Sequential Investment Under Uncertainty

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Motivation

- We study sequential investment in electric power generators in PJM.

- What drives the transitions?
  - Planning to Planning (**PLG → PLG**)
  - Planning to Construction (**PLG → CON**)
  - Planning to Indefinitely Postponed (**PLG → IDP**)
  - Planning to Canceled (**PLG → CNL**)

Real Options

- Uncertainty can accelerate or delay investment
  - McDonald & Siegel (1986): With irreversibility, **uncertainty** raises the option value of waiting and **delays investment**.
  - Marmer and Slade (2018): Large-scale projects with long construction lags, **uncertainty can accelerate investment**.

- Electric power generators (unregulated only) are a laboratory to test the theory.

- PJM has rich data + capacity prices.

New Revealed-Preference Measures

- ***Headwinds*** (resistance) & ***Turbulence*** (uncertainty)

- Our results suggest that uncertainty has opposite effects for fossil fuel vs renewables.
  - Higher ***Turbulence*** tends to push ***fossil fuel*** generators from PLG to CON.
  - Higher ***Turbulence*** tends to make ***renewable*** generators remain in PLG.

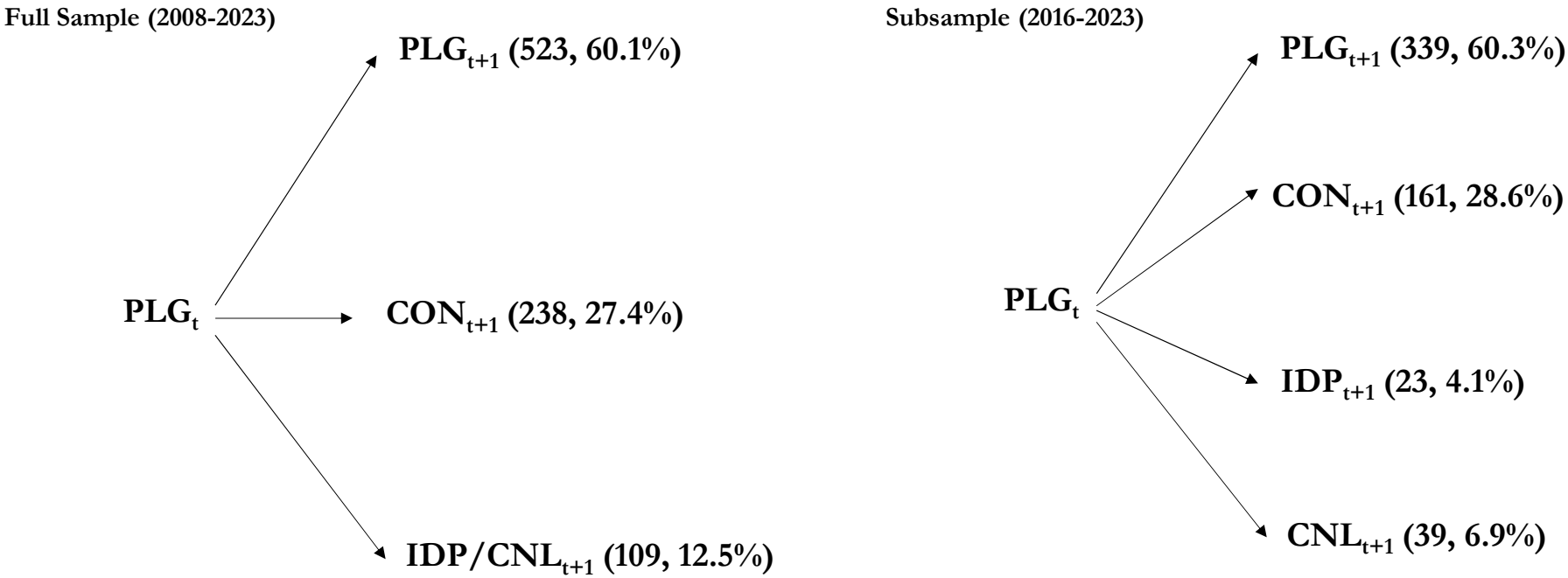
Data Sources

- EIA860
  - Every generator in the US (planned, canceled, existing, retired)
  - Status code
  - Nameplate capacity
  - In-service dates
- PJM
  - RPM (capacity) prices

EIA 860 Status

Stage	Stage Description	EIA Status Code	Status Code Description
PLG	Planning	**P**	Planned, no regulatory approval
PLG	Planning	**L**	Planned, regulatory approvals pending
PLG	Planning	**T**	Planned, regulatory approvals received
CON	Construction	**U**	Planned, under construction, less than 50%
CON	Construction	**V**	Planned, under construction, more than 50%
CON	Construction	**TS**	Planned, construction complete but not in operation
IDP	Indefinitely Postponed/Canceled **(2008-2015)**	**IP**	Indefinitely postposed or no longer in resource plan/Canceled
IDP	Indefinitely Postponed **(2016-2023)**	**IP**	Indefinitely postposed or no longer in resource plan
CNL	Cancelled **(2016-2023)**	**CN**	Cancelled, previously planned

Transitions from the Planning Stage (PLG)



Empirical Specification

- Outcome is transition from PLG in year t to
  - PLG, CON, IDP, or CNL in year t+1
- Multinomial Logit
  - PLG is the base category
- Covariates include
  - Duration in PLG
  - Capacity Prices
  - Nameplate Capacity
  - Group Size
  - *Headwinds* (resistance) & *Turbulence* (uncertainty) indices

Results

- Table 3 presents subsample results (Table 2 is for full sample)
  - Relative Risk Ratios (RRRs)
  - RRR > 1 → higher probability of transition relative to remaining in PLG
  - RRR < 1 → lower probability

- We do not interpret coefficient magnitudes
  - Marginal effects are well behaved

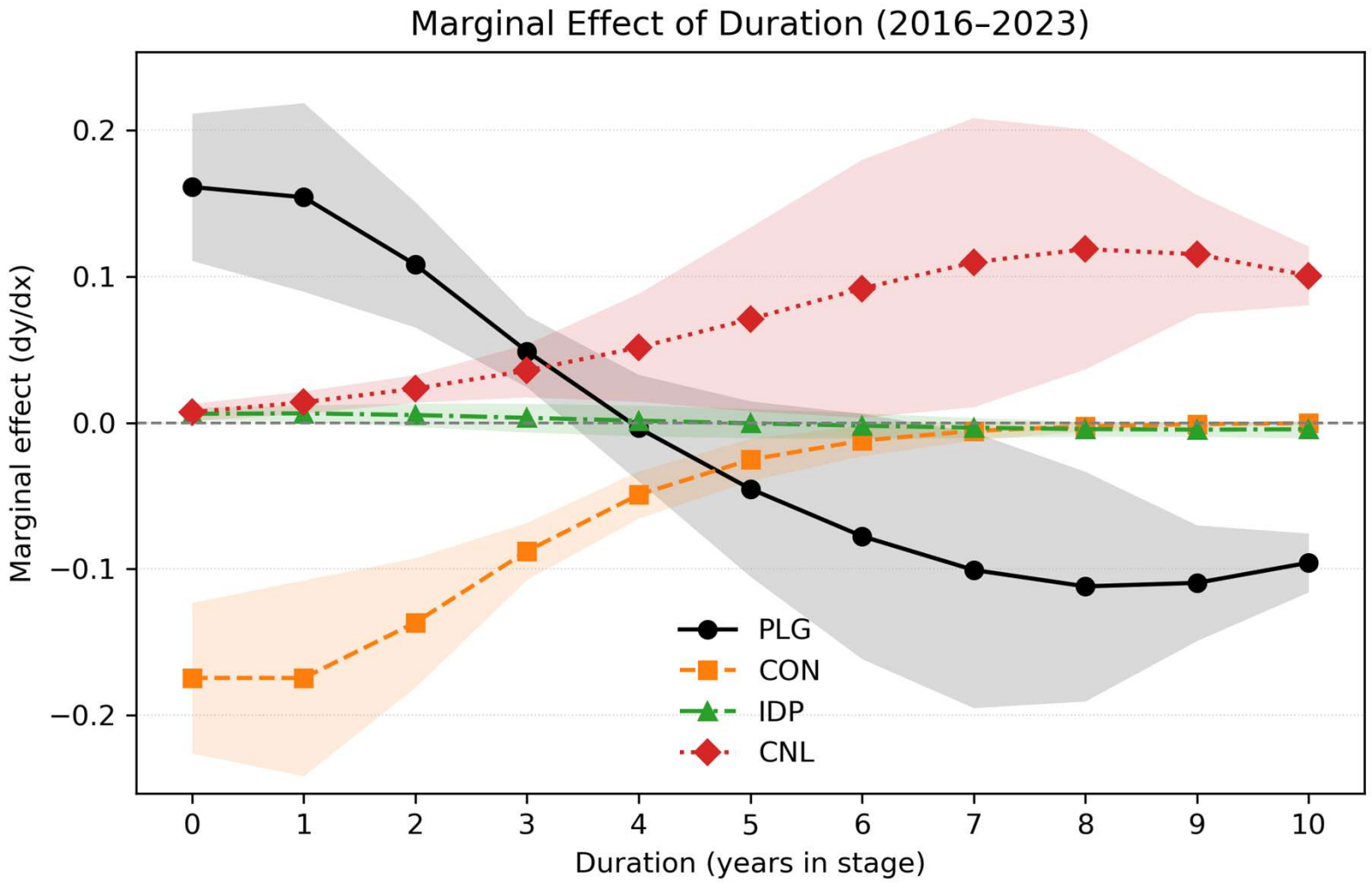
Table 3: Multinomial Logit Regression (2016–2023 Subsample, Unregulated Only). Odds ratios with p-values in parentheses. Base outcome = PLG.

	CON				IDP				CNL			
Variable	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Nameplate	0.986	0.985	0.982	0.985	0.991	0.984	0.987	0.985	0.961	0.953	0.947	0.947
	(0.050)	(0.059)	(0.027)	(0.087)	(0.352)	(0.128)	(0.202)	(0.144)	(0.000)	(0.000)	(0.000)	(0.000)
Duration	0.505	0.510	0.502	0.511	1.103	1.087	1.096	1.068	1.565	1.646	1.617	1.612
	(0.000)	(0.000)	(0.000)	(0.000)	(0.460)	(0.596)	(0.499)	(0.680)	(0.001)	(0.001)	(0.001)	(0.002)
CapPmt	1.025	1.025	1.024	1.031	1.030	1.018	1.028	1.035	1.004	0.998	1.006	1.003
	(0.000)	(0.000)	(0.000)	(0.000)	(0.016)	(0.218)	(0.030)	(0.006)	(0.725)	(0.877)	(0.671)	(0.826)
GroupSize	0.405	0.397	0.375	0.418	1.114	0.976	1.047	1.036	0.492	0.414	0.415	0.399
	(0.002)	(0.002)	(0.002)	(0.004)	(0.563)	(0.910)	(0.820)	(0.863)	(0.000)	(0.000)	(0.000)	(0.000)
Renewable	0.275	0.299	0.881	0.482	0.225	54.786	1.509	14.637	0.065	9.121	30.286	27.335
	(0.026)	(0.178)	(0.878)	(0.402)	(0.013)	(0.346)	(0.792)	(0.425)	(0.000)	(0.236)	(0.144)	(0.257)
ZonePlannedCap	0.989	0.989	0.989	0.988	1.005	1.004	1.005	1.006	0.998	0.998	0.999	0.999
	(0.099)	(0.089)	(0.095)	(0.074)	(0.713)	(0.767)	(0.742)	(0.652)	(0.877)	(0.885)	(0.935)	(0.940)
Headwinds (FF)	—	1.672	—	2.713	—	532.354	—	98.607	—	17.127	—	49.523
		(0.444)		(0.167)		(0.006)		(0.007)		(0.046)		(0.095)
Headwinds (Ren)	—	1.906	—	1.295	—	66.973	—	10.241	—	0.226	—	0.202
		(0.245)		(0.662)		(0.092)		(0.375)		(0.034)		(0.033)
Turbulence (FF)	—	—	2.414	18.151	—	—	4.298	0.647	—	—	13.893	12.667
			(0.066)	(0.037)			(0.020)	(0.892)			(0.043)	(0.187)
Turbulence (Ren)	—	—	1.205	0.109	—	—	1.663	0.002	—	—	0.352	0.333
			(0.597)	(0.119)			(0.471)	(0.056)			(0.012)	(0.715)
Constant	7.715	4.189	2.159	2.109	0.033	0.000	0.003	0.000	0.896	0.032	0.009	0.010
	(0.033)	(0.143)	(0.383)	(0.453)	(0.003)	(0.001)	(0.000)	(0.000)	(0.929)	(0.072)	(0.025)	(0.082)
Observations	562				562				562			
Pseudo R^2	0.1767	0.1998	0.1918	0.2109	0.1767	0.1998	0.1918	0.2109	0.1767	0.1998	0.1918	0.2109
Log Likelihood	-452.98	-440.25	-444.66	-434.15	-452.98	-440.25	-444.66	-434.15	-452.98	-440.25	-444.66	-434.15
AIC	947.96	934.51	943.33	934.29	947.96	934.51	943.33	934.29	947.96	934.51	943.33	934.29

Notes: Headwinds and Turbulence split by FF = Fossil Fuel and Ren = Renewable. Sample includes only unregulated generators in the 2016–2023 subsample.

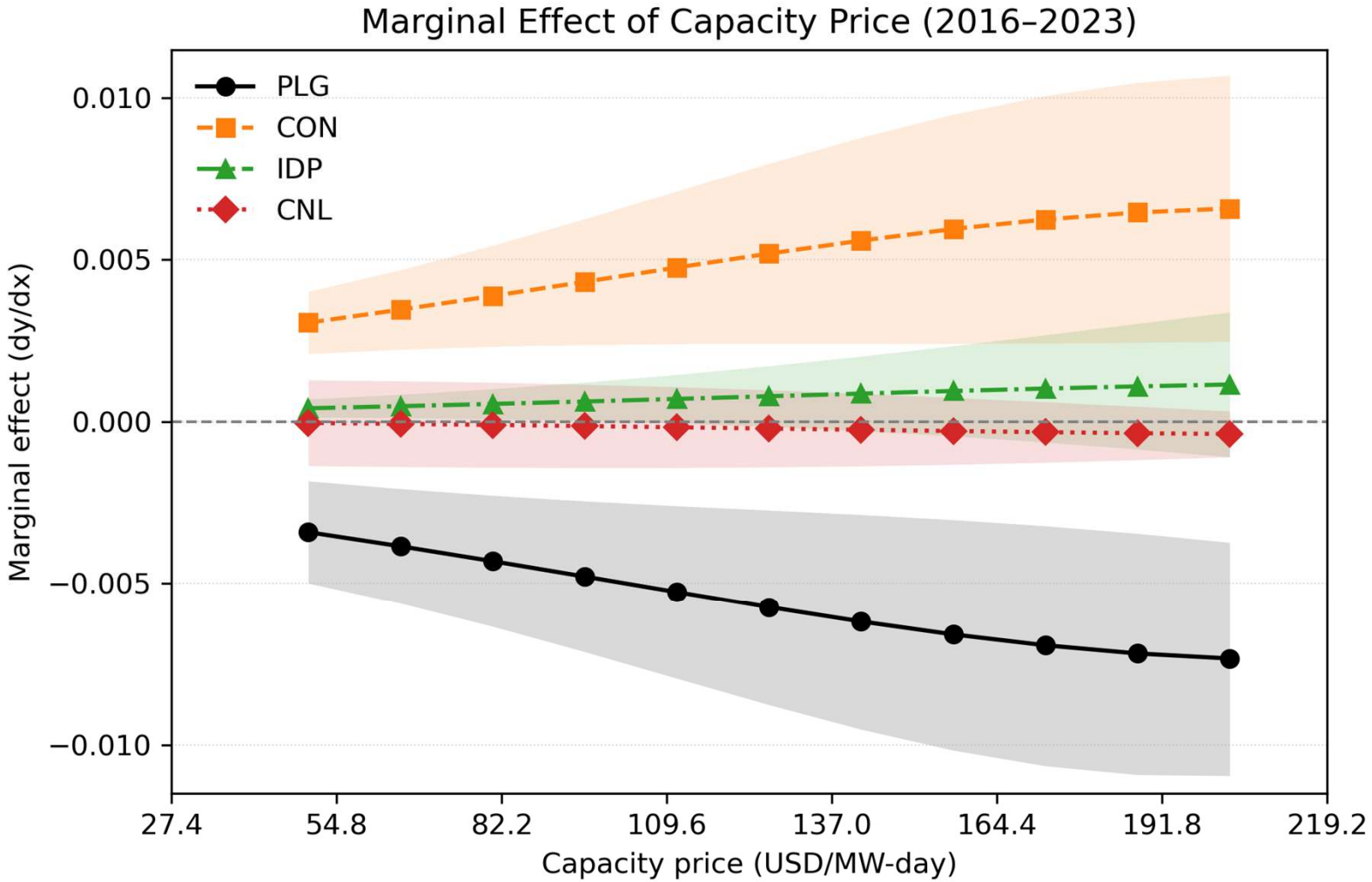
Duration RRRs (2016-2023)

Outcome	(1)	(2)	(3)	(4)
CON	0.505***	0.510***	0.502***	0.511***
IDP	1.103	1.087	1.096	1.068
CNL	1.565***	1.646***	1.617***	1.612***


Marginal Effect of Duration (2016–2023)
Marginal effect (dy/dx)
0.2
0.1
0.0
−0.1
−0.2
PLG
CON
IDP
CNL
0
1
2
3
4
5
6
7
8
9
10
Duration (years in stage)

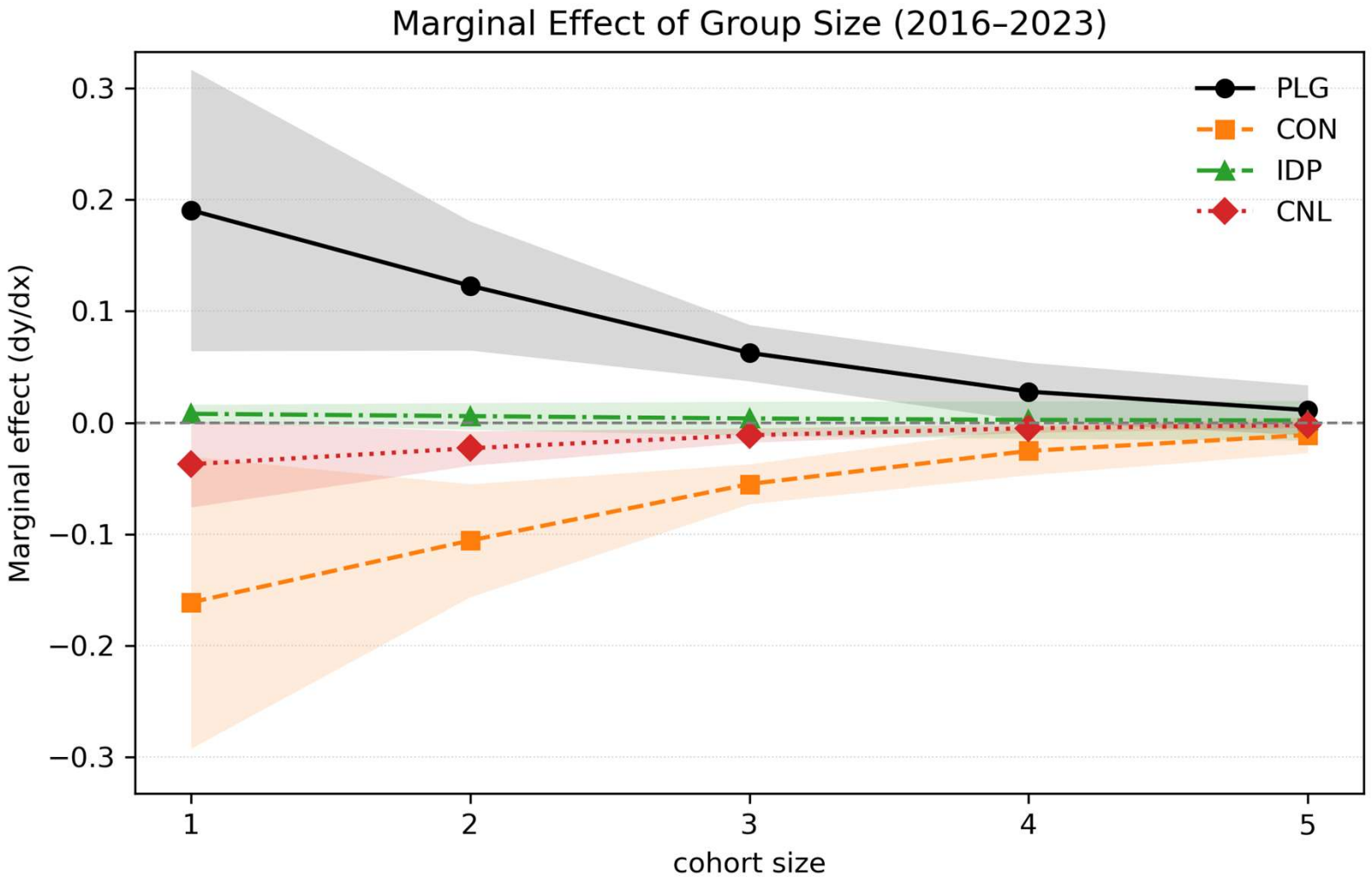
Capacity Payment RRRs (2016-2023)

Outcome	(1)	(2)	(3)	(4)
CON	1.025***	1.025***	1.024***	1.031***
IDP	1.030**	1.018	1.028**	1.035***
CNL	1.004	0.998	1.006	1.003


Marginal Effect of Capacity Price (2016–2023)
PLG
CON
IDP
CNL
0.010
0.005
0.000
−0.005
−0.010
Marginal effect (dy/dx)
27.4
54.8
82.2
109.6
137.0
164.4
191.8
219.2
Capacity price (USD/MW-day)

Group Size RRRs (2016-2023)

Outcome	(1)	(2)	(3)	(4)
CON	0.405***	0.397***	0.375***	0.418***
IDP	1.114	0.976	1.047	1.036
CNL	0.492***	0.414***	0.415***	0.399***


Marginal Effect of Group Size (2016–2023)
PLG
CON
IDP
CNL
Marginal effect (dy/dx)
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
1
2
3
4
5
cohort size

Headwinds & Turbulence

$$DiffYear_{i,t} = \left(cuyr_{i,t} + \frac{cumn_{i,t} - 1}{12} \right) - \left(efyr_{i,t} + \frac{efmn_{i,t} - 1}{12} \right), \tag{1}$$

where

- $efmn_{i,t}$: Effective Month - original in-service month.
- $efyr_{i,t}$: Effective Year - original in-service year.
- $cumn_{i,t}$: Current Month - most recently updated in-service month.
- $cuyr_{i,t}$: Current Year - most recently updated in-service year.

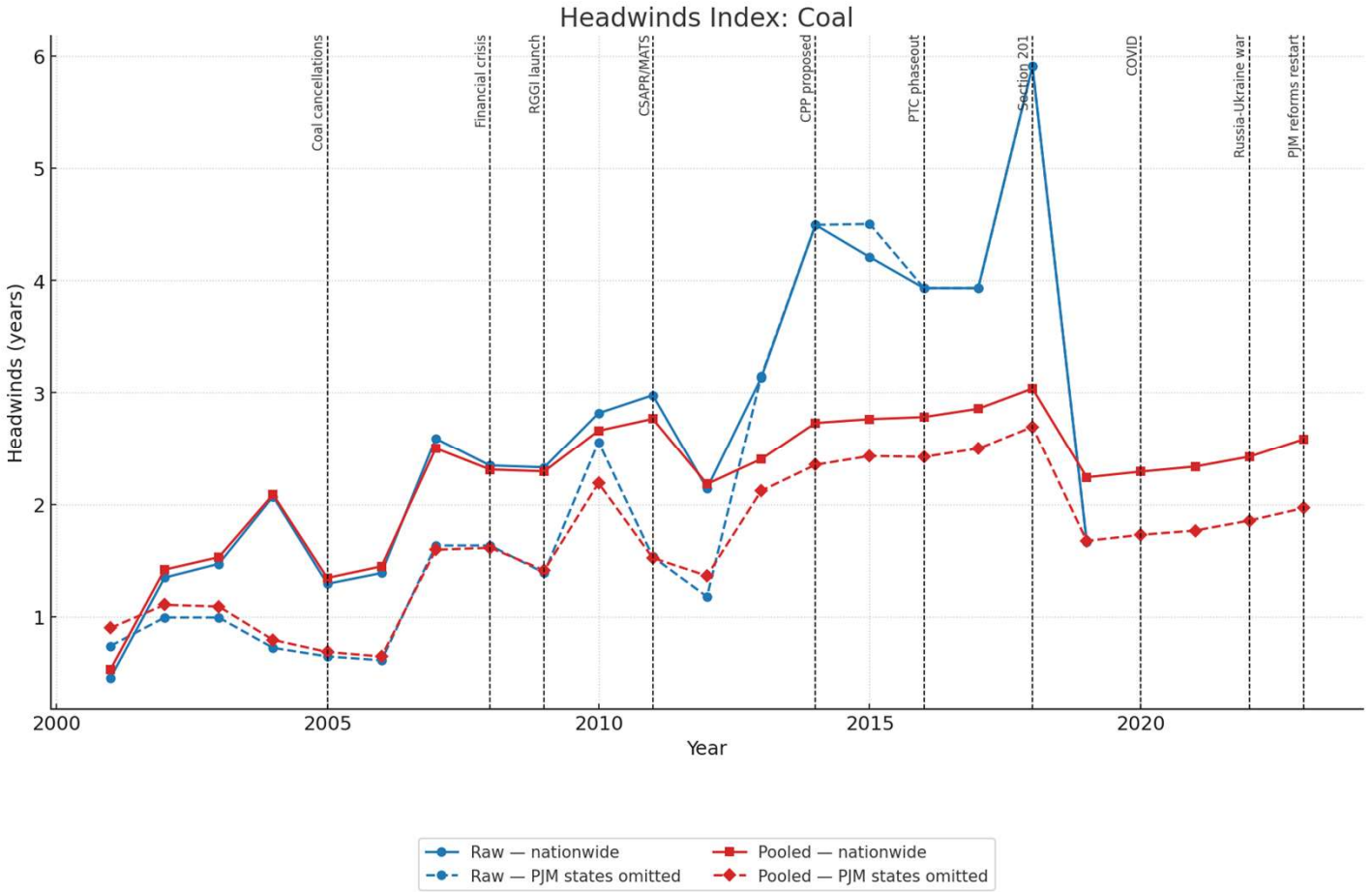
Headwinds & Turbulence

- ***Headwinds*** = capacity-weighted mean (by year & fuel type) *DiffYear*
  - Stronger ***Headwinds*** = more resistance (drag)

- ***Turbulence*** = capacity-weighted stdev (by year & fuel type) *DiffYear*
  - Greater ***Turbulence*** = more uncertainty

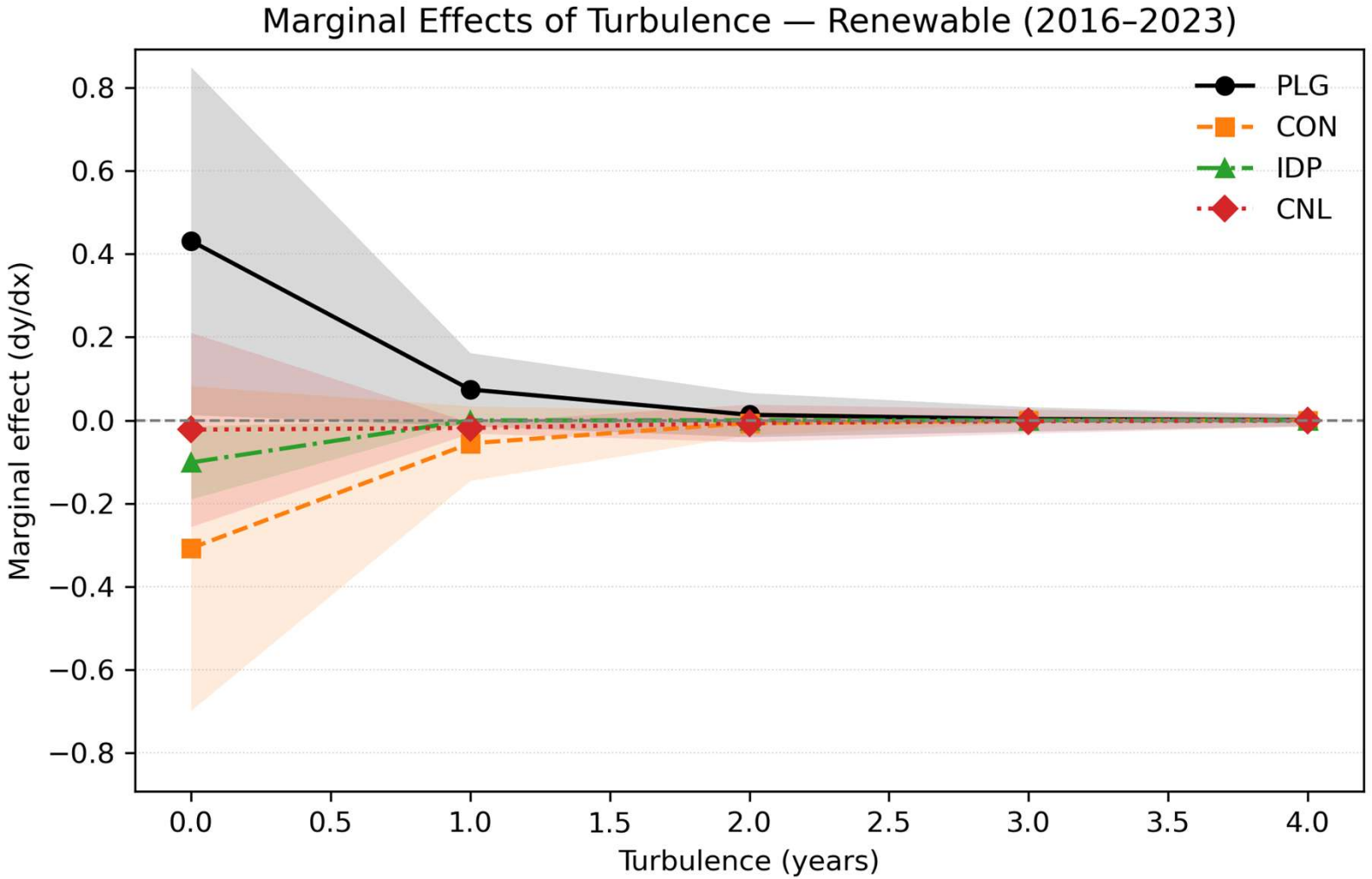
- ***Headwinds*** & ***Turbulence*** impound information from all sources
  - Regulatory & Policy
  - Profitability
  - Technological risk
  - Queue backlog

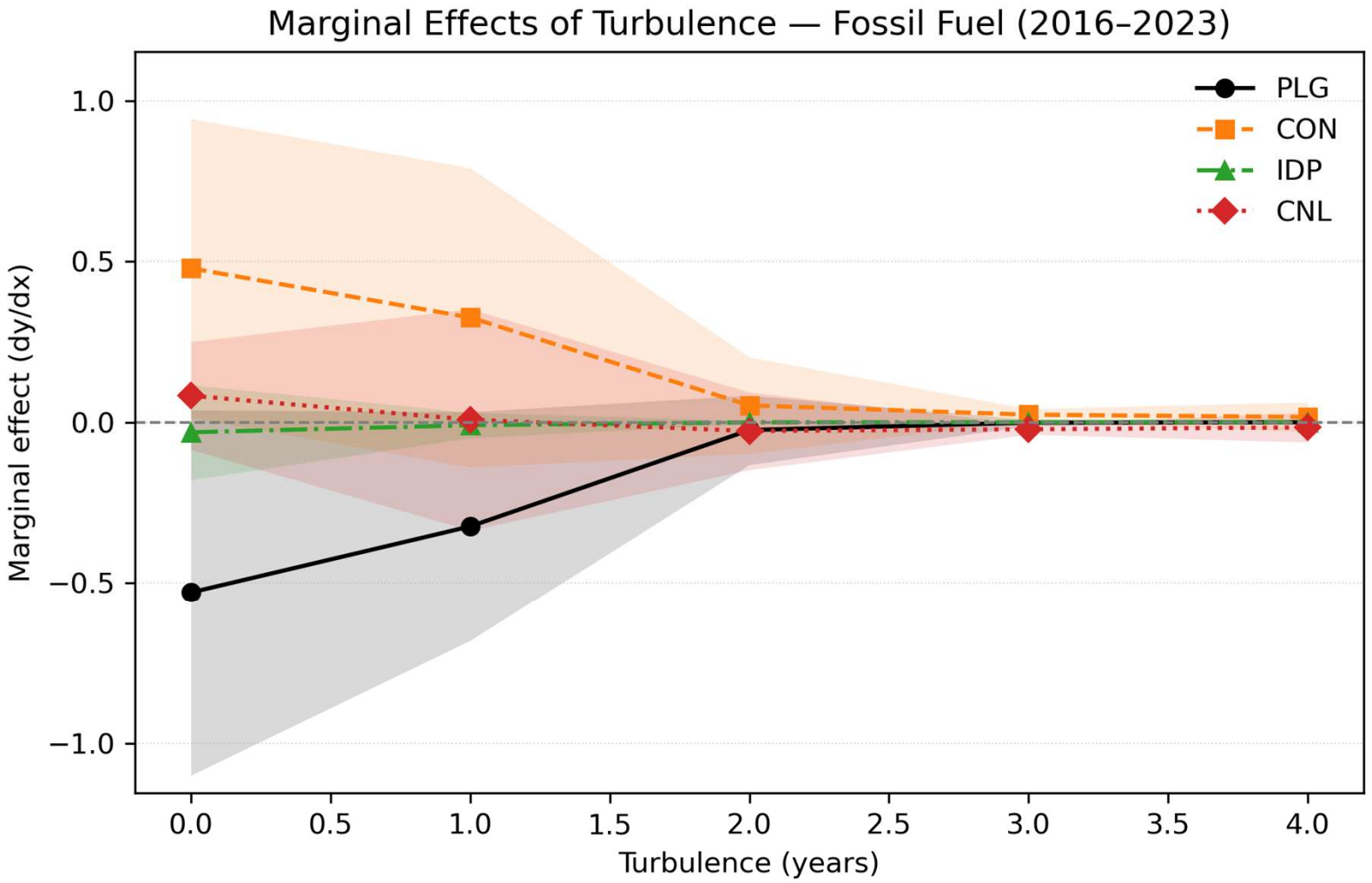
Coal Headwinds: Pooling & Endogeneity



Aggregation of Indices

- Fossil Fuel
  - Coal, Natural gas, Oil
- Renewable
  - Sun, Wind, Water
- The approach is flexible.
- Limitation is data sparsity, not methodology.


Marginal Effects of Turbulence — Renewable (2016–2023)
PLG
CON
IDP
CNL
Marginal effect (dy/dx)
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Turbulence (years)


Marginal Effects of Turbulence — Fossil Fuel (2016–2023)
PLG
CON
IDP
CNL
Marginal effect (dy/dx)
1.0
0.5
0.0
−0.5
−1.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Turbulence (years)

Summary (part 1)

- We study sequential investment in PJM.
  - PLG → PLG, CON, IDP, CNL.

- Duration, CapPmt, GroupSize , Nameplate
  - Stable across specifications
  - Consistent with real options theory

- RPM works.
  - Higher capacity prices increase the probability of CON with no change on the probability of CNL.

Summary (part 2)

- New measures of resistance (***Headwinds***) and uncertainty (***Turbulence***)

- Marginal effects suggest
  - ***Turbulence*** pushes fossil fuel generators out of PLG and into CON
    - Uncertainty = option value
  - ***Turbulence*** keeps renewables in PLG and out of CON.
    - Uncertainty = risk