Sequential Investment in PJM

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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**)

- How does uncertainty in the process affect the transitions?

Real Options

- Uncertainty can accelerate or delay investment
  - McDonald & Siegel (1986): with irreversibility, **uncertainty** raises the option value of waiting and **delays investment**.
  - Marmer, V. and Slade, M. E. (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

Data Sources

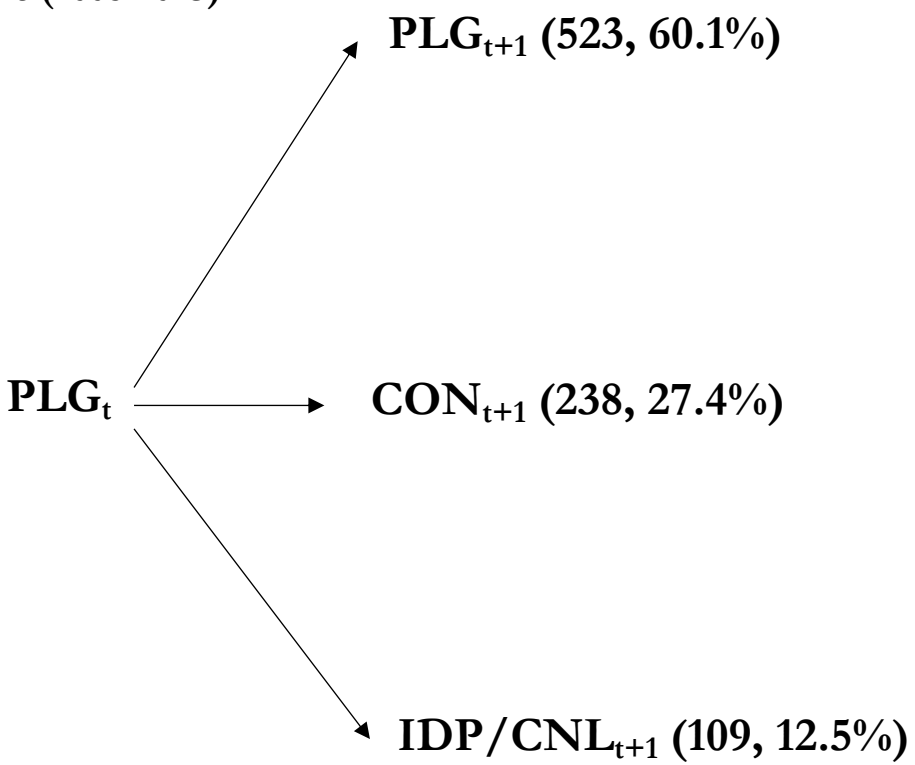
- EIA860
  - Every generator in the US (existing, planned, canceled)
  - Status code
  - Nameplate capacity
  - In-service dates
- PJM
  - RPM (capacity) prices

EIA 860 Status

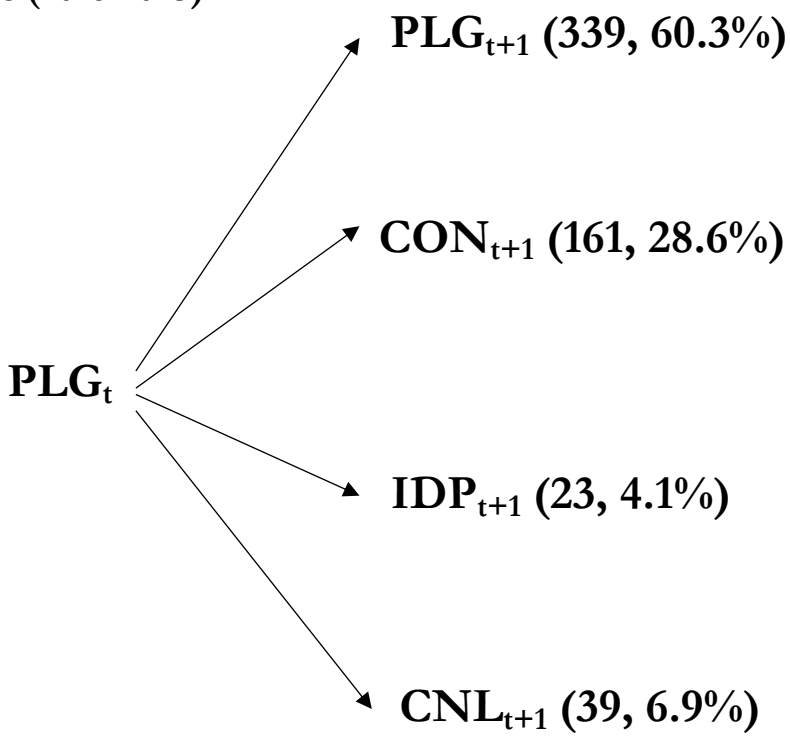
Stage	Stage Description	EIA Status Code	Status Code Description
PLG	Planning	**P**	Planned, no regulatory approval
PLG	Planning	**L**	Planned, regulatory approvals pending
PLG	Planning	**T**	Planned, regulatory approvals received
CON	Construction	**U**	Planned, under construction, less than 50%
CON	Construction	**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)

Full Sample (2008-2023)



Subsample (2016-2023)



Energy Information Administration (EIA) 860

- Every generator in the U.S. including Existing, Planned, and Canceled.
  - **Status** variable → **STAGE**

    - **PLG** = Planning (2008-2023)
    - **CON** = Under Construction (2008-2023)
    - **IDP** = Indefinitely Postponed/Canceled (2008-2015)
    - **IDP** = Indefinitely Postponed (2016-2023)
    - **CNL** = Canceled (2016-2023)

Headwinds & Turbulence

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

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

- We introduce new measures of **resistance** (***Headwinds***) and **uncertainty** (***Turbulence***) in the planning process.
  - Based upon revisions in in-service dates reported by the firms.

- ***Headwinds*** = capacity weighted mean (year and fuel type) *DiffYear*

- ***Turbulence*** = capacity weighted stdev (year and fuel type) *DiffYear*

Headwinds & Turbulence

- Stronger ***Headwinds*** = more **resistance** (drag) in the planning process
- Greater ***Turbulence*** = more **uncertainty** in the planning process

- ***Headwinds & Turbulence*** impound **resistance & uncertainty** from all sources
  - Regulatory
  - Profitability
  - Technological risk
  - Queue backlog
  - Etc.

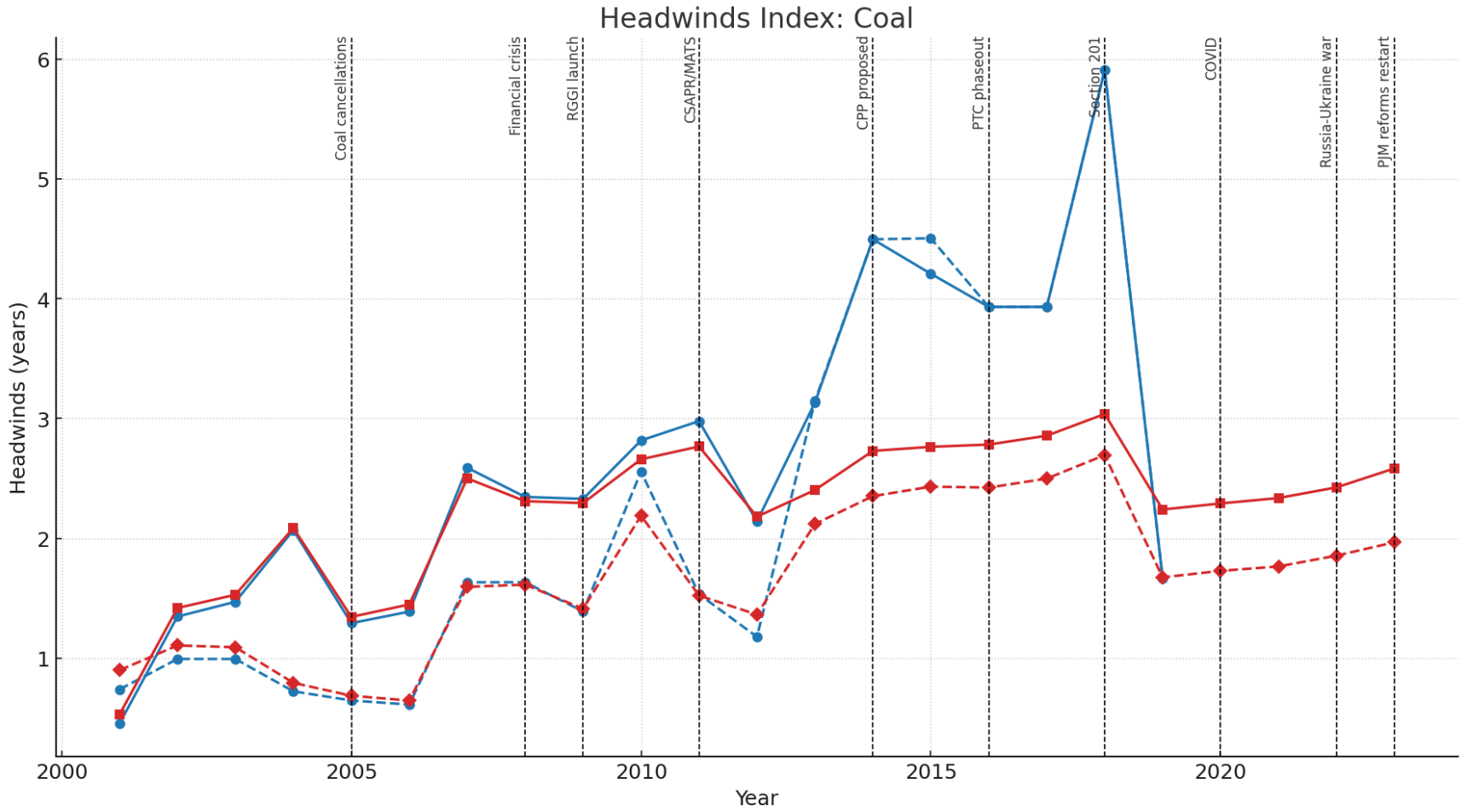
Partial Pooling (How we build the indices)

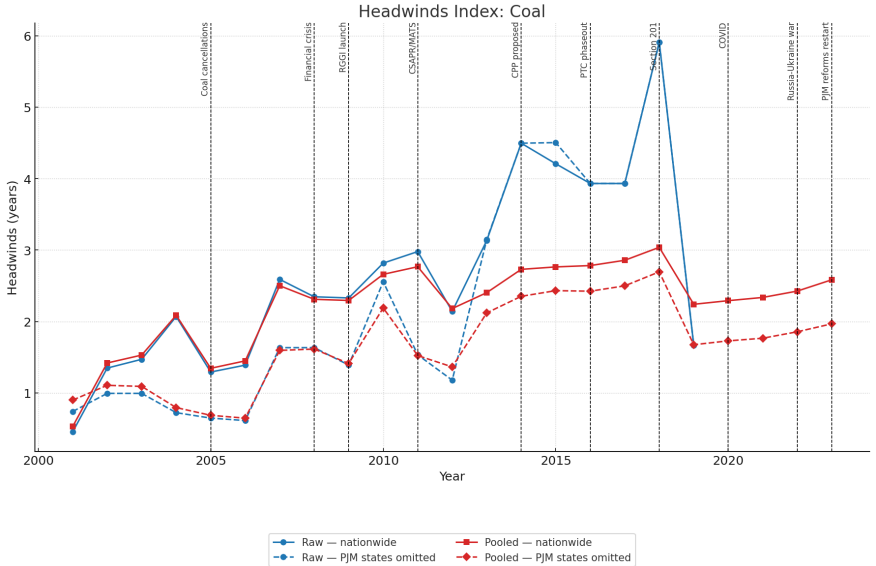
- Fuel × year cells can be sparse → raw means are noisy, especially in late years for coal, early years for solar, etc.
- Bayesian partial pooling:
  - Estimate fuel-specific time paths jointly.
  - Years with many projects look like simple averages.
  - Thin years are **shrunk toward the fuel-level mean**, not the grand mean.
  - Indices are built using **non-PJM states only** → avoids mechanical endogeneity with the PJM regressions.
  - Result: smooth, interpretable series that still preserve real differences across fuels and events.

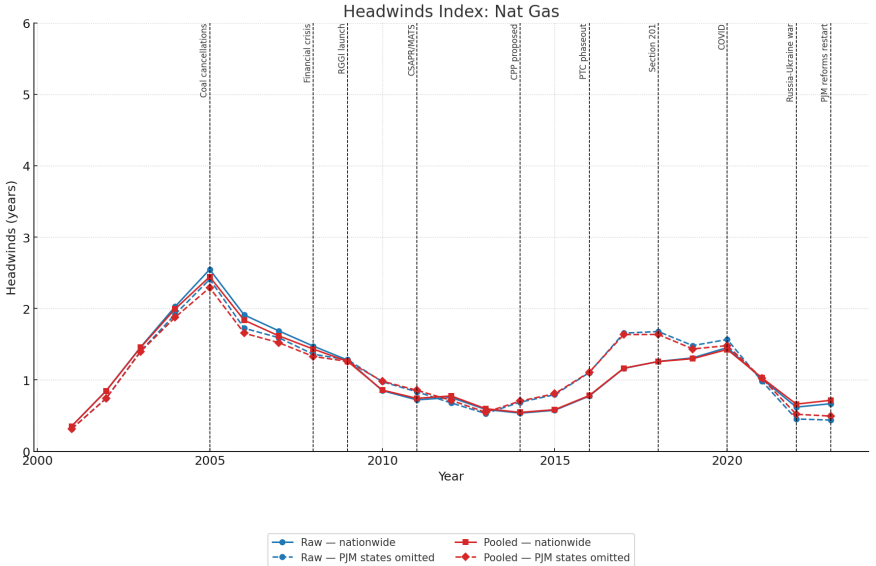
Table 6: Events annotated in Headwinds and Turbulence plots. These events are major policy and market shocks that are likely to influence planning delays and uncertainty; some correspond to visible changes in the indices in Figures 13 through 16, while others occur during broader periods of elevated or declining Headwinds and Turbulence.

Year	Event	Description
2005	Coal cancellations	Beginning of widespread coal cancellations driven by environmental regulation, grassroots opposition, and deteriorating project economics.
2007	Mass v. EPA	Supreme Court ruling establishing EPA authority to regulate greenhouse gases under the Clean Air Act.
2008	Financial crisis	Global recession and credit shock, sharply reducing electricity demand and delaying capital-intensive infrastructure.
2009	RGGI launch	Regional Greenhouse Gas Initiative takes effect, establishing a carbon price in the Northeast.
2011	CSAPR/MATS	EPA finalizes two major pollution rules: Cross-State Air Pollution Rule and Mercury and Air Toxics Standards.
2012	Wind PTC lapse	Expiration of wind production tax credit; causes major pipeline contraction and investment pause.
2013	Wind PTC restored	Reinstatement of the PTC via fiscal cliff bill; activity resumes but with uncertainty.
2014–2015	Clean Power Plan and PJM reforms	Announcement of CPP targets + PJM's stricter capacity accreditation rules following the polar vortex.
2016	PTC phaseout begins	Legislative deal begins gradual phase-down of wind credits, providing long-term investment certainty.
2017	Solar tariff probe	Section 201 trade complaint triggers procurement delays and risk repricing for solar developers.
2018	Solar tariffs imposed	President Trump imposes 30% import tariffs on solar panels under Section 201.
2020	COVID-19 pandemic	Global shutdowns disrupt supply chains, permitting, and construction across all fuel types.
2022	Russia–Ukraine crisis	International gas supply shock triggers extreme price volatility; alters fuel risk calculus.
2022.5	Inflation Reduction Act	Historic climate bill delivers 10-year tax credit certainty; reshapes expectations for renewable buildout.
2021–2022	PJM queue freeze	PJM halts interconnection intake due to study backlog; delays hundreds of GW.
2023	PJM reforms restart	Queue restarts under new cluster-based process, but backlog remains substantial.

Coal Headwinds: Events, Pooling, Exogeneity




Headwinds Index: Coal
Headwinds (years)
Year
Coal cancellations
Financial crisis
RGGI launch
CSAPR/MATS
CPP proposed
PTC phaseout
Section 201
COVID
Russia-Ukraine war
PJM reforms restart
Raw — nationwide
Raw — PJM states omitted
Pooled — nationwide
Pooled — PJM states omitted


Headwinds Index: Nat Gas
Headwinds (years)
Year
Coal cancellations
Financial crisis
RGGI launch
CSAPR/MATS
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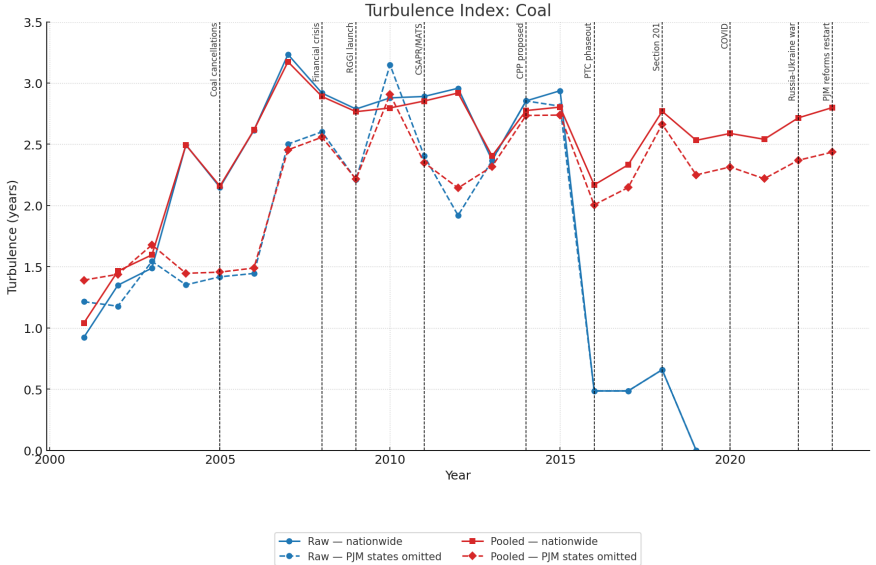
Turbulence Index: Coal
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Year
Coal cancellations
Financial crisis
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CSAPR/MATS
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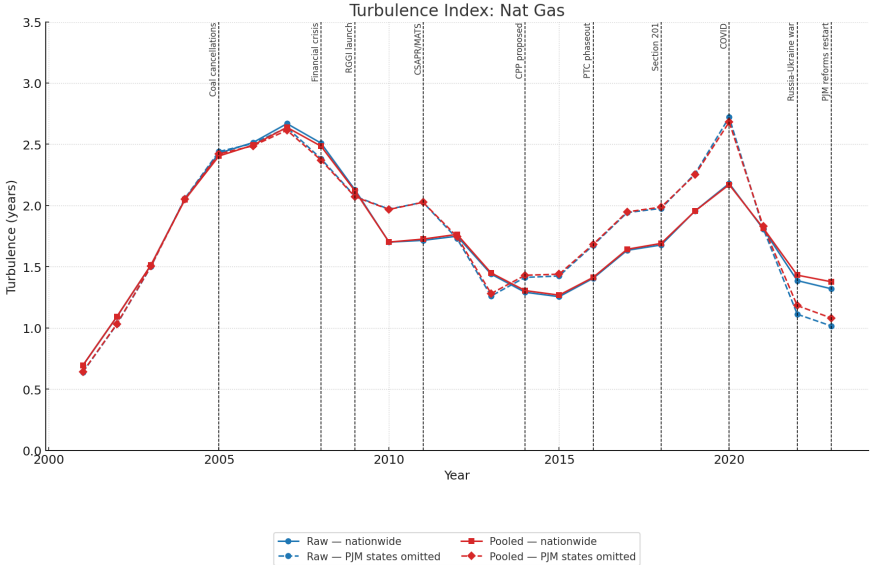
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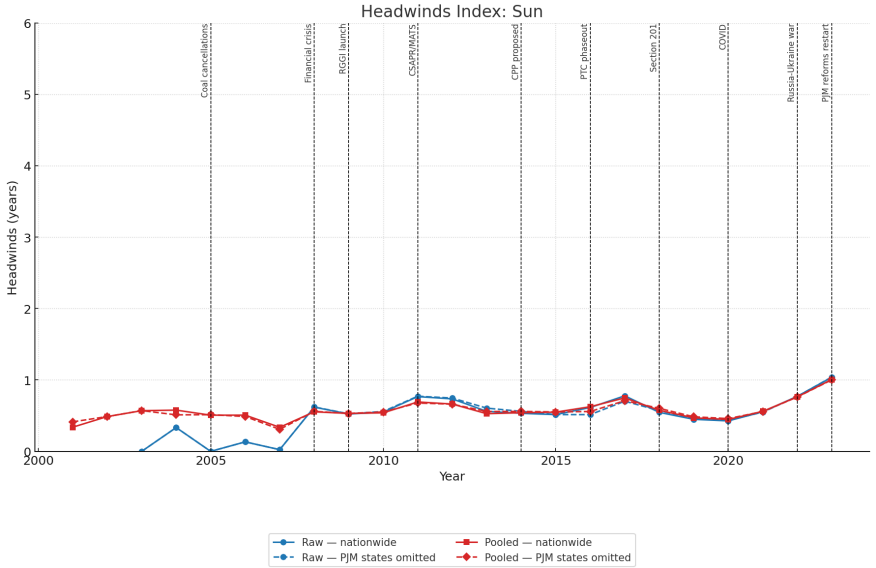
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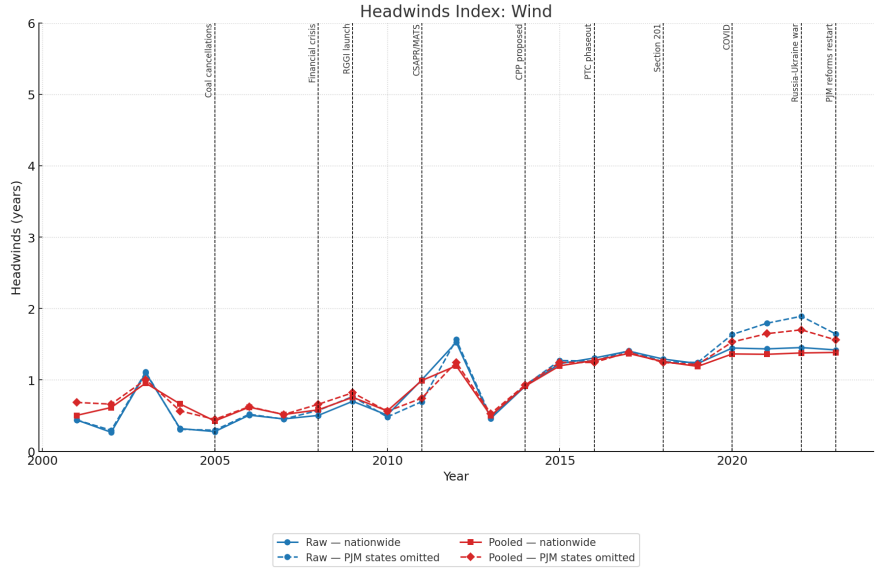
Headwinds Index: Wind
Headwinds (years)
Year
Coal cancellations
Financial crisis
RGGI launch
CSAPR/MATS
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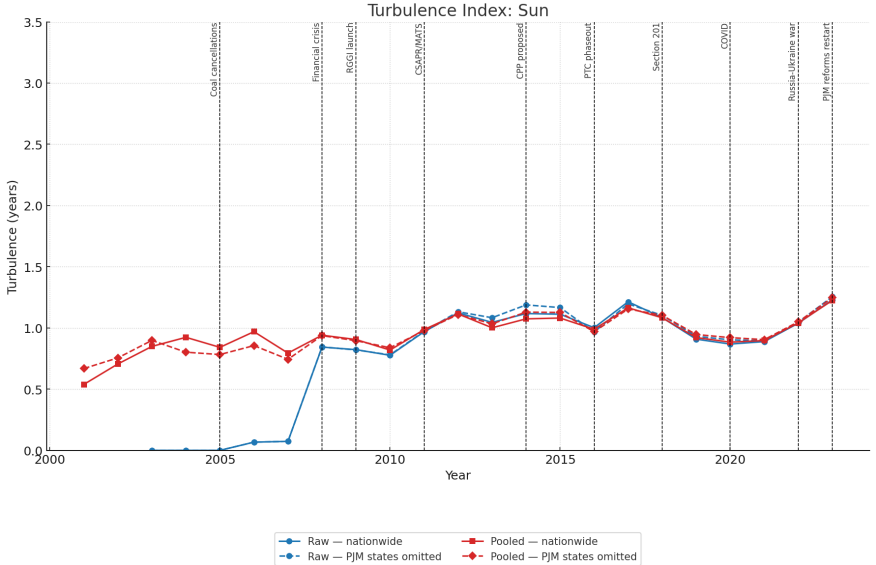
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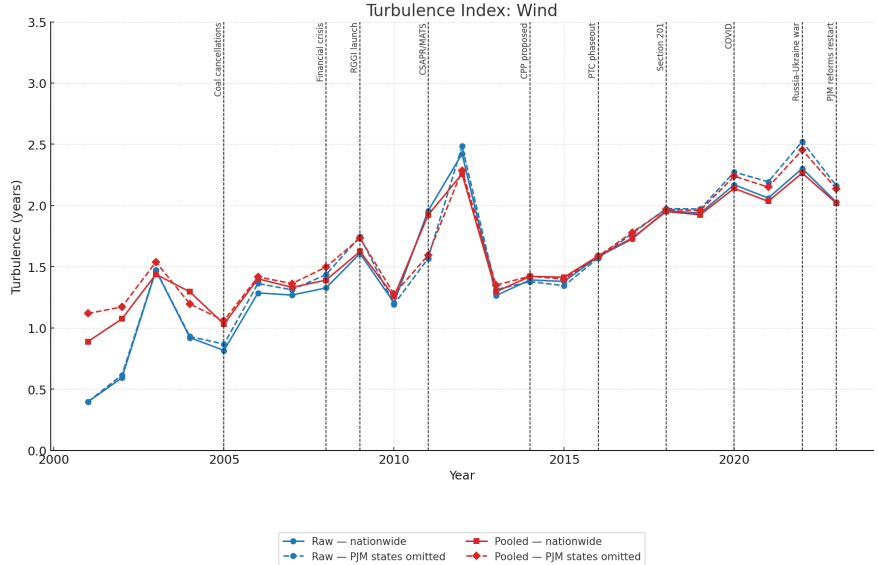
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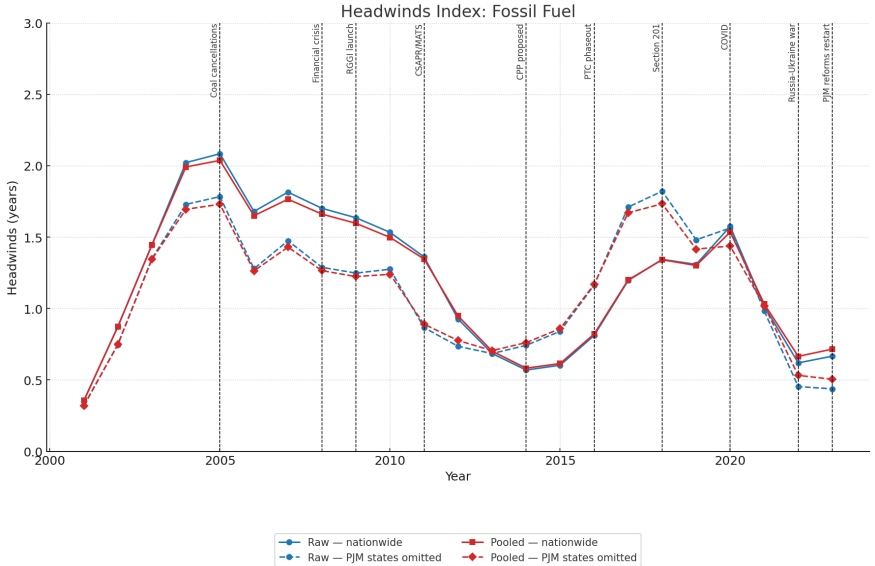
Aggregation of Indices

- Fossil Fuel
  - Coal
  - Natural gas
  - Oil

- Renewable
  - Sun
  - Wind
  - Water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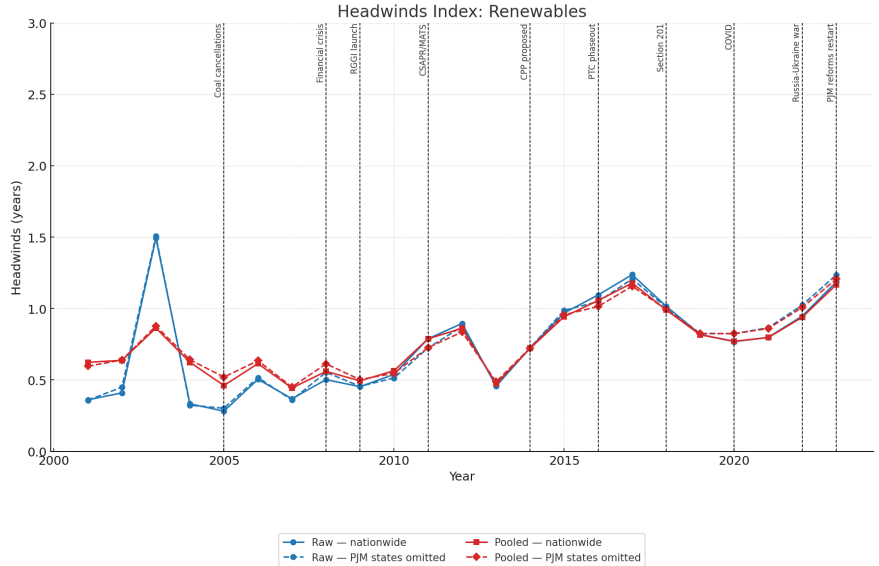
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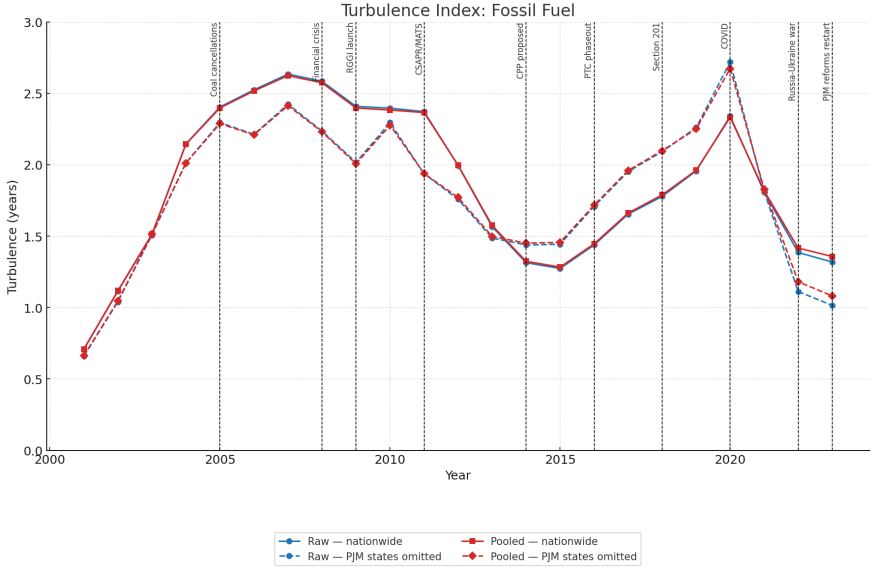
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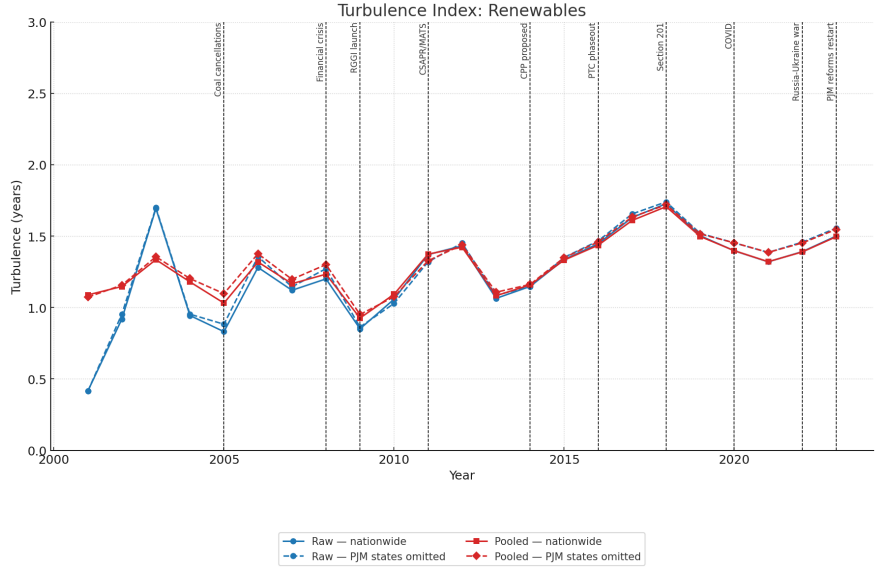
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$$\Pr\left(\text{STAGE}_{i,t+1} = m \mid \text{Transition}_{i,t}\right) = \frac{\exp\left(\text{Transition}_{i,t}\beta_m\right)}{\sum_{j=1}^{M} \exp\left(\text{Transition}_{i,t}\beta_j\right)}$$

$$\begin{aligned}\text{Transition}_{i,t} = {} & \beta_0 + \beta_1\, Nameplate_i + \beta_2\, Duration_{i,t} + \beta_3\, CapPmt_{t+1,z} + \beta_4\, GroupSize_{i,t} \\ & + \beta_5\, Renewable_i + \beta_6\, ZonePlannedCap_{t,z} \\ & + \beta_7\, Headwinds_{ff,t} + \beta_8\, Headwinds_{ren,t} \\ & + \beta_9\, Turbulence_{ff,t}^{(resid)} + \beta_{10}\, Turbulence_{ren,t}^{(resid)}\end{aligned} \tag{4}$$

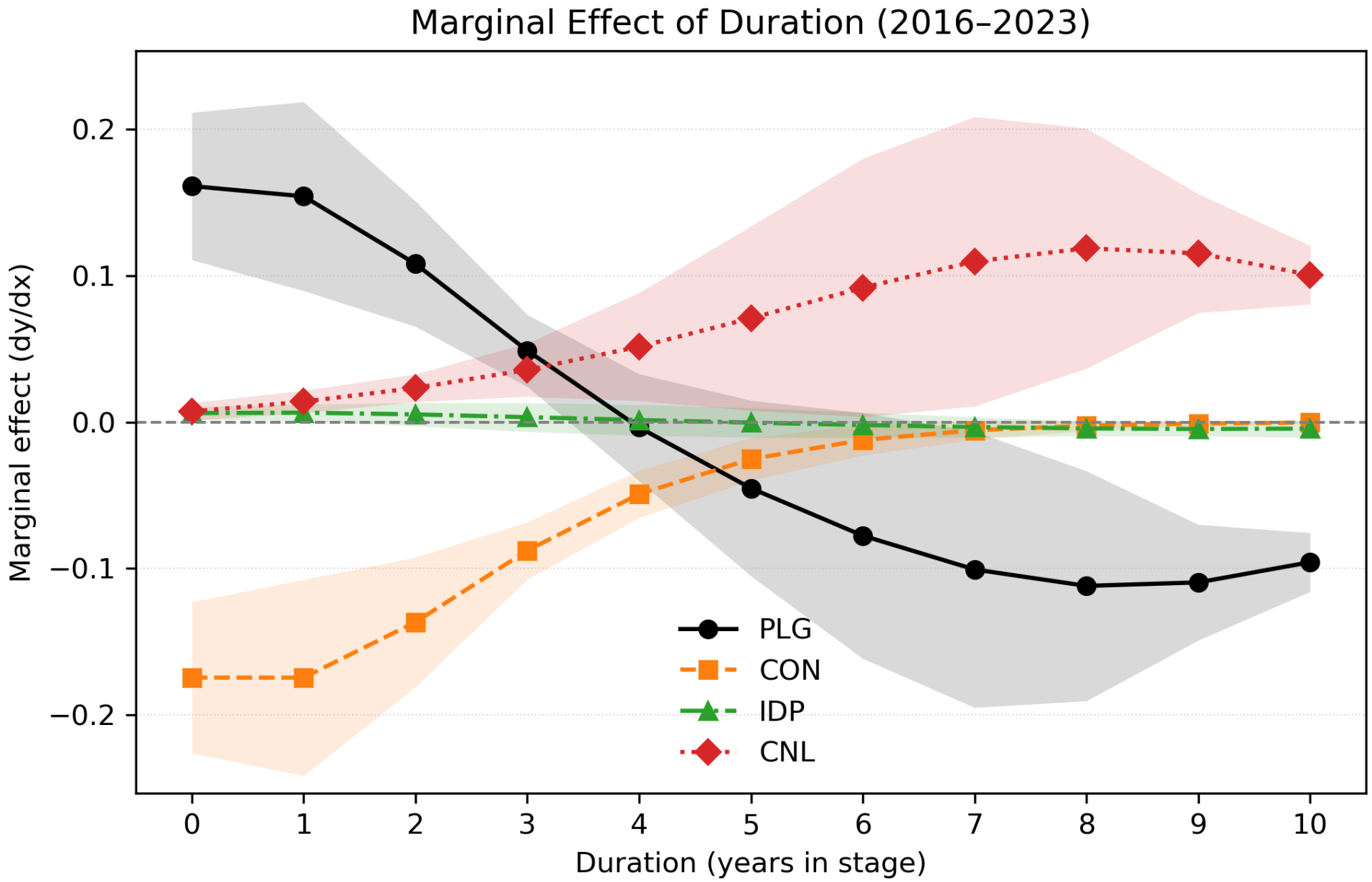
Table 3: Multinomial Logit Regression (2016–2023 Subsample, Unregulated Only). Odds ratios with p-values in parentheses. Base outcome = PLG.

	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 Odds Ratios (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
0
1
2
3
4
5
6
7
8
9
10
Duration (years in stage)
PLG
CON
IDP
CNL

Duration Marginal Effects (2016-2023)

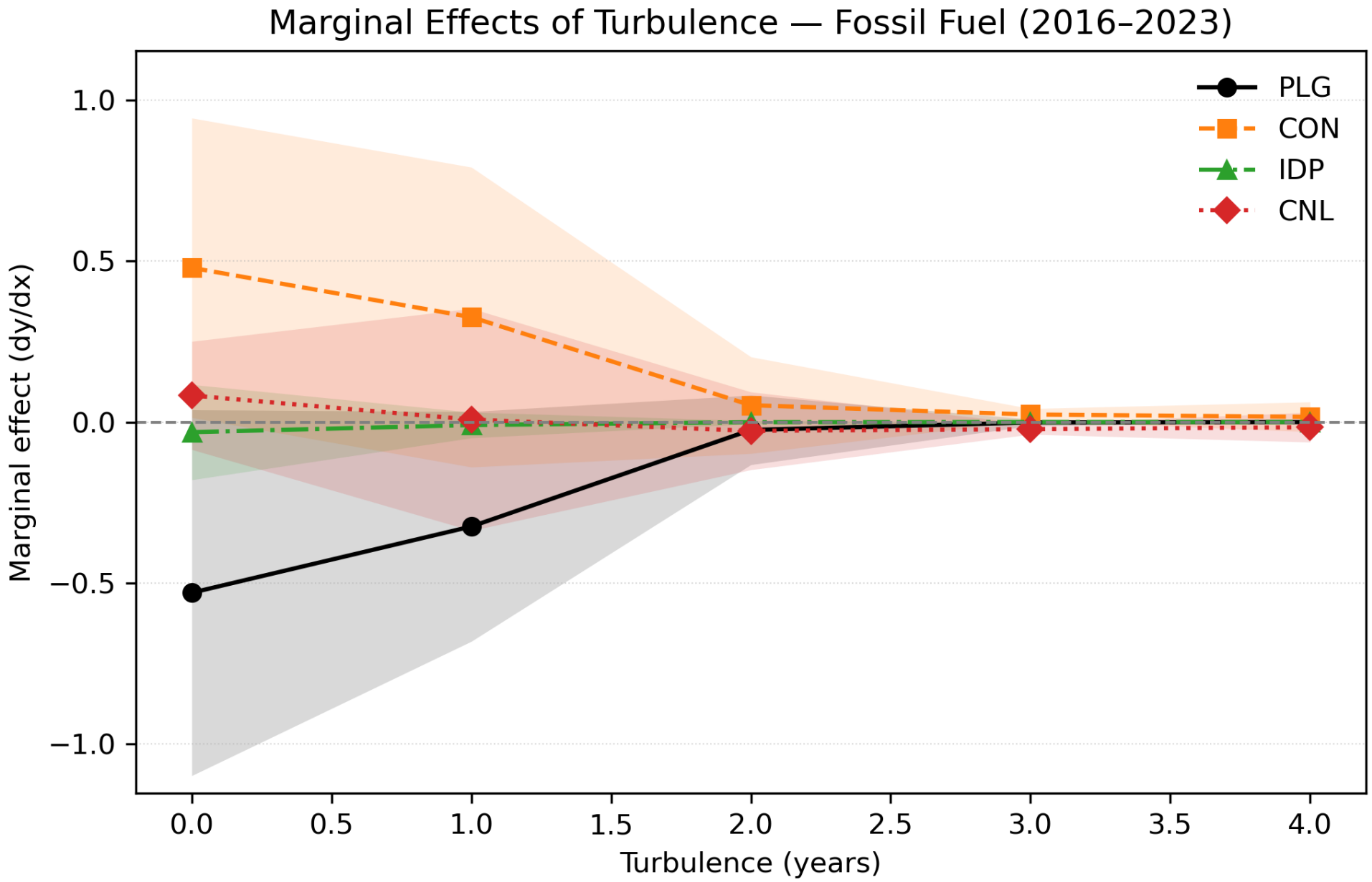
- Years 0-3
  - High probability of remaining in PLG

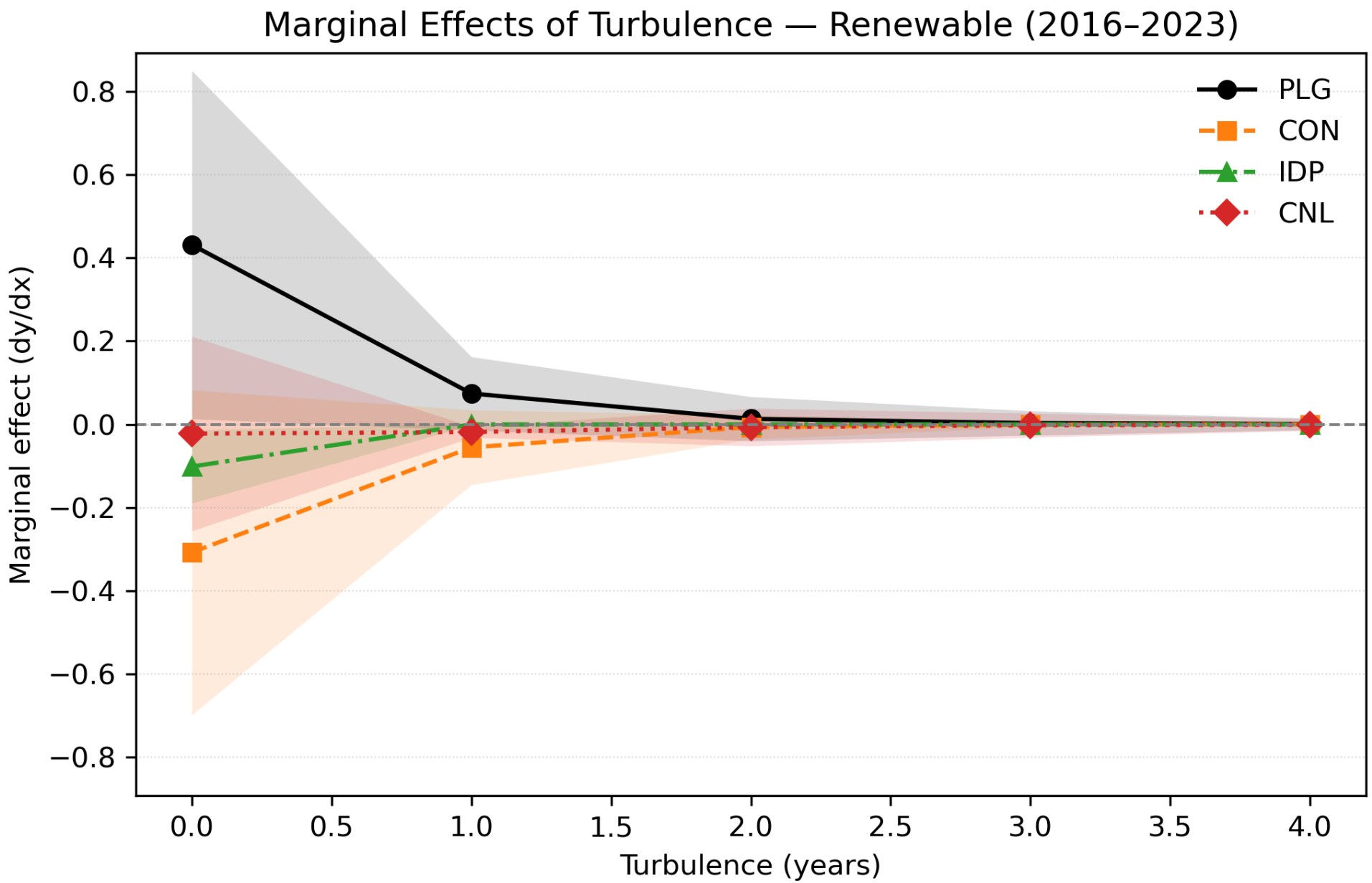
- After 3-4 years
  - Extra time in PLG sharply reduces CON
  - Extra time in PLG sharply increases CNL

- Consistent with real options and abandonment when project value falls below continuation value.

Headwinds & Turbulence Odds Ratios (2016-2023) Specification (4)

Outcome	CON	IDP	CNL
Headwinds (FF)	2.713	98.607***	49.523*
Headwinds (Ren)	1.295	10.241	0.202**
Turbulence (FF)	18.151**	0.647	12.667
Turbulence (Ren)	0.109	0.002*	0.333


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)


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)

Summary (part 1)

- We study sequential investment in PJM: PLG→PLG/CON/IDP/CNL.
  - We document how projects actually move through the pipeline.
  - We introduce new fuel-specific measures of drag (Headwinds) and uncertainty (Turbulence), which line up with known events.
  - We aggregate to fossil vs renewable indices for the regressions due to sparse data.

Summary (part 2)

- Coefficients on Duration, CapPmt, Nameplate, GroupSize are stable across specifications and consistent with real options theory.
- Coefficients on the indices are large and imprecise (limited IDP/CNL events), but marginal effects suggest:
  - Turbulence pushes fossil projects out of PLG and into CON
  - Turbulence keeps renewables in PLG and out of CON.
- This motivates a **fully Bayesian** version of the sequential model and a standalone paper on the indices (including monthly, national, and custom regional versions).