Appendix A: Methods for Empirical Estimation of Thermodynamic Geography

This appendix details the empirical estimation of the Relativistic Scalar–Vector Plenum (RSVP) fields—scalar potential (Φ), vector flow ($\sqsubseteq$), and entropy (S)—and the curvature control mechanisms via recursive futarchy, addressing the measurement and steering of thermodynamic geography.

A.1 Estimating RSVP Fields

The RSVP fields are mapped to observable proxies in economic and social systems, enabling curvature quantification across spatial and temporal scales.

- **Scalar Potential ($\Phi(x,t)$): Informational Density**
  - *Proxies*: GDP per capita, capital stock, human capital indices, patent filings, R&D expenditure, nighttime light intensity (VIIRS), broadband penetration, citation density, venture capital flows.
  - *Estimation*: Aggregate proxies into a scalar field via weighted summation:

$$\Phi(x,t) = \sum_i w_i p_i(x,t),$$

    where p_i are normalized proxies and w_i are weights (e.g., PCA loadings or expert priors). Compute gradients ($\nabla\Phi$) and Laplacian ($\Delta\Phi$) using finite differences on a spatial grid (e.g., 1 km^2 cells from OpenStreetMap).

- **Vector Flow ($\sqsubseteq(x,t)$): Exchange Dynamics**
  - *Proxies*: Trade flows (UN Comtrade), interbank transactions, shipping tracks (AIS), flight origin-destination matrices, migration flows, mobile call-detail records, internet peering traffic, coauthorship networks.
  - *Estimation*: Construct a vector field from flow matrices:

$$\sqsubseteq(x,t) = \sum_j f_{xj}(t) \cdot \frac{x_j - x}{|x_j - x|},$$

    where f_{xj} is the flow magnitude from location x_j to x. Compute divergence ($\nabla \cdot \sqsubseteq$) and curl ($\nabla \times \sqsubseteq$) for sources/sinks and circulation.

- **Entropy ($S(x,t)$): Volatility and Diversity**
  - *Proxies*: Output/price volatility, forecast error variance, sectoral diversity (Shannon entropy over NAICS codes), sentiment entropy (from X posts or media), job transition entropy, innovation diversity (patent topic entropy).
  - *Estimation*: Compute local entropy:

$$S(x,t) = -\sum_i p_i(x,t) \log p_i(x,t),$$

    for distributions p_i (e.g., sector shares, sentiment categories). Estimate diffusion (ΔS) and production rates ($\dot{S}$) via temporal differencing.

A.2 Curvature Metrics

Key curvature invariants quantify the morphology of value:

- **Gaussian Curvature of Φ**: $K = \frac{\det(\nabla^2 \Phi)}{(1+|\nabla \Phi|^2)^2}$, identifying hubs or bottlenecks.
- **Flow Divergence**: $\nabla \cdot \sqsubseteq$, detecting sources/sinks of exchange.
- **Entropy Gradient Coupling**: $\nabla \Phi \cdot \nabla S$, measuring innovation driven by capacity gradients.

These are computed on a discretized grid using finite-element methods, with data sourced from public repositories (e.g., World Bank, OpenAlex).

A.3 Recursive Futarchy for Curvature Control

Recursive futarchy adjusts field dynamics via a predictive tensor $\mathbb{T}_{ij}$, aggregated from market forecasts.

- **Tensor Construction**:

$$\mathbb{T}_{ij} = \sum_k w_k \mathbb{E}_{p_k} \left[\partial_i \ell_k \partial_j \ell_k \right], \quad \ell_k = \log p_k(\text{outcome} \mid \text{state}),$$

  where p_k are market-implied probabilities, $w_k \propto (\text{skill} \times \text{liquidity})$. Use Ensemble Kalman Filtering (EnKF) for real-time updates, with eigenvalue clipping to prevent runaway curvature.

- **Coefficient Adjustment**:

$$\begin{aligned} \lambda_\Phi(t+1) &= \lambda_\Phi(t) + \epsilon_\Phi \mathrm{Tr}(\mathbb{T}), \\ \eta_\sqsubseteq(t+1) &= \eta_\sqsubseteq(t) - \epsilon_\sqsubseteq \nabla \cdot \mathbb{T}, \\ \alpha_S(t+1) &= \alpha_S(t) + \epsilon_S \langle \nabla \Phi \cdot \nabla S \rangle. \end{aligned}$$

  These modulate capacity diffusion, flow friction, and entropy exploration, respectively.

- **Feedback Loop**: Implement via Model Predictive Control (MPC):

$$u(t) = \arg\min_u \mathcal{L}(u, \mathbb{T}) \quad \text{s.t.} \quad 0 < \dot{S}_{\text{civic}}(u) < \dot{S}_{\text{crit}},$$

  where $\mathcal{L}$ balances utility and resilience, and $\dot{S}_{\text{crit}}$ is calibrated from historical near-failures.

A.4 Data Sources

Field	Sources
Φ	World Bank WDI, VIIRS night lights, OpenAlex citations, USPTO patents
$\sqsubseteq$	UN Comtrade, AIS shipping, mobile CDR, internet peering (CAIDA)
S	FRED volatility, X sentiment, NAICS diversity, job transition data

Table 1: Data sources for RSVP field estimation.