Stability-Constrained Regime-Aware Forecasting for Heterogeneous Panel Time Series

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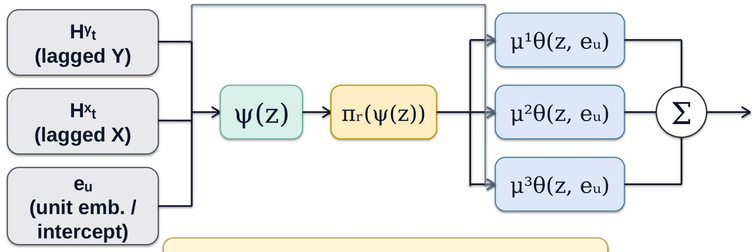
Soft-gated regime-aware forecasters can capture heterogeneity, but recursive stability depends on auditable gating, disagreement, and dwell-time terms that per-edge spectral control alone cannot guarantee.

1. Motivation

- Heterogeneous panel time series exhibit multicollinearity, latent unit heterogeneity, and regime-dependent relationships.
- Pooled additive predictors can cancel sign-changing regime-conditional effects.
- Recursive neural forecasting needs explicit stability verification.

Main empirical message — On V-Dem, regime-dependent signal exists, but no tested model significantly outperforms a random walk under seed-fair, country-clustered evaluation.

2. PANAR-X Architecture



$$\mu_\theta(z, e_u) = \sum_r \pi_r(\psi(z))\ \mu_\theta^{(r)}(z, e_u)$$

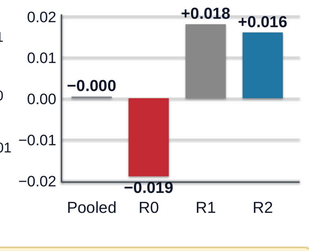
M1 = pooled Y-only, M1.5 = pooled Y + X, M2 = regime-aware soft-gated mixture.

3. Why Pooling Fails on V-Dem

A. Linear coefficients at lag t−4, by regime (sign reversals)

	Pooled	R0 (low)	R1 (mid)	R2 (high)
anti-system movements	+0.001	+0.000	+0.003	−0.002
judicial reform	−0.001	−0.004	+0.001	+0.004
party organization	−0.000	−0.019	+0.018	+0.016
media corruption	−0.001	−0.002	+0.004	−0.007

B. Party organization (focus from A)



Regime-conditional coefficients straddle zero and collapse under pooling.

V-Dem: 151 countries · 1970–2025 · last 10 years held out
Target: Δ clean elections · Cancellation in 24/24 constructions

4. Contraction Certificate

$$L_{eq}^{(r)} = (1 - \varepsilon^{(r)})\, L_Y^{(r)} + \varepsilon^{(r)}\, L_{max} + L_{\varphi,eq}^{(r)}\, M$$

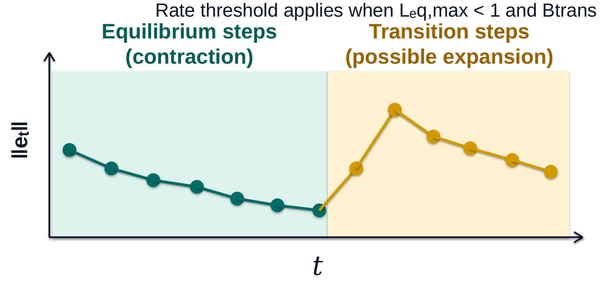
$$B_{trans} = L_{max} + L_\varphi\, M$$

$$\alpha^* = \frac{-\log(L_{eq,max})}{\log(B_{trans}) - \log(L_{eq,max})}$$

$$\rho = L_{eq,max}^{\,1-\alpha}\, B_{trans}^{\,\alpha} < 1$$

- $L_Y^{(r)}$: within-regime endogenous Lipschitz
- $\varepsilon^{(r)}$: gate leakage
- M: regime disagreement
- $L_{\varphi,eq}^{(r)}$, L_φ: gating sensitivity
- α: punctuation / switching rate

Rate threshold applies when $L_{eq,max} < 1$ and $B_{trans} > 1$.



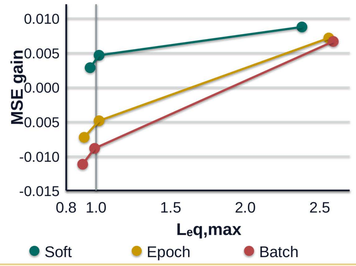
Intuition

Contraction within regimes, limited expansion at transitions, and an overall rate ρ < 1.

The audit decomposes instability into individually interpretable, post hoc computable terms.

5. Synthetic Stress Test

A. Stability–accuracy trade-off (across enforcement settings)



B. Mechanism: before vs. after

Setting	M	$L_{eq,max}$	Gap[1]	Audit
Soft penalty λM = 0	5.94	2.38	+0.0087	fail
Per-batch λM = 0.10	0.47	0.91	−0.0112	pass

[1] Pooled M1.5 MSE − M2 MSE; positive favors M2. 5 seeds per configuration; Table 5.

Per-edge spectral control alone is insufficient; the gating-driven term $L_{\varphi,eq}\, M$ can dominate. The disagreement penalty λM is a key control lever.

6. Two Real Panels

V-Dem Democracy Panel

151 countries · **45/45** audited runs pass · $L_{eq,max}$ = **0.13–0.29**

- Pooled models cancel regime-conditional signal.
- No tested model significantly outperforms random walk.

Model	Ensemble MSE
Random walk	0.00340
Stratified linear M1.5	0.00337
M2 (PANAR-X)	0.00339

Realized-Volatility Panel

8 equity indices · **4/5** seeds uncertified · $L_{eq,max}$ = **1.07–1.25** for failing seeds

Seed	$L_{eq,max}$	Btrans	α / α*	Audit
0	1.067	1.085	–	no
1	1.252	1.277	–	no
2	1.110	1.128	–	no
3	1.120	1.148	–	no
4	0.984	1.010	0.271 / 0.619	yes (ρ = 0.991)

- All per-regime networks meet the soft spectral target, yet 4/5 seeds fail the mixture audit through the gating term.

7. Forecasting Results and Practical Takeaways

Key findings

V-Dem	No tested model, pooled or stratified, linear or neural, significantly outperforms a random walk.
Volatility	Pooled linear regression captures the measurable headroom (28.2%); regime-aware structure does not improve out-of-sample forecasts.
Overall	We claim no predictive gains on these panels.

Audit first

1. Train a regime-aware model.
2. Audit L_Y, gate leakage, M, and switching terms.
3. If audit passes, check assumptions.
4. If not, target the failing term (especially disagreement) and retrain.

Audit estimates use held-out states; failure to certify is not proof of instability. Formal contraction requires valid bounds on the recursive dynamics.

Take-home messages

1. Pooling can hide regime-dependent predictive structure.
2. Soft-gated mixtures may fail certification despite spectrally compliant components.
3. The contraction audit is fast, interpretable, and retraining-free.

Limitations: the robust V-Dem finding is the cancellation mechanism; no predictive gains are claimed on the studied panels.

AIM-3D Lab
https://sites.nd.edu/aim3d/

Reproducibility package
doi.org/10.5281/zenodo.23717582