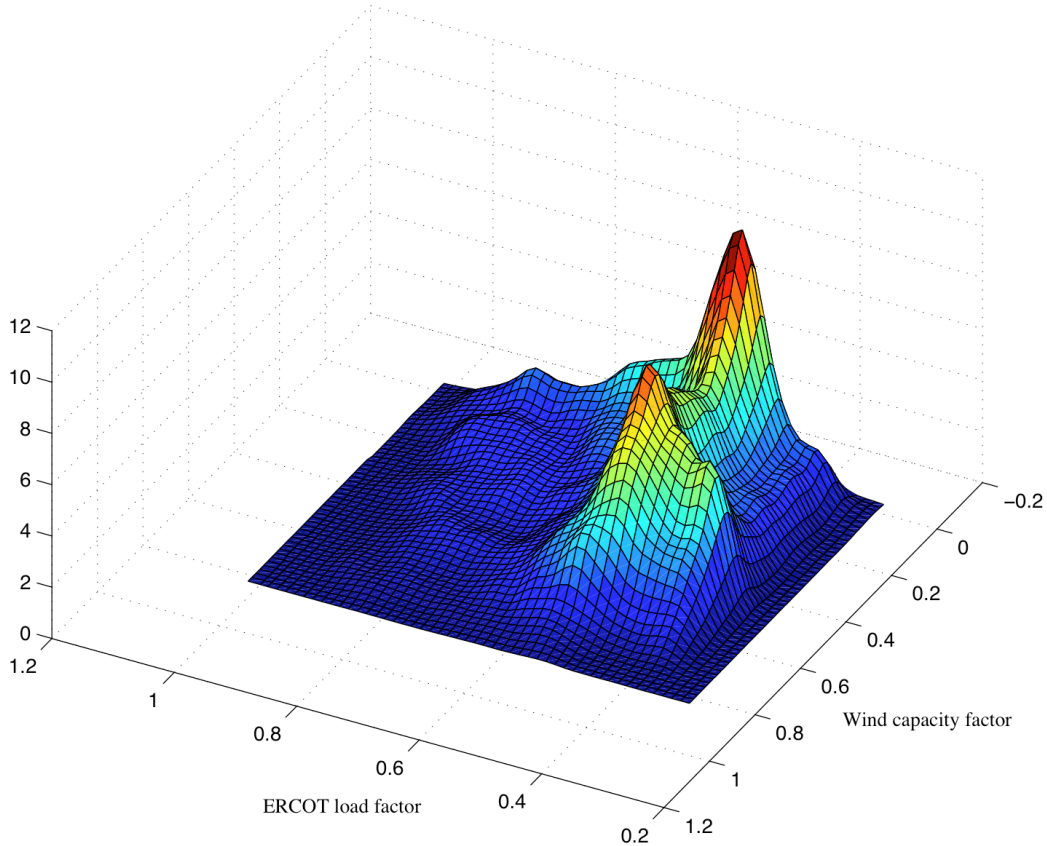
Valuing wind power output

- The average capacity factor of wind determines how much electricity is available for sale to recoup the up-front capital costs
- Assuming no reverse power flow to wind areas, the average capacity factor also determines how much the transmission lines will be used
- However, revenue also depends on the *price* of electricity when the wind is blowing, which is largely determined by the overall system load
- Similarly, the implicit "capacity value" of wind generation depends on how closely wind output tracks overall system load
- To investigate further, we calculated the pattern of wind capacity utilization as a function of the ERCOT system load

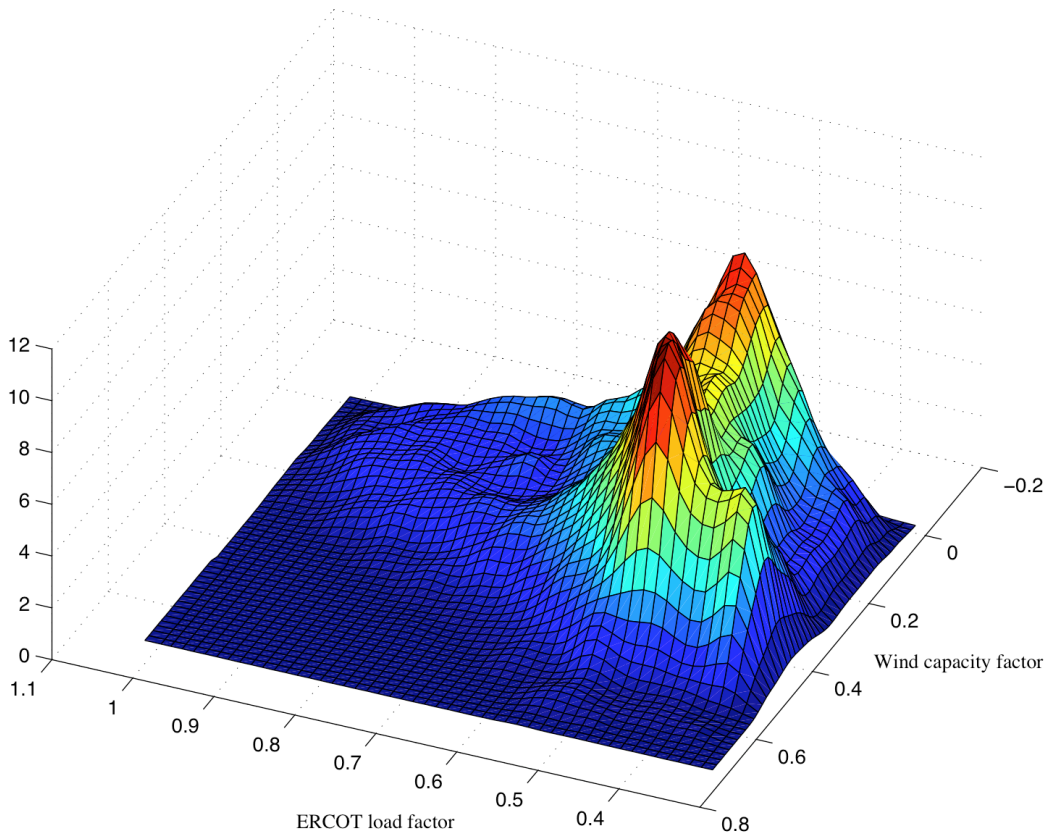
Wind capacity factor and ERCOT load, 2007



Wind capacity factor and ERCOT load, 2008



Wind capacity factor and ERCOT load, 2009



Systematic daily pattern in ERCOT wind output

2007 data

windcapf	Coef.	OPG Std. Err.	z	P>|z|	[95% Conf.	Interval]
windcapf						
_Ihour_1	-.0018536	.0026343	-0.70	0.482	-.0070167	.003309
_Ihour_2	-.009009	.0042213	-2.13	0.033	-.0172826	-.000735
_Ihour_3	-.02072	.0054422	-3.81	0.000	-.0313865	-.010053
_Ihour_4	-.0321016	.0064003	-5.02	0.000	-.0446459	-.019557
_Ihour_5	-.0449911	.0072219	-6.23	0.000	-.0591458	-.030836
_Ihour_6	-.0557725	.0079092	-7.05	0.000	-.0712743	-.040270
_Ihour_7	-.0718472	.0084013	-8.55	0.000	-.0883135	-.055380
_Ihour_8	-.0895515	.0086963	-10.30	0.000	-.1065959	-.072507
_Ihour_9	-.1028928	.0088724	-11.60	0.000	-.1202823	-.085503
_Ihour_10	-.1127387	.0089716	-12.57	0.000	-.1303227	-.095154
_Ihour_11	-.1234337	.0090276	-13.67	0.000	-.1411275	-.105739
_Ihour_12	-.1309192	.0090475	-14.47	0.000	-.1486519	-.113186
_Ihour_13	-.1361745	.0090462	-15.05	0.000	-.1539047	-.118444
_Ihour_14	-.139032	.008919	-15.59	0.000	-.156513	-.121551
_Ihour_15	-.1393946	.0086428	-16.13	0.000	-.1563341	-.12245
_Ihour_16	-.1365793	.0083455	-16.37	0.000	-.1529361	-.120222
_Ihour_17	-.1326055	.0078521	-16.89	0.000	-.1479954	-.117215
_Ihour_18	-.1286089	.0074018	-17.38	0.000	-.1431162	-.114101
_Ihour_19	-.108529	.0068139	-15.93	0.000	-.121884	-.095173
_Ihour_20	-.0707997	.0060878	-11.63	0.000	-.0827316	-.058867
_Ihour_21	-.0348511	.0050681	-6.88	0.000	-.0447844	-.024917
_Ihour_22	-.0119944	.003941	-3.04	0.002	-.0197187	-.004270
_Ihour_23	.0004864	.0023612	0.21	0.837	-.0041414	.005114
_cons	.3397349	.0150293	22.60	0.000	.310278	.369191
ARMA						
ar						
L1.	1.254581	.0074467	168.47	0.000	1.239985	1.269176
L2.	-.296615	.0068248	-43.46	0.000	-.3099913	-.283238
ma						
L24.	.0570291	.0097662	5.84	0.000	.0378878	.076170
/sigma	.0475944	.0002143	222.09	0.000	.0471743	.048014

2008 data

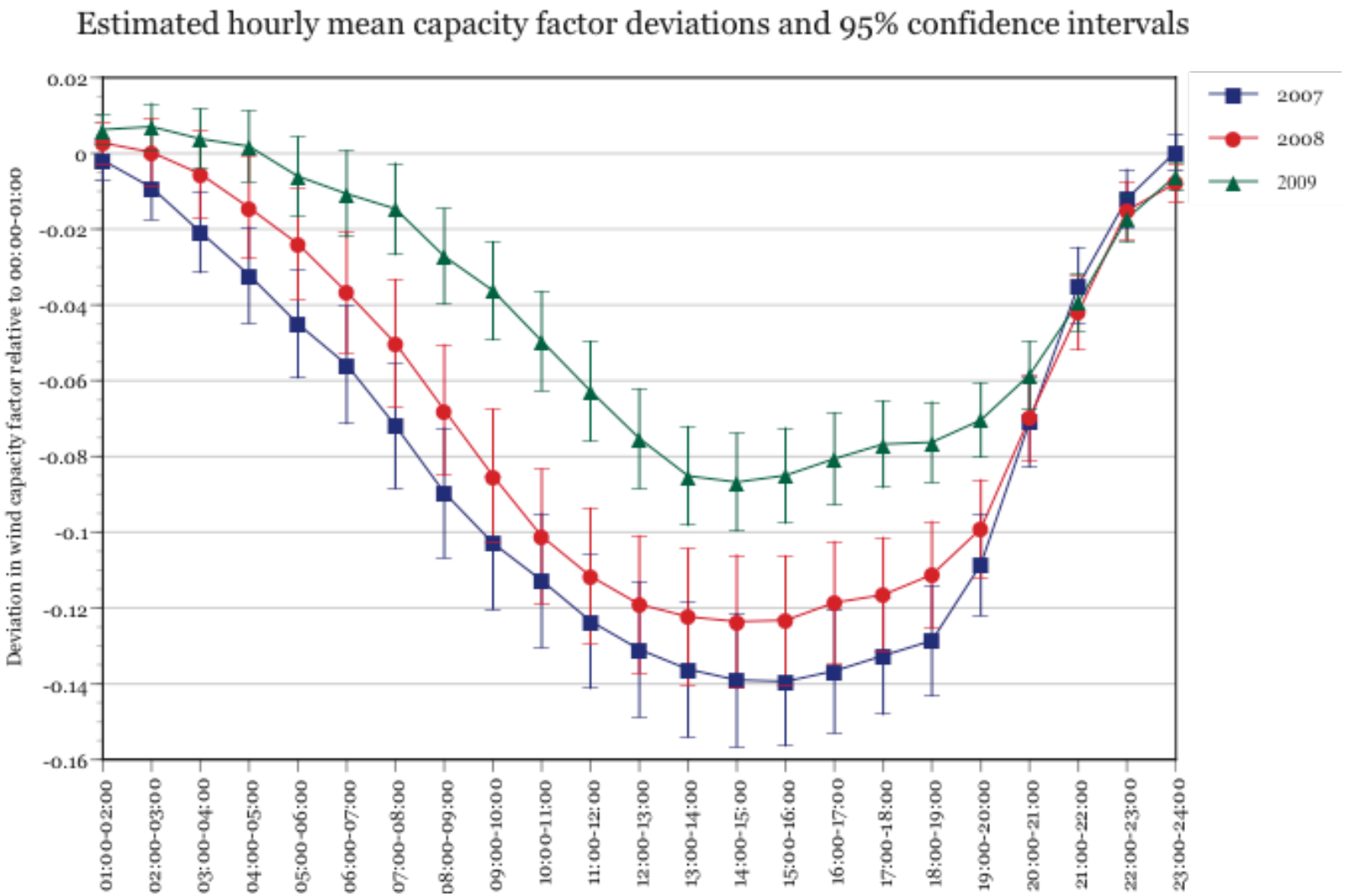
windcapf	Coef.	OPG Std. Err.	z	P>|z|	[95% Conf.	Interval]
windcapf						
_Ihour_1	.0027822	.0028412	0.98	0.327	-.0027864	.008350
_Ihour_2	.0002797	.0045341	0.06	0.951	-.0086069	.009166
_Ihour_3	-.0054225	.0058215	-0.93	0.352	-.0168325	.005987
_Ihour_4	-.0142872	.0068255	-2.09	0.036	-.0276651	-.000909
_Ihour_5	-.0239001	.0075329	-3.17	0.002	-.0386644	-.009135
_Ihour_6	-.0366257	.0081116	-4.52	0.000	-.0525242	-.020727
_Ihour_7	-.0501049	.0085472	-5.86	0.000	-.0668571	-.033352
_Ihour_8	-.0677501	.008781	-7.72	0.000	-.0849605	-.050539
_Ihour_9	-.0851137	.008925	-9.54	0.000	-.1026064	-.06762
_Ihour_10	-.1010894	.0090353	-11.19	0.000	-.1187982	-.083380
_Ihour_11	-.1115758	.0091282	-12.22	0.000	-.1294668	-.093684
_Ihour_12	-.1190387	.0091975	-12.94	0.000	-.1370655	-.101011
_Ihour_13	-.1223346	.0091406	-13.38	0.000	-.1402498	-.104419
_Ihour_14	-.123572	.0089481	-13.81	0.000	-.14111	-.106034
_Ihour_15	-.1232514	.0086293	-14.28	0.000	-.1401645	-.106338
_Ihour_16	-.1186124	.0082107	-14.45	0.000	-.1347051	-.102519
_Ihour_17	-.1165187	.0076779	-15.18	0.000	-.131567	-.101470
_Ihour_18	-.1112412	.0071381	-15.58	0.000	-.1252316	-.097250
_Ihour_19	-.0990561	.0065493	-15.12	0.000	-.1118924	-.086219
_Ihour_20	-.0698331	.0058598	-11.92	0.000	-.0813181	-.058348
_Ihour_21	-.0419448	.0049869	-8.41	0.000	-.0517189	-.032170
_Ihour_22	-.0150872	.003851	-3.92	0.000	-.0226351	-.007539
_Ihour_23	-.0078471	.00254	-3.09	0.002	-.0128254	-.002868
_cons	.361696	.0149454	24.20	0.000	.3324036	.390988
ARMA						
ar						
L1.	1.203352	.0076306	157.70	0.000	1.188396	1.21830
L2.	-.2467094	.0069429	-35.53	0.000	-.2603173	-.233101
ma						
L12.	-.0436322	.0101712	-4.29	0.000	-.0635673	-.023697
L24.	.0482166	.0094283	5.11	0.000	.0297374	.066695
/sigma	.0499354	.0002471	202.11	0.000	.0494512	.050419

Systematic daily pattern in ERCOT wind output

2009 data

windcapf	Coef.	OPG Std. Err.	z	P>|z|	[95% Conf.	Interval]
windcapf						
_Ihour_1	.0062733	.0019676	3.19	0.001	.0024169	.0101297
_Ihour_2	.0070804	.0030652	2.31	0.021	.0010728	.0130881
_Ihour_3	.0038654	.0040067	0.96	0.335	-.0039876	.0117184
_Ihour_4	.001873	.0047215	0.40	0.692	-.0073809	.0111269
_Ihour_5	-.0060739	.0053063	-1.14	0.252	-.0164741	.0043262
_Ihour_6	-.0106403	.005774	-1.84	0.065	-.0219572	.0006765
_Ihour_7	-.0146536	.0061191	-2.39	0.017	-.0266468	-.0026604
_Ihour_8	-.0271477	.0063862	-4.25	0.000	-.0396643	-.014631
_Ihour_9	-.036207	.0065538	-5.52	0.000	-.0490523	-.0233617
_Ihour_10	-.0495123	.0066251	-7.47	0.000	-.0624972	-.0365274
_Ihour_11	-.0627278	.0066511	-9.43	0.000	-.0757638	-.0496919
_Ihour_12	-.0752365	.0066573	-11.30	0.000	-.0882846	-.0621885
_Ihour_13	-.0851194	.0066195	-12.86	0.000	-.0980935	-.0721454
_Ihour_14	-.0867464	.006533	-13.28	0.000	-.0995509	-.0739418
_Ihour_15	-.0850341	.0063865	-13.31	0.000	-.0975515	-.0725167
_Ihour_16	-.0805977	.0061397	-13.13	0.000	-.0926314	-.0685641
_Ihour_17	-.0767598	.0058017	-13.23	0.000	-.0881309	-.0653888
_Ihour_18	-.0762292	.0053877	-14.15	0.000	-.0867888	-.0656695
_Ihour_19	-.0703643	.0049677	-14.16	0.000	-.0801009	-.0606277
_Ihour_20	-.0584854	.0045061	-12.98	0.000	-.0673172	-.0496536
_Ihour_21	-.0392986	.0038416	-10.23	0.000	-.046828	-.0317692
_Ihour_22	-.0171443	.0031007	-5.53	0.000	-.0232215	-.0110671
_Ihour_23	-.0059577	.0019278	-3.09	0.002	-.009736	-.0021794
_cons	.2838462	.0103588	27.40	0.000	.2635434	.3041491
ARMA						
ar						
L1.	1.177857	.0075825	155.34	0.000	1.162995	1.192718
L2.	-.2256977	.007156	-31.54	0.000	-.2397232	-.2116722
ma						
L12.	-.0230617	.0103449	-2.23	0.026	-.0433374	-.002786
L24.	.0569449	.0101987	5.58	0.000	.0369558	.0769339
/sigma	.0375156	.0001875	200.07	0.000	.0371481	.0378832

ERCOT daily deviations in wind utilization



Daily pattern of wind output in ERCOT

- Reduced afternoon decline relative to midnight is consistent with the evidence of reduced correlation across sites
  - Development of coastal wind farms may have increased afternoon output
  - But curtailment, which occurs when wind output is maximum, would also reduce capacity utilization more at night
- Large wind output at night when system demand is low likely contributed to negative wholesale prices in ERCOT
  - Prices were negative in 0.965% of the 15-minute market intervals in 2007, 13.94% of the intervals in 2008 and 8.76% of in 2009
  - The minimum 15-minute price in the ERCOT west zone was –$999.01 in 2007, –$1981.81 in 2008 and –$1000.00 in 2009

Wind capacity availability at ERCOT peak

- Probability distributions of wind capacity availability for the top 5% or top 1% of hourly loads in 2008:

ERCOT load	Mean	Standard deviation	Min	Percentiles 1	5	10	25	50	75	90	95	99	Max
Top 5%	.2183	.1835	.0013	.0031	.0109	.0230	.0720	.1664	.3343	.4790	.6129	.7290	.7531
Top 1%	.1441	.1305	.0035	.0035	.0079	.0110	.0448	.1079	.2092	.3735	.4021	.5696	.5696

- Probability distributions of wind capacity availability for the top 5% or top 1% of hourly loads in 2009:

ERCOT load	Mean	Standard deviation	Min	Percentiles 1	5	10	25	50	75	90	95	99	Max
Top 5%	.1584	.0823	.0177	.0243	.0350	.0492	.0931	.1578	.2172	.2763	.3069	.3365	.3835
Top 1%	.1448	.0708	.0294	.0294	.0350	.0473	.0892	.1478	.1852	.2446	.2705	.3077	.3077

- ERCOT counts 9% of wind capacity as “firm”

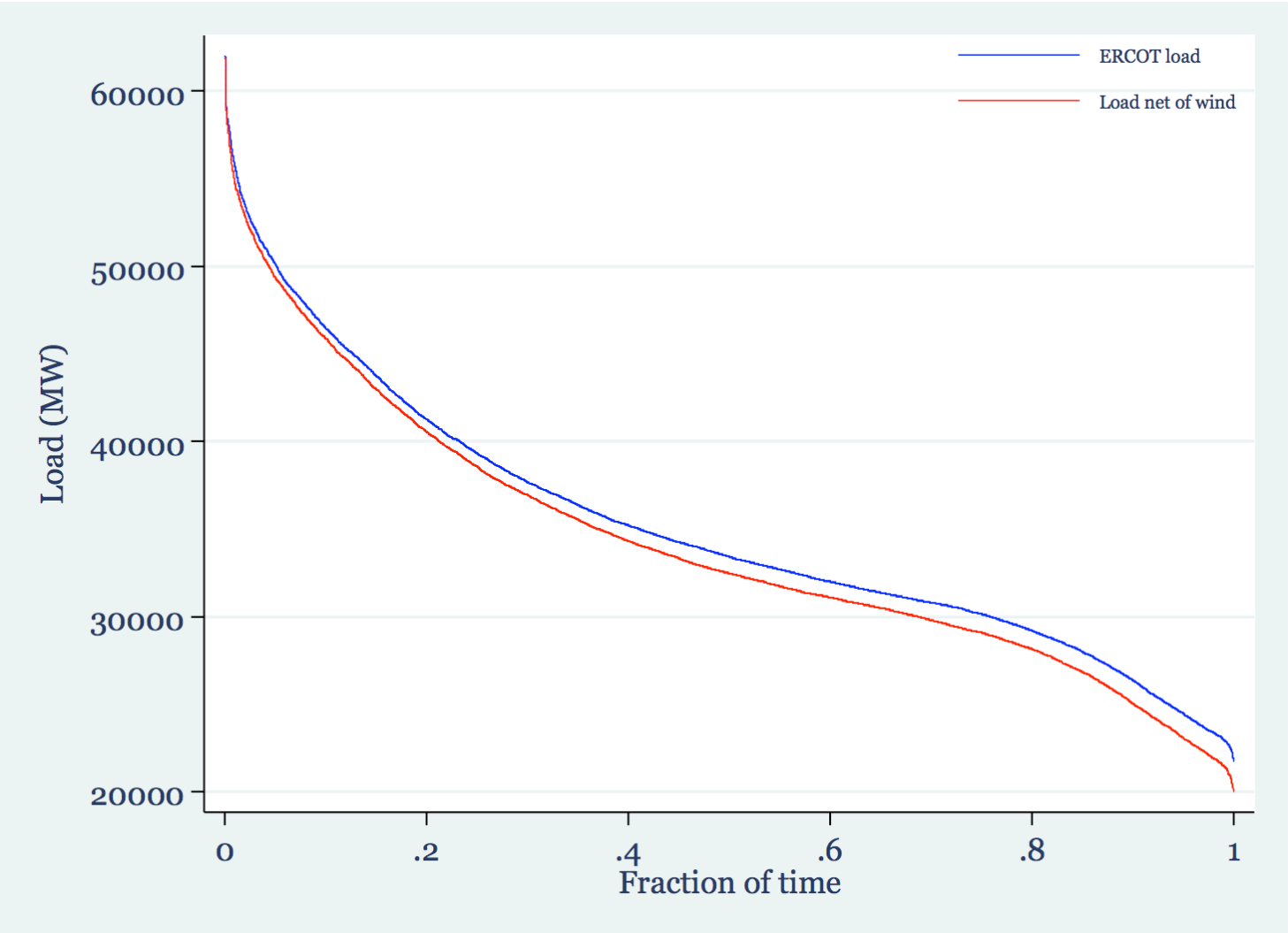
System operation with significant wind

- Ramp-up and ramp-down events can cause particular difficulty for supply security
- Accommodating these requires an inventory of plants that can increase or decrease output quickly and at low cost
- With current plants, wind has caused very expensive cycling of coal-fired plants
  - Not only does cycling reduce operating efficiency; it also increases pollutant output
  - If a thermal plant reaches minimum generation level, it may be cheaper to curtail wind output even though the explicit operating costs for the latter are virtually zero
  - Interruptible supply contracts and real-time pricing may help
- Handling ramp events also requires accurate wind forecasts
  - In the optimal part of a wind generator's operating range, the percentage change in power output is more than 3 times the percentage change in wind speed

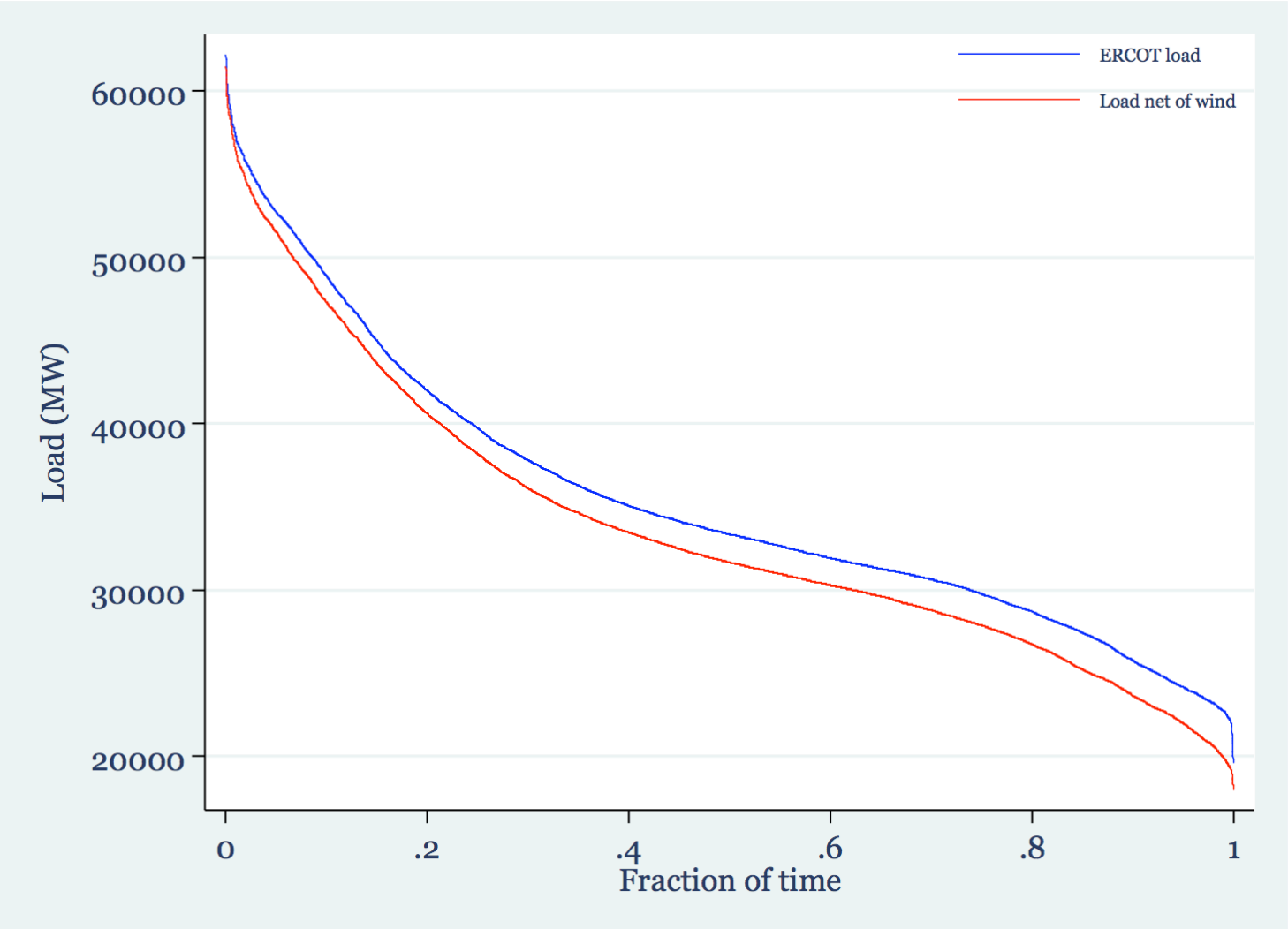
Wind output as negative demand

- Wind (or other exogenous production) can be thought of as "negative demand"
  - Unless the wind output is curtailed, the remaining system has to meet the overall demand *less* the exogenous contribution from wind
  - Wind output typically will increase the variability of demand on the rest of the system
    - In 2008, mean overall ERCOT load = 35365.98MW, std dev = 8357.114, while the mean load *net of wind* = 33650.35MW, std dev = 8639.491
    - In 2009, mean overall ERCOT load = 35073.38MW, std dev = 8763.766, while the mean load *net of wind* = 33022.11MW, std dev = 9179.48
- Thinking of wind output as negative demand is useful for thinking about the implications of increased wind capacity for the likely configuration of the rest of the system – including forecasting the effects on demands for other fuels

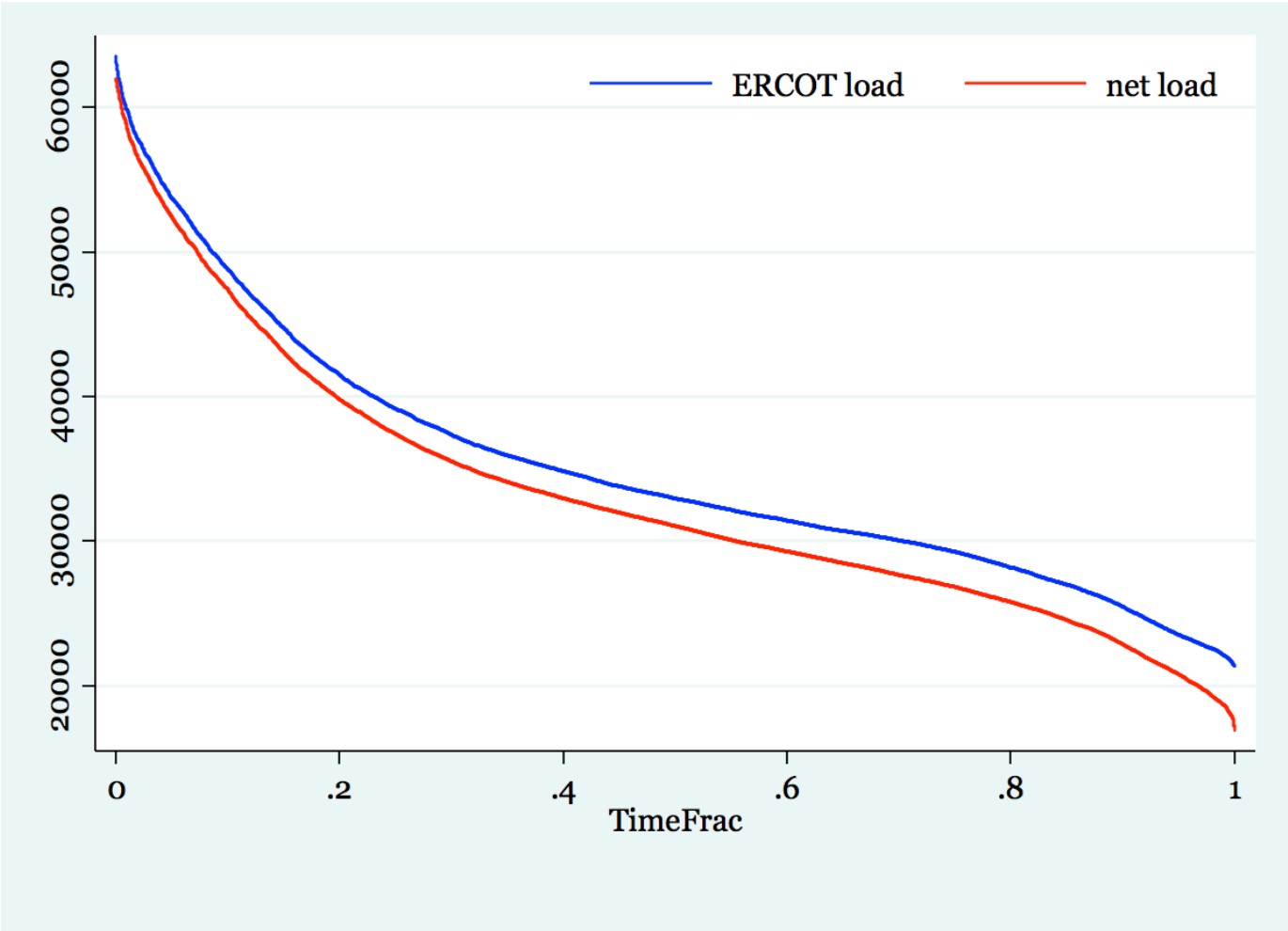
Load, and net load, duration curves, 2007



Load, and net load, duration curves, 2008



Load, and net load, duration curves, 2009



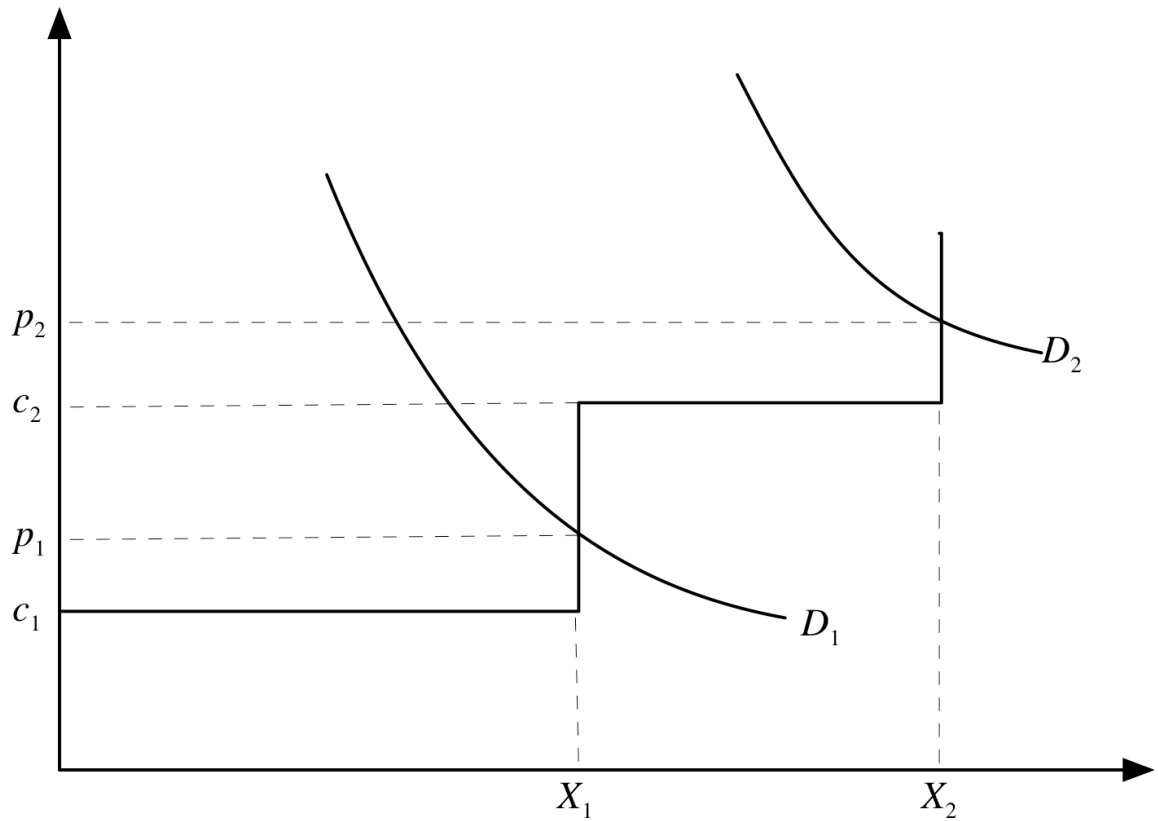
Model of capacity investment

- Assume that any one firm can choose two types of thermal capacity
  - Base load power has a relatively low operating cost per unit of output c_1 but a relatively high capital cost per unit of capacity K_1
  - "Peaking load" (actually, intermediate and peaking) plants have a higher operating cost $c_2 > c_1$ per unit of output but a lower capital cost per unit of capacity $K_2 < K_1$
- Either type of capacity has the same useful life span time of T periods, with the length of each period normalized to 1
- Each period is divided into an off-peak period $[0, t]$ and a peak period $[t, 1]$
  - The off-peak has a lower demand for electricity (*net* of wind) d_1 and a lower wholesale electricity price p_1
  - The peak period has both higher demand $d_2 > d_1$ and a higher wholesale price $p_2 > p_1$
- The relevant risk adjusted continuously compounded interest rate is r
- Assume decisions of each firm are small enough relative to the market that none of them will affect operating or capital costs, or wholesale electricity prices

Key results

- Peak-load plants will not be used in any sub-period unless base-load plants are fully utilized in that sub-period
- Unless the cost parameters, discount rate and time split *t* between periods imply that the difference in capital cost per unit of capacity exactly equals the present value of the saving in operating cost…
  - during peak periods alone, base-load plants will be fully utilized in the base period
  - during both periods, peak-load plants will not be used in the base period
- Unless the cost parameters, discount rate and time split *t* between periods satisfy either of the special conditions given above, base load plants will supply all the output in the base load period and both types of plants will be fully utilized in the peak load period
- Implication: once investment adjusts, wind generation will reduce the demand for base load thermal capacity more than intermediate and peak load
- Lower costs of cycling gas turbines in particular will reinforce this tendency

Competitive equilibrium with peak and off-peak periods

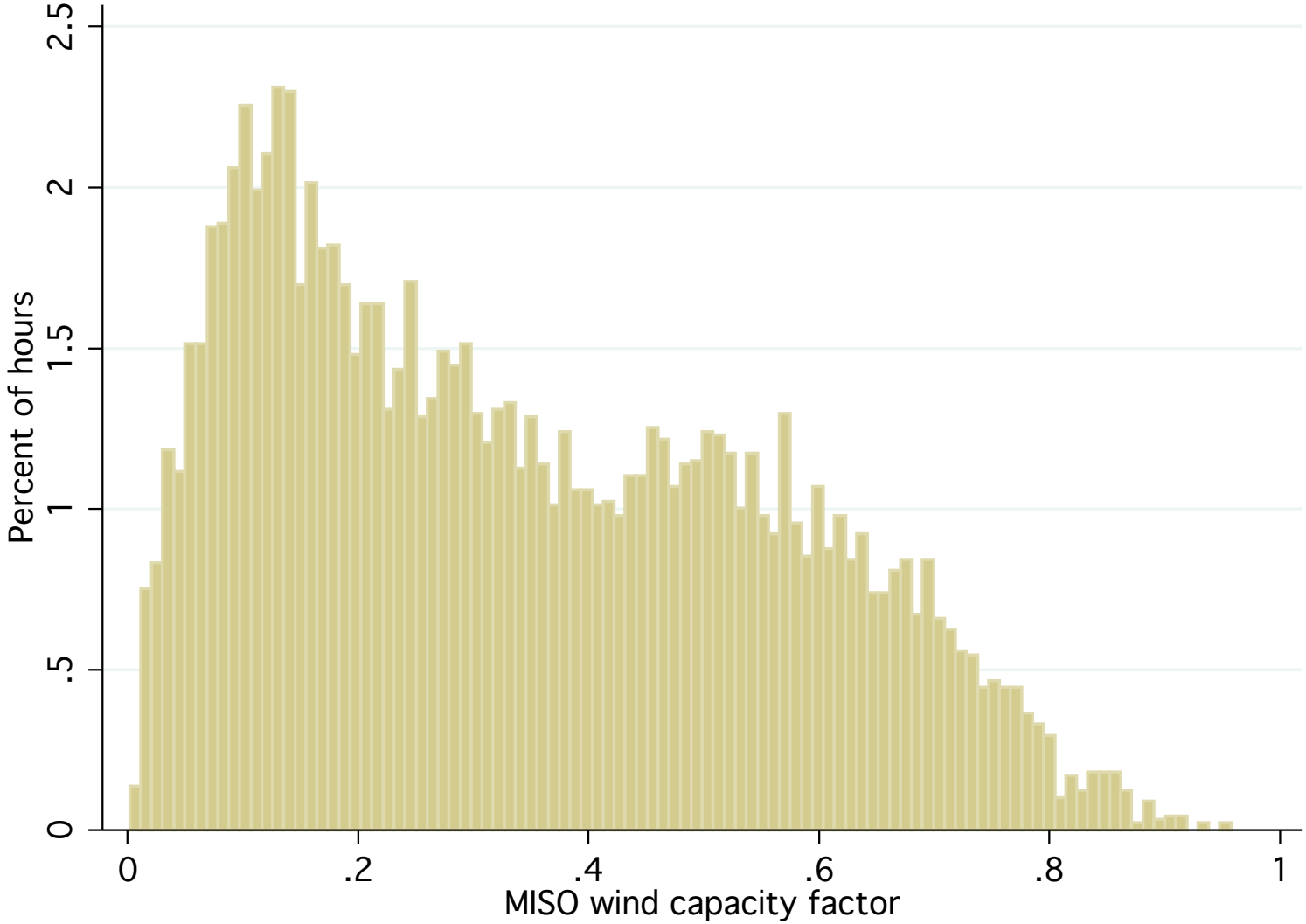


Conclusions

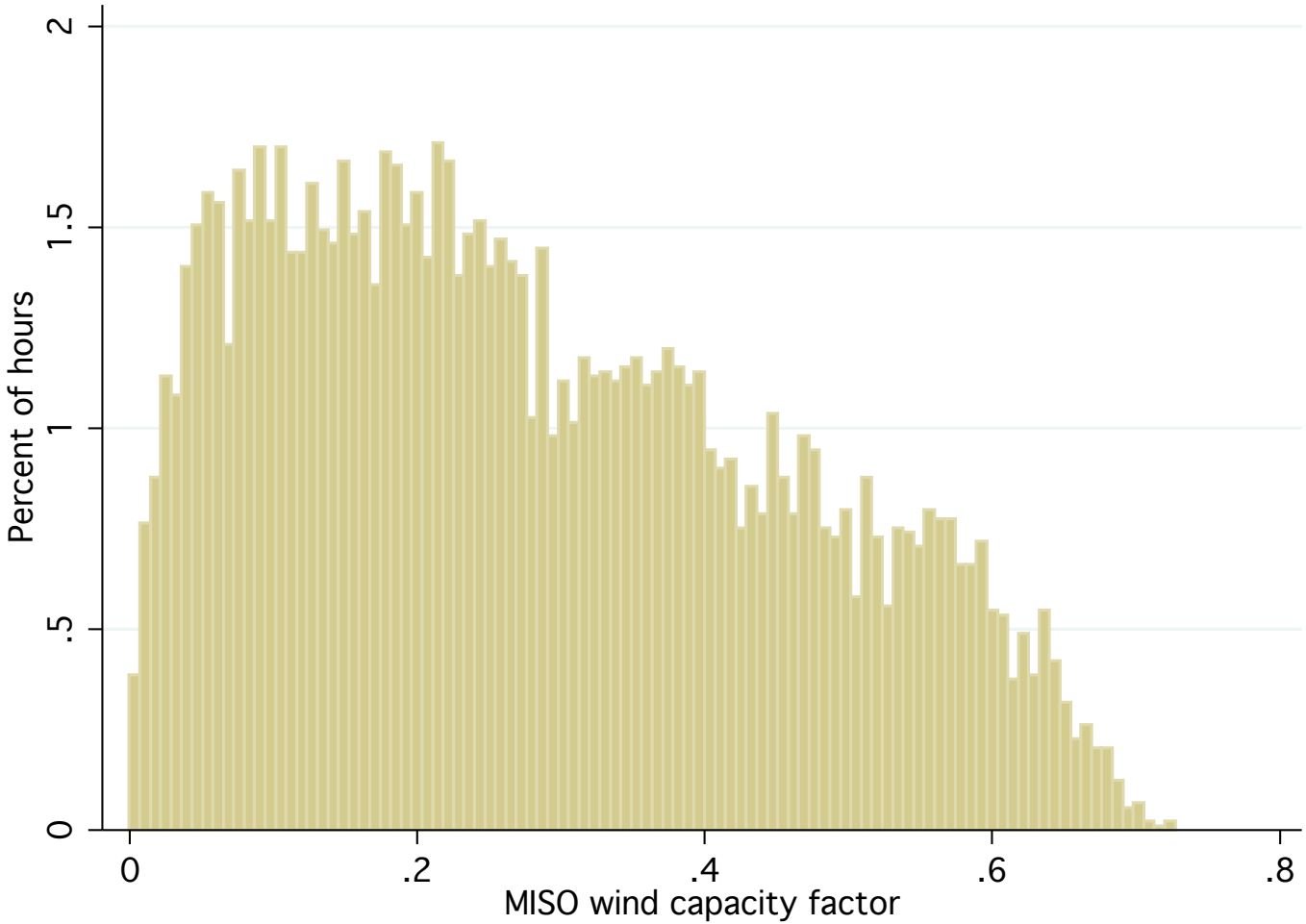
- Policies are likely to increase the proportion of wind generation in ERCOT
- This is likely to impact base load more than intermediate or peaking load
  - It would not appear prudent to allow more than the 9% of wind capacity ERCOT currently allows to count toward the reserve margin
- For system operations, wind places a premium on accurate wind speed forecasts
- For system planning, wind can be thought of as negative demand with other plants required to meet load *net* of wind output
- Wind has offsetting implications for natural gas demand:
  - Reduced base load demand net of wind may favor gas-fired *capacity*
  - Intermittency of wind may reinforce this since gas turbines in particular are less costly to cycle
  - Since combustion turbines are less efficient than CCGT, however, more of these may raise natural gas demand
  - On the other hand, wind generation would reduce the capacity factor of gas plants reducing natural gas demand

Addendum: MISO slides

MISO wind capacity utilization 2008



MISO wind capacity utilization 2009



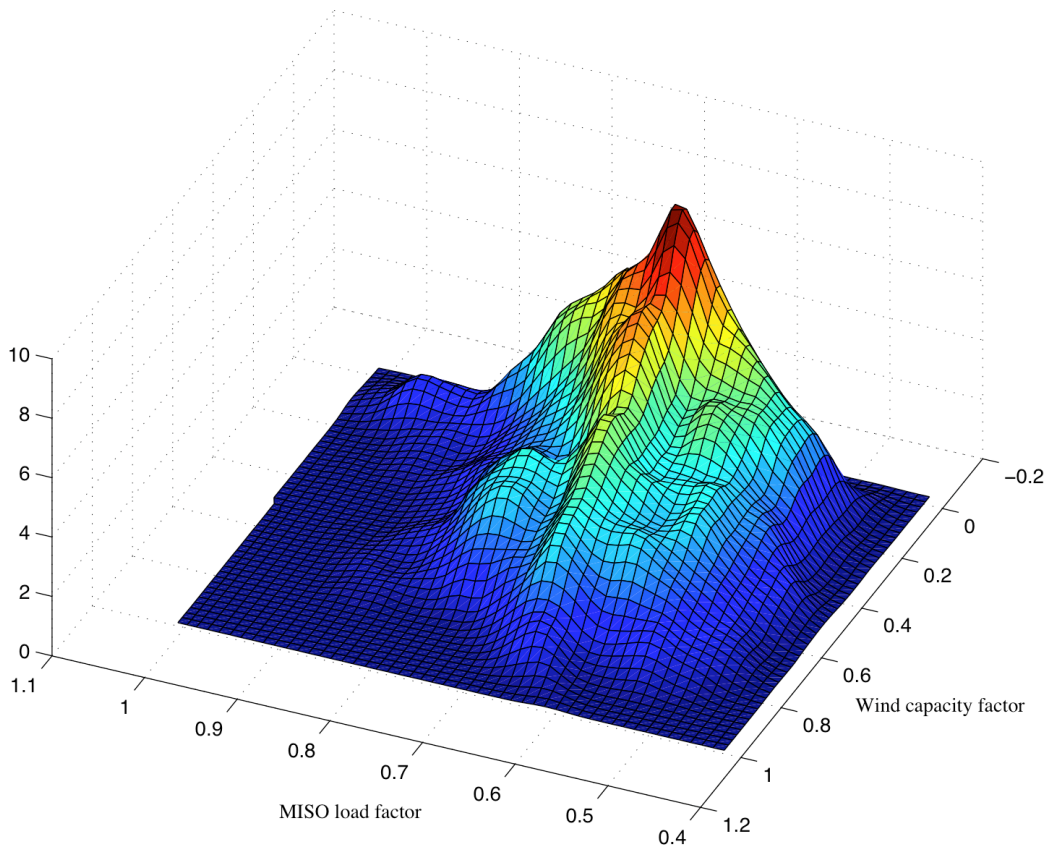
Wind capacity utilization in MISO

- Analysis based on hourly data from MISO for 2008, 2009
- Summary statistics:

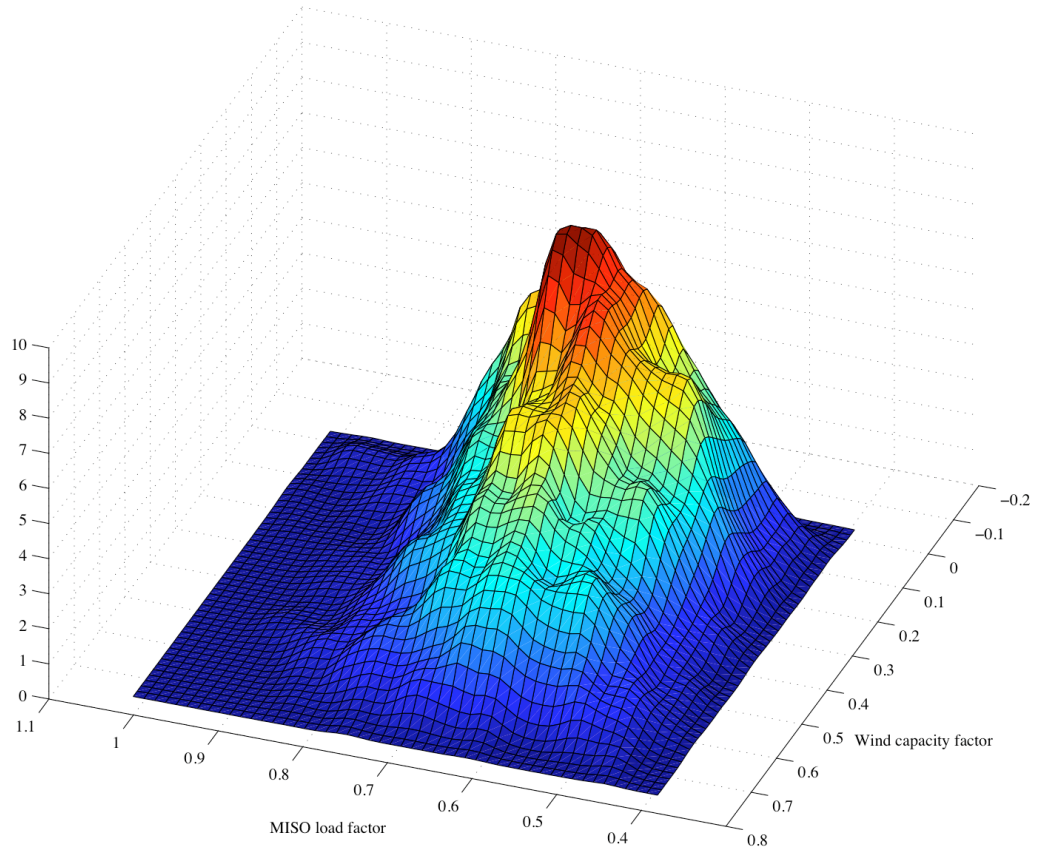
	Mean	Standard deviation	Min	Percentiles 1	5	10	25	50	75	90	95	99	Max
2008	0.3413	0.2152	0.0020	0.0220	0.0561	0.0840	0.1521	0.3039	0.5123	0.6578	0.7221	0.8280	0.9576
2009	0.2806	0.1746	-0.0005	0.0129	0.0398	0.0636	0.1349	0.2539	0.4095	0.5445	0.5941	0.6600	0.7272

- Again note the reduced mean, standard deviation and range in 2009
- *t*-test for mean utilization in 2009 < mean utilization in 2008: 20.52

Wind capacity factor and MISO load, 2008



Wind capacity factor and MISO load, 2009



Systematic daily pattern in MISO wind output

2008 data

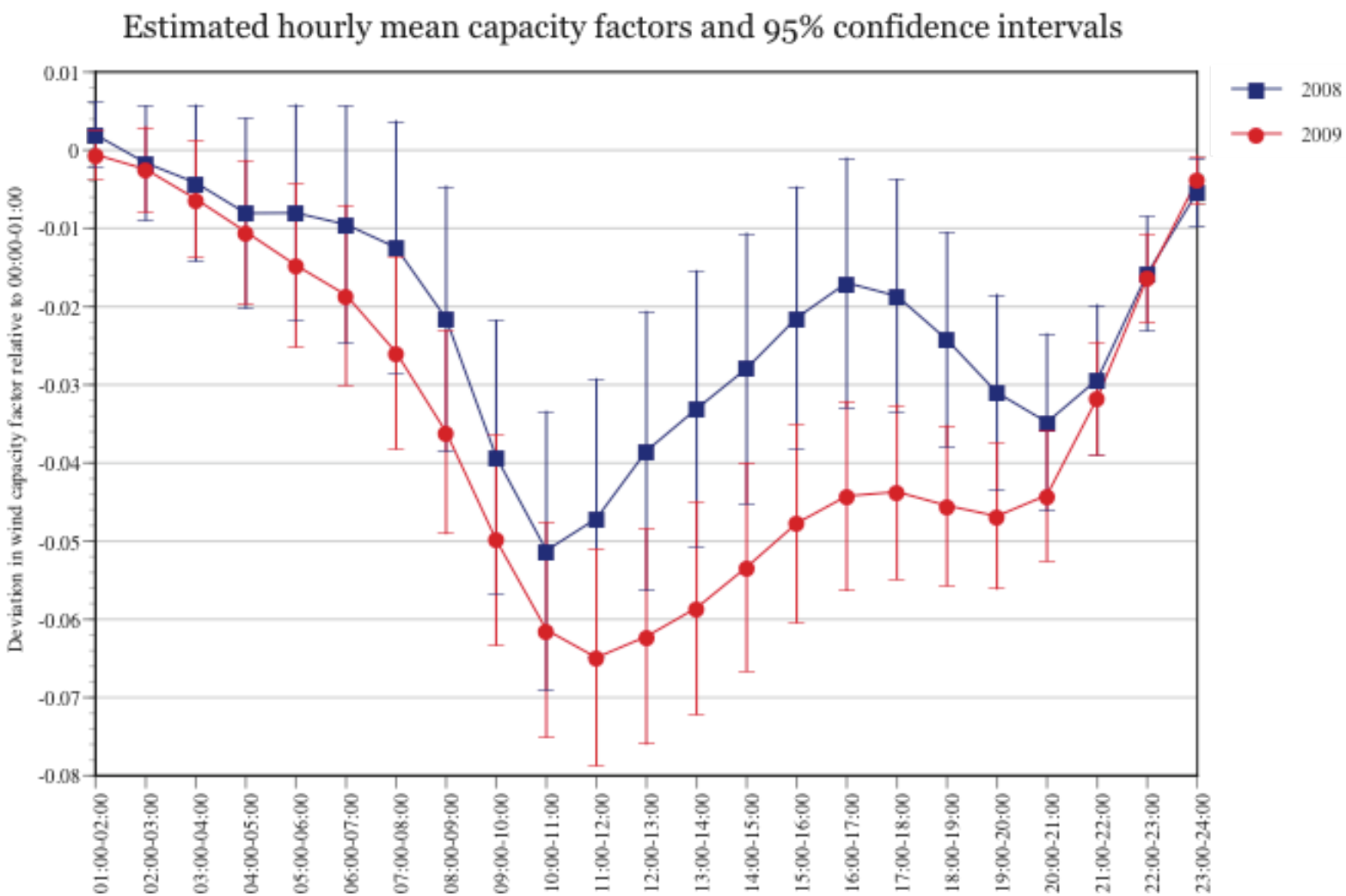
wind_lf	Coef.	OPG Std. Err.	z	P>|z|	[95% Conf.	Interval]
wind_lf						
_Ihour_1	.001984	.002126	0.93	0.351	-.0021829	.0061509
_Ihour_2	-.0016285	.0037099	-0.44	0.661	-.0088998	.0056428
_Ihour_3	-.0041615	.005059	-0.82	0.411	-.0140769	.0057539
_Ihour_4	-.0080453	.0061676	-1.30	0.192	-.0201336	.0040429
_Ihour_5	-.008031	.0070417	-1.14	0.254	-.0218323	.0057704
_Ihour_6	-.0094962	.0077171	-1.23	0.218	-.0246214	.005629
_Ihour_7	-.012427	.0082327	-1.51	0.131	-.0285628	.0037088
_Ihour_8	-.0215346	.0086197	-2.50	0.012	-.0384288	-.0046403
_Ihour_9	-.0392264	.0088927	-4.41	0.000	-.0566557	-.0217971
_Ihour_10	-.0512045	.0090533	-5.66	0.000	-.0689486	-.0334603
_Ihour_11	-.0471143	.009108	-5.17	0.000	-.0649656	-.029263
_Ihour_12	-.0384465	.0090779	-4.24	0.000	-.0562389	-.0206542
_Ihour_13	-.0330773	.0089905	-3.68	0.000	-.0506984	-.0154561
_Ihour_14	-.0278963	.008796	-3.17	0.002	-.0451361	-.0106565
_Ihour_15	-.0214404	.0085308	-2.51	0.012	-.0381604	-.0047203
_Ihour_16	-.0169363	.0081214	-2.09	0.037	-.0328538	-.0010187
_Ihour_17	-.0186309	.0075887	-2.46	0.014	-.0335044	-.0037574
_Ihour_18	-.0242172	.0069781	-3.47	0.001	-.037894	-.0105404
_Ihour_19	-.0309852	.0063726	-4.86	0.000	-.0434752	-.0184951
_Ihour_20	-.0347822	.0057486	-6.05	0.000	-.0460493	-.0235151
_Ihour_21	-.0293441	.0048658	-6.03	0.000	-.038881	-.0198073
_Ihour_22	-.0157807	.0037051	-4.26	0.000	-.0230426	-.0085188
_Ihour_23	-.0053569	.0021706	-2.47	0.014	-.0096113	-.0011026
_cons	.3629932	.0164574	22.06	0.000	.3307372	.3952491
ARMA						
ar						
L1.	1.517765	.0069326	218.93	0.000	1.504177	1.531352
L2.	-.5431038	.006636	-81.84	0.000	-.5561101	-.5300975
ma						
L12.	.0083736	.0094129	0.89	0.374	-.0100754	.0268226
L24.	.0894375	.0095411	9.37	0.000	.0707373	.1081376
/sigma	.0317296	.0001622	195.58	0.000	.0314116	.0320475

Systematic daily pattern in MISO wind output

2009 data

wind_lf	Coef.	OPG Std. Err.	z	P>|z|	[95% Conf.	Interval]
wind_lf						
_Ihour_1	-.0005419	.0015545	-0.35	0.727	-.0035888	.0025049
_Ihour_2	-.0024395	.0027492	-0.89	0.375	-.0078278	.0029488
_Ihour_3	-.0062231	.0037929	-1.64	0.101	-.013657	.0012109
_Ihour_4	-.0104371	.0046443	-2.25	0.025	-.0195397	-.0013345
_Ihour_5	-.0146929	.0053061	-2.77	0.006	-.0250927	-.0042932
_Ihour_6	-.0185131	.005841	-3.17	0.002	-.0299613	-.0070649
_Ihour_7	-.0258427	.0062701	-4.12	0.000	-.0381319	-.0135536
_Ihour_8	-.0360368	.0066096	-5.45	0.000	-.0489914	-.0230823
_Ihour_9	-.049844	.0068407	-7.29	0.000	-.0632515	-.0364364
_Ihour_10	-.0613471	.006976	-8.79	0.000	-.0750197	-.0476744
_Ihour_11	-.0648777	.0070329	-9.22	0.000	-.078662	-.0510935
_Ihour_12	-.062211	.0069947	-8.89	0.000	-.0759203	-.0485017
_Ihour_13	-.0585171	.0069238	-8.45	0.000	-.0720874	-.0449467
_Ihour_14	-.0533089	.0067522	-7.90	0.000	-.066543	-.0400748
_Ihour_15	-.0477212	.0064475	-7.40	0.000	-.060358	-.0350843
_Ihour_16	-.0442312	.0061406	-7.20	0.000	-.0562665	-.0321959
_Ihour_17	-.0436966	.0056634	-7.72	0.000	-.0547967	-.0325965
_Ihour_18	-.045462	.0051985	-8.75	0.000	-.0556509	-.035273
_Ihour_19	-.0468033	.0047322	-9.89	0.000	-.0560782	-.0375284
_Ihour_20	-.0441194	.004263	-10.35	0.000	-.0524747	-.035764
_Ihour_21	-.0317094	.0036551	-8.68	0.000	-.0388732	-.0245456
_Ihour_22	-.0163087	.0028527	-5.72	0.000	-.0218999	-.0107174
_Ihour_23	-.0038206	.001575	-2.43	0.015	-.0069076	-.0007337
_cons	.3142481	.0141593	22.19	0.000	.2864964	.3419999
ARMA						
ar						
L1.	1.534159	.006898	222.41	0.000	1.520639	1.547679
L2.	-.5559453	.0066729	-83.31	0.000	-.569024	-.5428666
ma						
L24.	.0915876	.0094127	9.73	0.000	.073139	.1100363
/sigma	.0232662	.0001158	200.96	0.000	.0230393	.0234931

MISO daily deviations in wind utilization



Wind capacity availability at MISO peak

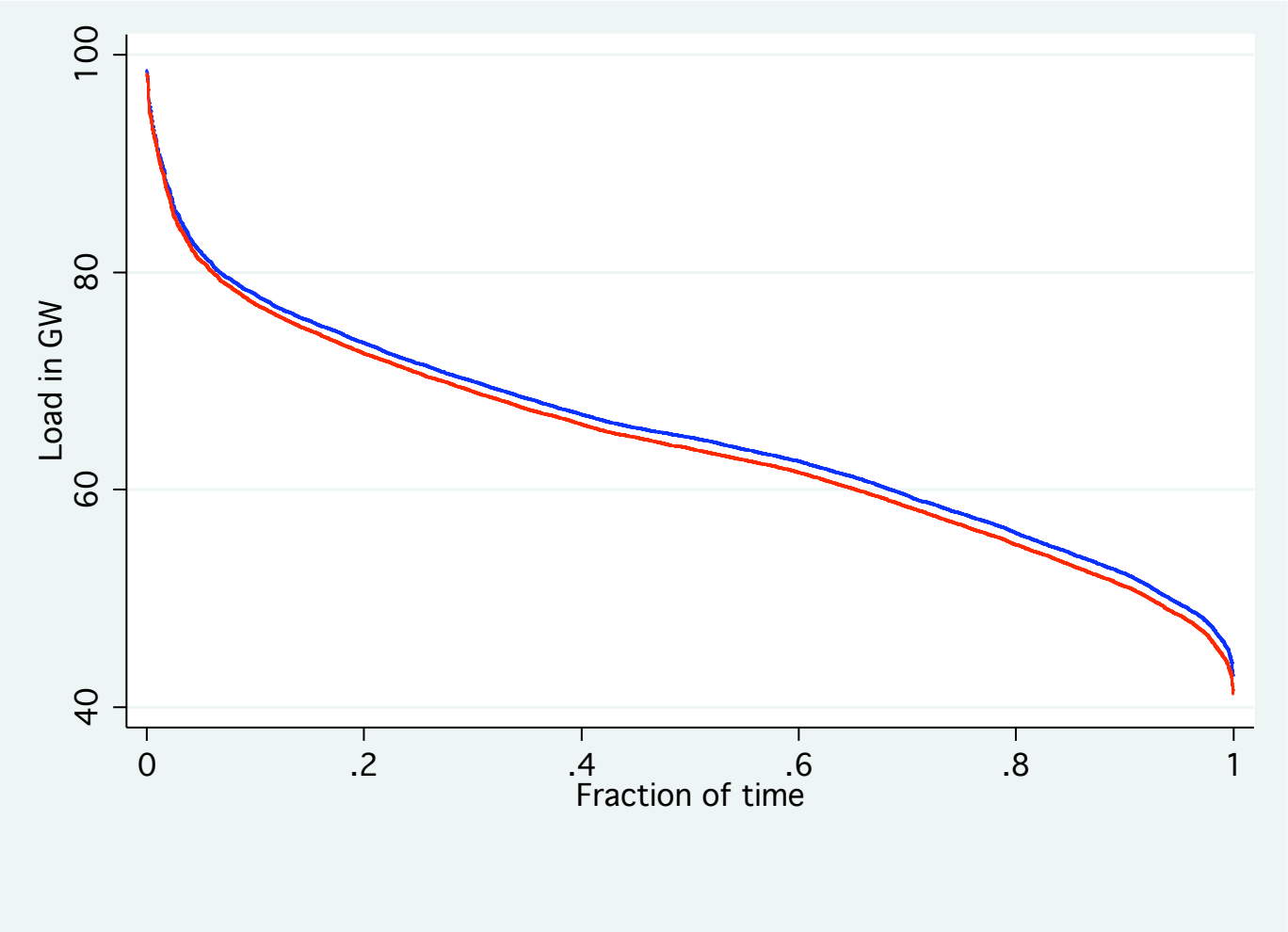
- Probability distributions of wind capacity availability for the top 5% or top 1% of hourly loads in 2008:

ERCOT load	Mean	Standard deviation	Min	Percentiles 1	5	10	25	50	75	90	95	99	Max
Top 5%	.2275	.1924	.0084	.0180	.0389	.0558	.0942	.1444	.3207	.5620	.6666	.7525	.7720
Top 1%	.1289	.0733	.0333	.0333	.0469	.0553	.0913	.1104	.1446	.1923	.3114	.4328	.4328

- Probability distributions of wind capacity availability for the top 5% or top 1% of hourly loads in 2009:

ERCOT load	Mean	Standard deviation	Min	Percentiles 1	5	10	25	50	75	90	95	99	Max
Top 5%	0.2523	0.1861	0.0039	0.0146	0.0312	0.0440	0.0822	0.2178	0.4011	0.5398	0.5779	0.6597	0.6920
Top 1%	0.1935	0.1628	0.0165	0.0165	0.0340	0.0403	0.0548	0.1305	0.2998	0.4921	0.5166	0.5555	0.5555

MISO load, and net load, duration curves, 2008



MISO load, and net load, duration curves, 2009