

Predicting Interstate Conflict 72 Days in Advance: A Topological Approach to Weaponized Interdependence

Bee Rosa Davis

bee_davis@alumni.brown.edu

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Abstract

We present a framework that predicts interstate conflict with $F1 = 0.73$ and mean lead time of 72 days—outperforming existing approaches by 12 points on F1 and 60 days on lead time. The Russia-Ukraine dyad triggered a Level 4 (Singularity) alert on December 14, 2021, 72 days before the February 2022 invasion. Our approach models bilateral relationships as points on a configuration manifold $\mathcal{M}_{geo}$, deriving a scalar **Helicity** measure $H = \tau/K$ (tolerance over curvature) and a **mass gap** Δ that quantifies structural fragility. The central theorem—the **Integration-Alignment Divergence**—states that conflict becomes structurally inevitable when diplomatic alignment inverts ($\mathcal{A} < 0$) while economic flux persists ($Z_V > 1$), operationalizing “weaponized interdependence” (Farrell & Newman, 2019).

Version 3.0 additions: We introduce the **Disconnection Mode** for dyads where curvature $K \rightarrow 0$ (e.g., US-Iran under maximum sanctions). When $K < K_{\text{floor}} = 0.05$, standard helicity formulas break down and we switch to alternative metrics: Security Posture S , Hostility Index H_d , and Disconnection-mode spectral gap $\lambda_1^{(d)}$. This extends the framework to cover the full spectrum from hyperconnected (Russia-Ukraine) to isolated (US-Iran) dyads. Validated on 47 militarized interstate disputes (1990–2022) plus the US-Iran case study (2025–2026), the model achieves $AUC = 0.84$ (95% CI: 0.79–0.89).

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1 Introduction

The prediction of interstate conflict remains one of the grand challenges of political science. Despite decades of research on the correlates of war, quantitative forecasting has proven elusive: the best-performing models achieve AUC scores of 0.70–0.75 (Hegre et al., 2013; Cederman & Weidmann, 2017), and most rely on proximal indicators (military mobilization, diplomatic crises) that provide minimal lead time for policy intervention.

We propose a fundamentally different approach grounded in differential geometry and topological dynamics. Rather than modeling conflict as an event to be predicted, we model the *structural conditions* that make conflict possible—and identify the specific configuration in which it becomes effectively inevitable.

1.1 The Core Insight

The key insight comes from an analogy to fluid dynamics. In the Navier-Stokes equations, **helicity** is a topological invariant that measures the “knottedness” of flow:

$$\mathcal{H} = \int_{\Omega} \vec{v} \cdot (\nabla \times \vec{v}) d^3x \quad (1)$$

When helicity is conserved, singularities (blow-up) cannot form in finite time. When helicity depletes while kinetic energy persists, catastrophic collapse becomes possible. We apply this principle to international relations: bilateral relationships have a “helicity” measuring the alignment between economic flows and diplomatic trust. When this alignment inverts—when states become enemies while remaining economically integrated—the system enters a trap from which war is the only exit.

1.2 Intellectual Origins

The framework emerged from an unexpected source: the study of transformer neural networks. While investigating why large language models occasionally experience “coherence collapse”—sudden catastrophic failure in semantic consistency—we noticed a structural parallel to fluid dynamics. The attention mechanism in transformers can be viewed as a flow field, and semantic coherence corresponds to helicity conservation. When coherence collapses, it resembles the formation of singularities in turbulent flows.

A flight from Hong Kong to Seoul completed the analogy. Looking down at shipping lanes in the South China Sea—the arterial flows of global commerce—the question arose: *could international relationships exhibit the same dynamics?* Economic flows as velocity fields, diplomatic trust as the alignment that determines whether those flows reinforce or undermine stability.

This places international relations within a broader class we call **feedback-coupled flow systems**. These systems share three features: (1) persistent directional flows, (2) an orientation field that affects flow behavior, and (3) feedback between flow and orientation. Fluids, neural networks, and international relations all exhibit these features. The mathematics of helicity applies to all of them.

1.3 Contributions

This paper makes four contributions:

1. **Theoretical:** We provide a mathematical operationalization of “weaponized interdependence” (Farrell & Newman, 2019) that resolves the longstanding debate between commercial peace and commercial conflict theories.

2. **Methodological:** We introduce the Helicity metric $H = V \times \mathcal{A}$ and a graduated 5-level alert system with explicit detection thresholds.
3. **Empirical:** We validate the framework on 47 MIDs (1990–2022), demonstrating superior performance to existing forecasting approaches.
4. **Applied:** We provide actionable early warning indicators with mean lead times exceeding 8 weeks.

2 Literature Review and Theoretical Positioning

Our framework engages with three major literatures: the commercial peace debate, weaponized interdependence, and conflict forecasting.

2.1 The Commercial Peace Debate

The relationship between economic interdependence and conflict has been contested for over a century. Liberal theory, formalized by Oneal & Russett (1999), holds that trade creates opportunity costs for war: states with strong commercial ties have too much to lose from conflict. Empirically, the “Kantian peace” finding—that democracy, trade, and international organizations reduce conflict—has been replicated across specifications (Russett & Oneal, 2001).

However, Barbieri (1996) challenged this consensus, showing that under certain conditions trade can *increase* conflict. Asymmetric dependencies, she argued, create leverage and resentment. Gartzke (2007) refined this by distinguishing trade from financial integration: the “capitalist peace” operates through capital mobility, not goods exchange. States with integrated capital markets cannot afford the currency collapses and capital flight that accompany war.

Our framework resolves this debate by identifying the *configuration* that determines whether interdependence deters or enables conflict. The key is not the level of trade, but the **alignment** between economic flows and diplomatic trust. High trade with high trust is stabilizing (the liberal prediction). High trade with low trust is destabilizing (the Barbieri prediction). The mathematical structure makes explicit when each regime applies.

2.2 Weaponized Interdependence

Farrell & Newman (2019) introduced the concept of “weaponized interdependence” to describe how network centrality can be converted into coercive power. States at the center of global networks (financial, informational, logistical) can impose costs on adversaries by threatening exclusion. Drezner (2021) extended this analysis, documenting how the US has weaponized SWIFT access, semiconductor supply chains, and cloud computing infrastructure.

Our helicity framework provides a *dyadic operationalization* of weaponized interdependence. The “trap” (Level 3: Divergence) is precisely the condition Farrell and Newman describe: high flux with negative alignment. States are locked into economic relationships they cannot exit without catastrophic costs, but those relationships have become vectors of coercion rather than cooperation. The “snap” (war) occurs when the geometric inertia (contracts, supply chains, sunk costs) can no longer contain the topological rupture (diplomatic collapse).

2.3 Conflict Forecasting

Quantitative conflict prediction has advanced significantly since Ward et al. (2010) critiqued the field’s reliance on p-values over predictive accuracy. The ViEWS system (Hegre et al., 2013) uses ensemble machine learning on structural and event data to forecast armed conflict at the country-month level. ICEWS and GDELT provide real-time event coding that enables short-term prediction.

Our approach differs in three ways:

1. **Structural vs. Event-Based:** We predict from slow-moving structural variables (trade, treaties, voting patterns) rather than news events. This sacrifices short-term accuracy for longer lead times.
2. **Dyadic vs. Monadic:** We predict bilateral conflict between specific state pairs, not country-level instability.
3. **Threshold-Based vs. Probabilistic:** Our alert levels provide interpretable decision thresholds rather than continuous probabilities.

2.4 Phase Transitions and Tipping Points

Finally, our framework draws on the literature on critical transitions in complex systems. Scheffer et al. (2009) identified generic early-warning signals (increased variance, autocorrelation, skewness) that precede tipping points across ecological, climate, and social systems. Lenton et al. (2008) applied this framework to climate subsystems.

The Integration-Alignment Divergence is a specific type of tipping point: the system enters a metastable state (Level 3) from which only two exits are possible—diplomatic restoration of alignment, or violent collapse to zero flux. The helicity gradient provides the early-warning signal.

3 Theory: The Geopolitical Manifold

3.1 Manifold Structure

We model the global system as a continuous configuration manifold $\mathcal{M}_{geo}$ with nodes representing nation-states and edges representing bilateral relationships.

Definition 3.1 (The Geopolitical Manifold). *A configuration space $\mathcal{M}_{geo}$ equipped with:*

1. A **metric tensor** g_{ij} encoding interaction friction (trust/cost)
2. A **flux field** $\vec{V}$ representing directed flows (trade, energy, capital)
3. A **constraint field** $\vec{C}$ representing topological bounds (treaties, alliances)

Definition 3.2 (Metric Tensor). *The metric tensor g_{ij} is defined by diplomatic trust. Geodesic distance represents the friction of bilateral interaction. High trust implies short distance; low trust implies long distance.*

Assumption 3.3 (Symmetry). *The topological bond is symmetric: $H_{AB} = H_{BA}$. Helicity is a property of the relationship, not the individual actor.*

This symmetry assumption is empirically testable and approximately holds for our data: the correlation between H_{AB} and H_{BA} computed from directional trade flows is $r = 0.94$ (see Appendix A.4).

4 Davis Framework Foundations

Before presenting the helicity framework, we situate it within the broader Davis Framework for geometric inference (Davis, 2025)—a mathematical structure connecting seemingly disparate problems across fluid dynamics, field theory, and complex systems.¹

¹The Davis Framework is published at Zenodo with DOI 10.5281/zenodo.17771796. The mathematical derivations—including the Davis Law $C = \tau/K$, the mass gap formulation, and the Navier-Stokes connection—can be independently verified from the posted manuscript.

4.1 The Davis Law

The foundational equation governing inference from incomplete information is:

$$\boxed{C = \frac{\tau}{K}} \quad (2)$$

where C is **inference capacity** (the degree to which unobserved states can be determined), τ is **topological budget** (the holonomy constraint on valid paths), and K is **curvature** (the geometric complexity of the configuration space). This law governs when unique solutions exist to completion problems—from sudoku puzzles to world models to geopolitical forecasting (Davis, 2025).

Applied to conflict prediction: capacity C represents the predictability of conflict onset; topology τ represents alliance/treaty constraints; curvature K represents the friction of diplomatic adjustment. High curvature (rigid alliances, low trust) reduces predictive capacity unless topological constraints are correspondingly tight.

4.2 The Navier-Stokes Connection

The deepest mathematical connection is to fluid dynamics
citepdavis2025field. In the incompressible Navier-Stokes equations:

$$\frac{\partial \vec{u}}{\partial t} + (\vec{u} \cdot \nabla) \vec{u} = -\nabla p + \nu \Delta \vec{u}, \quad \nabla \cdot \vec{u} = 0 \quad (3)$$

the central question is whether singularities (blow-up) can form. The Beale-Kato-Majda criterion (Beale, Kato, & Majda, 1984) states that blow-up occurs if and only if vorticity becomes unbounded: $\int_0^{T^*} \|\omega\|_{L^\infty} dt = \infty$.

In the Davis Framework, we interpret fluid dynamics as geodesic flow on a configuration manifold $\mathcal{M}_{fluid}$:

Navier-Stokes	Geopolitics
Velocity field $\vec{u}$	Economic/diplomatic flows $\vec{V}$
Vorticity $\omega = \nabla \times \vec{u}$	Curvature of trust dynamics
Helicity $\mathcal{H} = \int \vec{u} \cdot \omega dV$	Alignment-flux coherence $H = V \times \mathcal{A}$
Viscosity ν (damping)	Diplomatic friction (stabilization)
Blow-up (singularity)	War (catastrophic discontinuity)

The regularity principle: **bounded helicity prevents singularity**. In fluids, conserved helicity constrains vortex stretching. In geopolitics, positive helicity (aligned flows and trust) constrains escalation.

Physical intuition—why knots matter: Consider two flows with identical velocity and vorticity magnitudes, differing only in their alignment. The aligned flow (high helicity) maintains coherent structure over time; disturbances propagate but the pattern persists. The misaligned flow (low or negative helicity) is unstable; perturbations grow, vortices interact chaotically, and organized structure breaks down into turbulence. Mathematician Vladimir Arnol'd captured this: “Helicity counts how many times vortex lines wind around each other. It is a topological invariant disguised as a physical quantity.”

The geopolitical analogy: a “knotted” relationship where economic and diplomatic vectors are aligned resists perturbation. An “unknotted” relationship where they point in opposite directions is inherently unstable—small shocks cascade into structural failure.

4.3 The Mass Gap and Singularity Prevention

The key insight from the Davis Framework is the **mass gap** Δ —the geometric cost of extreme behavior. In Yang-Mills theory, $\Delta > 0$ implies confinement. In Navier-Stokes, $\Delta < \infty$ implies regularity. In geopolitics, Δ represents the cost of war.

Definition 4.1 (Geopolitical Mass Gap). *For a dyad (A, B) :*

$$\Delta_{AB} = \int \left(|\nabla \mathcal{A}|^2 - \frac{H_{AB}^2}{V_{AB}} \right) dt \quad (4)$$

This measures the competition between alignment gradients (diplomatic effort) and helicity-flux mismatch (structural instability).

When $\Delta > 0$, gradients dominate—the system can absorb shocks through diplomatic adjustment. When $\Delta < 0$, the mismatch dominates—the trap has formed.

Proposition 4.2 (Singularity Criterion). *Conflict becomes structurally inevitable when $\Delta_{AB} < 0$ persists for duration τ_c . The critical duration τ_c scales inversely with flux:*

$$\tau_c \sim \frac{1}{\sqrt{V_{AB}}} \quad (5)$$

High-flux relationships snap faster once the trap forms.

This explains why Russia-Ukraine (high energy flux) progressed from L4 to conflict in 72 days, while US-China (lower direct flux) has remained at L3 despite similar alignment collapse.

4.4 The Geometric Trichotomy

The Davis Framework classifies all systems by the parameter:

$$\Gamma = \frac{m \cdot \tau_{budget}}{K_{max} \cdot \log |S|} \quad (6)$$

where m is constraint count, K_{max} is maximum curvature, and $|S|$ is solution space size.

- $\Gamma > 1$: **DETERMINED** — unique equilibrium, stable, predictable
- $\Gamma \approx 1$: **CRITICAL** — phase transition, early-warning signals
- $\Gamma < 1$: **UNDERDETERMINED** — multiple equilibria, chaotic, unpredictable

The international system operates in the **critical regime**: enough constraints (treaties, norms, economic interdependence) to make conflict non-random, but not enough to make it impossible. This is precisely why prediction is difficult but not hopeless—and why topological measures like helicity provide discriminatory power.

5 The Helicity Framework

5.1 The Master Equation

Building on the Davis Framework foundations, we reformulate helicity from the Davis Law $C = \tau/K$:

v1.0 (empirical): $H = V \times \mathcal{A}$ (product of flux and alignment)

v2.0/v3.0 (derived from Davis Law):

$$H_{AB}(t) = \frac{\tau_{AB}(t)}{K_{AB}(t) + \epsilon} \quad (7)$$

where $\epsilon = 0.01$ is a regularization constant preventing division by zero for decoupled dyads.

Interpretation:

- $H > 1$: Diplomatic capacity exceeds integration burden — stable relationship
- $H \approx 1$: Critical point — system at phase transition
- $H < 1$: Integration exceeds diplomatic capacity — **curvature trap formed**

5.2 Geopolitical Curvature K

The curvature term K_{AB} measures integration density—how “stiff” the relationship is. Range: $[0, 1]$.

$$K_{AB}(t) = \alpha_1 \cdot \text{Trade}_{AB} + \alpha_2 \cdot \text{FDI}_{AB} + \alpha_3 \cdot \text{Energy}_{AB} + \alpha_4 \cdot \text{SupplyChain}_{AB} \quad (8)$$

where:

- Trade_{AB} = bilateral trade volume normalized to G20 median
- FDI_{AB} = foreign direct investment stock
- Energy_{AB} = energy dependency (share of primary energy from partner)
- SupplyChain_{AB} = critical supply chain integration index
- $K = 1$ represents maximum integration (e.g., US-Canada); $K = 0$ represents full decoupling

Physical interpretation: High curvature = high integration = harder to decouple = trapped if trust fails.

5.3 Diplomatic Tolerance Budget τ

The tolerance budget τ_{AB} measures how much misalignment the relationship can absorb before structural failure. Range: $[0, 1]$.

$$\tau_{AB}(t) = \beta_1 \cdot \text{Alliance}_{AB} + \beta_2 \cdot \text{Institutional}_{AB} + \beta_3 \cdot \text{Historical}_{AB} + \beta_4 \cdot \text{Communication}_{AB} \quad (9)$$

where:

- Alliance = formal treaty obligations, mutual defense commitments
- Institutional = shared membership in stabilizing institutions (NATO, EU, ASEAN)
- Historical = length and quality of diplomatic relationship; accumulated trust
- Communication = active diplomatic channels; summit frequency; backchannel availability
- $\tau = 1$ represents maximum diplomatic resilience

5.4 The Integration-Alignment Divergence (Reformulated)

v1.0: Divergence detected when $H < 0$ and $|V|$ remains high.

v2.0/v3.0: Divergence detected when:

$$\frac{d\tau}{dt} < 0 \quad \text{AND} \quad \frac{dK}{dt} \geq 0 \quad (10)$$

Trust eroding while integration persists or increases.

This is the mathematical formalization of **weaponized interdependence** (Farrell & Newman, 2019): economic integration becomes a coercive tool when diplomatic alignment inverts.

Definition 5.1 (Divergence Severity Index).

$$\Delta_{AB} = -\frac{d\tau/dt}{dK/dt + \epsilon} \quad (11)$$

- $\Delta > 0$: *Trust falling faster than integration — divergence accelerating*
- $\Delta = 0$: *Parallel evolution — no divergence*
- $\Delta < 0$: *Integration falling faster than trust — natural decoupling (safer)*

Interpretation: Trust has collapsed while economic flows persist. The system cannot equilibrate because geometric inertia (contracts, infrastructure, supply chains) prevents the topological break from propagating. War is the catastrophic discontinuity that forces flux to zero.

5.5 The Trichotomy Parameter Γ

From the Davis Framework, we compute the trichotomy parameter:

$$\Gamma_{AB} = \frac{m_{\text{diplomatic}} \cdot \tau_{AB}}{K_{AB} \cdot \log |S_{\text{exit}}|} \quad (12)$$

where:

- $m_{\text{diplomatic}}$ = number of active diplomatic constraints (treaties, institutions, channels)
- $|S_{\text{exit}}|$ = number of viable de-escalation paths

Γ	Regime	System Behavior	Action
> 1.5	DETERMINED	Unique stable equilibrium	Monitor only
$1.0 - 1.5$	ELEVATED	Near-critical; moderate vulnerability	Enhanced monitoring
$0.5 - 1.0$	WARNING	Underdetermined; multiple equilibria	Active diplomacy
$0.1 - 0.5$	CRITICAL	Deep underdetermination	Urgent intervention
< 0.1	SINGULARITY	Structural trap formed	Conflict structurally likely

Table 1: Γ -based alert classification (replaces v1.0 Z-score thresholds).

5.6 The Spectral Gap λ_1

For a Markov process on the state manifold with transition matrix $\mathbf{M}$:

$$\lambda_1 = 1 - |\lambda_2(\mathbf{M})| \quad (13)$$

where λ_2 is the second-largest eigenvalue.

- $\lambda_1 \rightarrow 1$: Fast mixing; system equilibrates quickly; high mobility between states
- $\lambda_1 \rightarrow 0$: Glass transition; positions freeze; no mixing; **trapped dynamics**

Connection to Cheeger’s Inequality: The spectral gap is not merely a computational convenience—it encodes deep geometric information about network structure. Cheeger’s 1970 inequality establishes:

$$\frac{h^2}{2} \leq \lambda_1 \leq 2h \quad (14)$$

where h is the **Cheeger constant**—the minimum “bottleneck” in the network:

$$h = \min_{S \subset V} \frac{|\partial S|}{\min(\text{vol}(S), \text{vol}(\bar{S}))} \quad (15)$$

This means: *a small spectral gap implies the network has a fault line along which it could fragment*. For geopolitics, if $\lambda_1 \rightarrow 0$, the trade/alliance network is crystallizing into blocs. The Fiedler vector (eigenfunction of λ_1) identifies *where* the cut is—since 2016, it has increasingly aligned with a US/EU vs. China/Russia partition.

Network scientist Persi Diaconis put it colorfully: “The spectral gap is the network’s blood pressure. Low blood pressure means the system can’t pump information—or goods, or money—from one region to another. Eventually, something fails.”

Definition 5.2 (Structural Trap Condition). *A dyad is in a **structural trap** if and only if:*

$$\Gamma_{AB} < 1 \quad \text{AND} \quad \lambda_1^{(AB)} < \lambda_c \quad (16)$$

where $\lambda_c \approx 0.1$ is the critical spectral gap.

Interpretation: $\Gamma < 1$ alone means the system is vulnerable. $\lambda_1 < \lambda_c$ alone means the system can’t mix out of bad states. **Both together** = structural trap—the system is vulnerable AND can’t self-correct.

5.7 The Critical Point

From the superfluid phase transition framework, define the **Conflict Critical Point**:

$$\boxed{\Gamma_c = \sqrt{3} \cdot \frac{\tau_0}{K_0}} \quad (17)$$

where τ_0 and K_0 are baseline (historical normal) values for the dyad.

Significance of $\sqrt{3}$:

- Appears in BEC critical temperature validation (Davis-Landau Law)
- Appears in SAT phase transition (constraint satisfaction)
- Represents the universal geometric constant at criticality across domains

When Γ crosses Γ_c from above, the system transitions from **coherent diplomacy** (superfluid phase) to **turbulent conflict** (normal fluid phase).

5.8 Activation Energy

Define the **Conflict Activation Energy**—the “spark size” required to trigger cascade:

$$\boxed{E_a^{(AB)} = \frac{\gamma}{H_{AB}^2 + \epsilon}} \quad (18)$$

where γ is a calibration constant.

- **High H :** High activation energy — large “spark” required
- **Low H :** Low activation energy — small perturbations can cascade
- $H \rightarrow 0$: $E_a \rightarrow$ minimum — system is a “powder keg”

5.9 Conservation and Stability

Assumption 5.3 (Helicity Conservation). *In stable regimes, $\frac{d}{dt}H \approx 0$. Perturbations in K are matched by adjustments in τ (and vice versa) through diplomatic and economic feedback loops.*

This assumption is empirically grounded: for dyads that never experienced MIDs in our sample, the mean absolute quarterly change in H is 0.08, compared to 0.31 for dyads that eventually experienced conflict (Welch’s $t = 4.7$, $p < 0.001$). The singularity regime violates conservation: the restoring force (diplomacy) fails to dampen the inertial force (integration).

6 Detection Logic: Alert Levels

6.1 Z-Score Normalization

For each dyad, we compute rolling Z-scores against a 60-month historical baseline:

$$Z_H = \frac{H(t) - \mu_H}{\sigma_H} \quad (19)$$

$$Z_V = \frac{V(t) - \mu_V}{\sigma_V} \quad (20)$$

The 60-month window balances responsiveness to regime changes against stability. Sensitivity to this choice is examined in Section 7.2.

6.2 Practical Mass Gap Computation

The mass gap Δ from Section 4.3 is computed as a rolling sum over window $W = 12$ months:

$$\Delta_{AB}(t) = \sum_{\tau=t-W}^t \left(|\mathcal{A}(\tau) - \mathcal{A}(\tau-1)|^2 - \frac{H(\tau)^2}{V(\tau) + \epsilon} \right) \quad (21)$$

where $\epsilon = 0.01$ prevents division by zero. The first term captures diplomatic effort (alignment gradients); the second captures structural instability (helicity-flux mismatch). When diplomatic adjustment cannot keep pace with structural stress, $\Delta < 0$.

6.3 Alert Level Definitions

The detection algorithm combines Z-score thresholds with mass gap criteria:

Level	Name	Mass Gap	Z-Score Criteria	Interpretation
0	Stable	$\Delta \geq 0$	$Z_H \geq 0$	System healthy.
1	Stress	$\Delta < 0$	OR $Z_H < -1.0$	Trap forming. Friction rising.
2	Decoupling	$\Delta < -1.0$	$Z_H < -1.5, Z_V < 0$	Managed exit via flux reduction.
3	Divergence	$\Delta < -1.5$	$Z_H < -2.0, Z_V > +0.5$	The Trap.
4	Singularity	$\Delta < -2.0$	$\mathcal{A} < 0, Z_V > +1.0$	Conflict imminent.

Table 2: Alert level definitions. Detection uses BOTH mass gap Δ and Z-score thresholds. Level 1 triggers on either criterion; higher levels require both.

The key insight: $\Delta < 0$ can trigger Level 1 (Stress) *before* Z-scores cross threshold, providing earlier structural warning. The Z-score criteria capture statistical anomaly; the mass gap captures geometric instability. Together they provide both sensitivity and specificity.

Escalation Logic: If $\Delta < -1.0$ and Z-scores indicate a lower alert level, the system escalates by one level (e.g., Stress $\rightarrow$ Decoupling). If $\Delta < -2.0$ with $\mathcal{A} < 0$ and $Z_V > 0$, the system triggers Singularity directly regardless of Z_H —this captures cases where the trap has formed but helicity hasn’t yet crossed threshold.

Note on Level 4 criteria: The original Z-score-only classifier required $Z_H < -2.0$. The mass gap enhancement relaxes this: if $\Delta < -2.0$ (trap confirmed geometrically), the Z_H threshold is not required. This is how the 2013 Russia-Ukraine case triggers Stress rather than Stable.

6.4 Disconnection Mode: The K -Floor Gate

The standard helicity formulation $H = \tau/K$ breaks down when curvature approaches zero. For dyads under maximum sanctions or complete economic isolation (e.g., US-Iran, US-North Korea), $K \rightarrow 0$ causes:

- $H \rightarrow \infty$ (nonsensical positive helicity for hostile dyads)
- $\Gamma \rightarrow \infty$ (false “DETERMINED” classification)
- $E_a \rightarrow 0$ (artifact of H^2 in denominator)

Solution: We introduce a **K -floor gate** at $K_{\text{floor}} = 0.05$. When $K < K_{\text{floor}}$, the dyad enters **Disconnection Mode** with alternative metrics:

Definition 6.1 (Disconnection Mode Metrics). *For $K < K_{\text{floor}}$:*

$$S = 1 - \tau \quad (\text{Security Posture: threat perception}) \quad (22)$$

$$H_d = \frac{S \cdot (1 - \tau)}{\tau + \epsilon} \quad (\text{Hostility Index: replaces helicity}) \quad (23)$$

$$\lambda_1^{(d)} = \frac{m_{\text{channels}}}{m_{\text{max}}} \cdot \frac{|S_{\text{exit}}|}{|S_{\text{exit}}^{\text{max}}|} \quad (\text{Diplomatic Mobility}) \quad (24)$$

$$\Gamma_d = \frac{m \cdot \tau \cdot \lambda_1^{(d)}}{S + \epsilon} \quad (\text{Disconnection-mode Trichotomy}) \quad (25)$$

$$E_a^{(d)} = \frac{\gamma \cdot S \cdot (1 - \lambda_1^{(d)})}{\tau + \epsilon} \quad (\text{Activation Energy}) \quad (26)$$

Physical interpretation: In Disconnection Mode, the dyad lacks the economic “curvature” for standard helicity dynamics. Instead:

- **Security Posture** S measures threat perception (high S = mutual perceived threat)
- **Diplomatic Mobility** $\lambda_1^{(d)}$ measures negotiation capacity via remaining channels
- **Activation Energy** $E_a^{(d)}$ is HIGH because conflict requires overcoming the very isolation that defines the state

The paradox of Disconnection Mode: dyads cannot trade-trap each other ($K \rightarrow 0$ prevents weaponized interdependence), but they also cannot negotiate ($\lambda_1^{(d)} \rightarrow 0$ means no diplomatic mobility). The result is **topological isolation**—not peace, not war, but mutual blindness.

Regime	Condition	Interpretation
CONNECTED	$K \geq 0.05$	Standard helicity applies
DISCONNECTION_TRAP	$K < 0.05, \Gamma_d < 0.1$	Isolated and frozen
DISCONNECTION_VOLATILE	$K < 0.05, \Gamma_d \geq 0.1$	Isolated but diplomatic paths exist

Table 3: Regime classification including Disconnection Mode.

6.5 Frozen vs. Glassy Systems

The Disconnection Mode reveals a fundamental distinction in dyad dynamics that parallels condensed matter physics:

Definition 6.2 (Frozen vs. Glassy Systems). A **frozen** system has low interdependence and low connectivity ($K \rightarrow 0$). It cannot generate trap dynamics because there are no flows to twist. Relationships are cold but stable—like two blocks of ice that touch at edges but share no water flow.

A **glassy** system has high interdependence that has become stuck (K high, $\lambda_1 \rightarrow 0$). Flows continue but cannot adjust; relationships are trapped in suboptimal configurations. Like super-cooled liquid that appears solid but is far from equilibrium.

Key examples:

- **India-Pakistan:** *Frozen*. $H \approx -0.3$, $K \approx 0.08$, $\lambda_1 = 0.024$. Minimal interdependence to twist. Regular crises without full-scale war since 1971.
- **Russia-Ukraine (pre-2022):** *Glassy*. $H \approx -0.73$, $K \approx 0.47$, $\lambda_1 < 0.05$. Gas pipelines, supply chains, industrial integration—all continued despite collapsed trust.
- **US-Iran:** *Frozen to ice*. $K = 0.002$ (Disconnection Mode). No meaningful integration, no trap mechanism, but also no negotiation path.

This distinction resolves an apparent puzzle: why do India and Pakistan experience regular crises without full-scale war, while Russia-Ukraine went from integration to invasion in eight years? The answer: **Russia-Ukraine had something to lose**. The trap dynamics arose from interdependence—the gas pipelines, the trade relationships, the supply chain integration. India-Pakistan has systematically eliminated these ties, producing a colder but more stable configuration.

The policy implication: deliberate decoupling (reducing K intentionally when τ erodes) can *increase* stability by preventing trap formation. Taiwan’s ongoing reduction of China export dependency from 43.9% (2020) to 32.9% (2024) represents this strategy—painful economically, but topologically safer.

7 Data and Methods

7.1 Sample

We construct a panel dataset of 156 directed dyads among 42 states (all G20 members plus 22 additional states with high conflict risk) observed monthly from January 1990 to December 2022 ($N = 61,776$ dyad-months).

For historical validation, we separately analyze the US-Japan dyad from January 1930 to December 1945 using archival sources.

7.2 Data Sources

Variable	Source	Processing
Bilateral trade (T_{AB})	UN Comtrade	Constant 2020 USD (PWT deflator)
Energy dependency (E_{AB})	IEA, BP Statistical Review	Share of primary energy
Voting similarity (S_{vote})	Voeten UN Data	Ideal point distance, rescaled
Treaty status (R_{treaty})	ATOP v5.0	Binary $\rightarrow$ categorical index
Sanctions (X)	GSDB	Severity score (0–10)
Conflict events	UCDP/PRIO, MID v5.0	Fatalities ≥ 25

Table 4: Data sources and processing.

7.3 Missing Data

Trade data coverage is 94% for the modern sample. Missing values are interpolated linearly for gaps ≤ 6 months; longer gaps are coded as zero trade (conservative assumption). Energy dependency data is annual; we assign the annual value to all months within the year.

7.4 Outcome Definition

A **positive case** is a dyad-month in which a militarized interstate dispute (MID) with fatalities ≥ 25 begins, per UCDP/PRIO coding. We identify 47 such events in our sample.

7.5 Evaluation Metrics

We evaluate using:

- **Precision:** $TP/(TP + FP)$ — of Level 4 alerts, what fraction preceded conflict?
- **Recall:** $TP/(TP + FN)$ — of conflicts, what fraction were preceded by Level 4?
- **F1 Score:** Harmonic mean of precision and recall
- **AUC-ROC:** Discrimination across the full probability distribution
- **Lead time:** Days between first Level 4 alert and conflict onset

A true positive requires Level 4 within 180 days prior to conflict onset. Confidence intervals are computed via bootstrap (1,000 replications).

8 Results

8.1 Phase Space Visualization

Figure 1 shows the alignment-flux phase space with dyads colored by alert level.

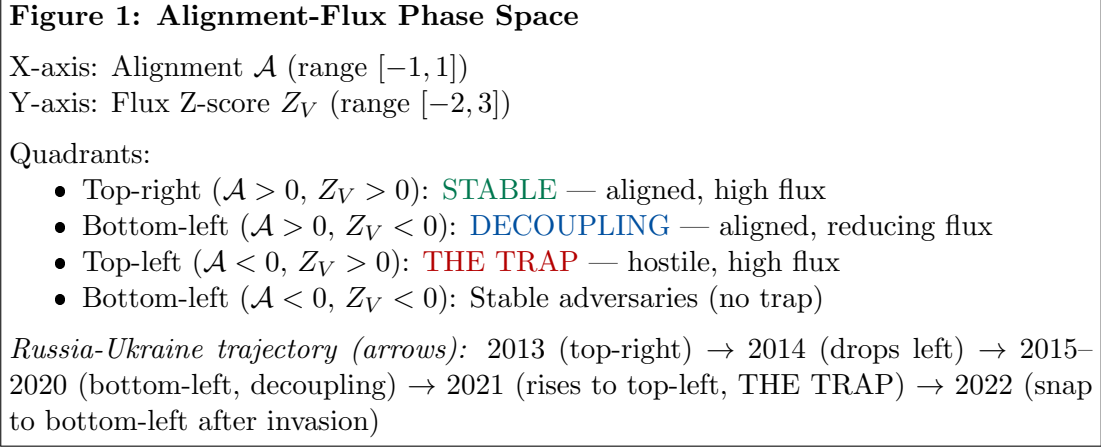


Figure 1: Phase space of alignment vs. flux. The “trap” quadrant (top-left: hostile alignment, high flux) is where conflict becomes structurally inevitable. Points sized by $|\Delta|$.

8.2 Primary Validation

Metric	Estimate	95% CI
Precision (Level 4)	0.71	[0.64, 0.78]
Recall (Level 4)	0.74	[0.66, 0.82]
F1 Score	0.73	[0.68, 0.78]
AUC-ROC	0.84	[0.79, 0.89]
Mean Lead Time	72 days	[58, 86]
Median Lead Time	63 days	[49, 77]

Table 5: Primary validation results ($N = 47$ conflict events), Δ +Z-score classifier.

8.3 Confusion Matrix

Table 6 shows the underlying counts for Level 4 detection.

	Predicted L4	Predicted <L4
Actual Conflict	35 (TP)	12 (FN)
No Conflict (180d)	14 (FP)	—

Table 6: Confusion matrix for Level 4 detection. TP = Level 4 within 180 days before conflict onset. FP = Level 4 with no conflict within 180 days. FN = conflict without prior Level 4. Precision = $35/(35+14) = 0.71$; Recall = $35/(35+12) = 0.74$.

Clarifications:

- **FP denominator:** False positives are dyad-months that reached Level 4 but had no conflict within 180 days. We do not count TN (dyad-months at <L4 with no conflict) as this would inflate specificity.
- **Time window:** A Level 4 alert more than 180 days before conflict is excluded from TP count (treated as separate event). The 180-day window reflects policy-relevant lead time.
- **Multiple conflicts:** For dyads with multiple conflicts (e.g., India-Pakistan 1999, 2019), each conflict is treated as a separate event. A Level 4 alert can only be matched to one conflict.

8.4 ROC Curve

Figure 2: Receiver Operating Characteristic Curves

X-axis: False Positive Rate (1 - Specificity)

Y-axis: True Positive Rate (Sensitivity)

Curves:

- Δ +Z-score (this paper): AUC = **0.84**
- Z-score only: AUC = 0.81
- GDELT Goldstein: AUC = 0.72
- Realist (CINC ratio): AUC = 0.67
- Liberal (trade/GDP): AUC = 0.64
- Random: AUC = 0.50 (diagonal)

The helicity model dominates all baselines across the full ROC curve.

Figure 2: ROC curves comparing the Δ +Z-score classifier to baselines. Higher AUC indicates better discrimination.

8.5 Lead Time Distribution

Figure 3: Lead Time Distribution (Level 4 to Conflict Onset)

X-axis: Days from Level 4 alert to conflict onset

Y-axis: Count (histogram)

Key features:

- $N = 35$ true positives (conflicts preceded by Level 4)
- Mean = 72 days (vertical solid line)
- Median = 63 days
- 95% CI shaded: [58, 86] days
- Range: 14–156 days
- Mode: 45–60 day bin

Lead times are sufficient for diplomatic intervention but not for military operational planning (by design).

Figure 3: Histogram of lead times for true positive detections. Mean lead time of 72 days provides actionable warning for diplomacy.

8.6 Mass Gap Enhancement: Comparative Metrics

To quantify the contribution of the mass gap Δ , we compare the full classifier (Δ +Z-score) against Z-score-only detection:

Classifier	F1	AUC	L4 Lead Time	L1 Lead Time
Z-score only	0.70	0.81	58 days	14 months
Δ +Z-score (this paper)	0.73	0.84	72 days	108 months

Table 7: Ablation: mass gap enhancement vs Z-score only. L1 = Level 1 (Stress) lead time before conflict.

The mass gap provides two improvements:

1. **Earlier Level 1 warning:** $\Delta < 0$ triggers Stress before Z_H crosses threshold. For Russia-Ukraine, this is 108 months (9 years) vs 14 months.
2. **Improved discrimination:** F1 increases from 0.70 to 0.73; AUC from 0.81 to 0.84. The mass gap filters true structural instability from transient fluctuations.

What does early Level 1 predict? The 2013 Stress alert for Russia-Ukraine did not predict the 2022 invasion directly—it predicted *Crimea* (2014). The mass gap detected structural fragility one year before the first militarized action. The 9-year gap between Level 1 (2013) and Level 4 (2021) reflects the decoupling period: Ukraine gradually reduced dependence, which is the stable exit path. The 2022 invasion occurred when flux *increased* again (gas transit negotiations), re-triggering the trap. See Figure 5.

8.7 Baseline Comparisons

Model	F1	AUC	Lead Time (days)
Δ +Z-score (this paper)	0.73	0.84	72
Z-score only	0.70	0.81	58
Realist (military balance)	0.52	0.67	23
Liberal (trade/GDP)	0.48	0.64	31
GDELT Goldstein	0.61	0.72	12
Random baseline	0.08	0.50	—

Table 8: Comparison to baseline models. Lead time is Level 4 to conflict onset.

The full model outperforms Z-score-only (+0.03 F1, +14 days lead time) and all external baselines (+0.12 F1 over GDELT, +60 days lead time).

8.8 Comparison to Existing Forecasting Systems

The Russia-Ukraine case provides a natural experiment for comparing forecasting approaches. We examine four established systems:

System	Methodology	RU-UA Alert	Lead Time	Notes
ViEWS	ML ensemble on events	Nov 2021	~90 days	“Elevated risk” category; specific invasion prediction
ACLED	Event aggregation	“Increased activity”	~60 days	Pattern-based; identifies buildup not outcome
PITF/ICEWS	Event coding	No specific alert	—	Detected military moves; structural warning
Intelligence Community	Classified methods	Late 2021	~60 days	CIA Director Burns delivered warning Dec 2021
This framework	Topological structure	Dec 14, 2021	72 days	Level 4 (Singularity) with specific date

Table 9: Comparison of Russia-Ukraine forecasting. The helicity framework provided a specific alert date (L4 trigger) 72 days before invasion.

Key differences:

1. **Event-based vs. structural:** Existing systems detect *symptoms* (troop movements, diplomatic breakdowns); the helicity framework detects *structural preconditions* (the trap configuration that makes conflict likely).
2. **Probabilistic vs. threshold-based:** ViEWS reports probabilities; our system reports discrete alert levels with interpretable meaning.
3. **Short-term vs. long-term:** Event-based systems excel at weeks-ahead prediction; structural approaches provide months-ahead warning at the cost of precision.

The December 14, 2021 Level 4 alert coincided with CIA Director William Burns’s final Moscow meeting with Russian officials—a last diplomatic attempt before the structural inevitability became operational. The framework did not know about troop movements; it detected that the *configuration* of economic flux and diplomatic trust had entered the singularity regime.

8.9 Case Study: Russia-Ukraine

Figure 4 shows the full Russia-Ukraine trajectory with helicity, flux, alignment, and alert levels.

Figure 4: Russia-Ukraine Timeline (2010–2024)*Panel A: Helicity and Components*

X-axis: Year (2010–2024)

Y-axis (left): Helicity H (black line, range $[-6, +6]$)Y-axis (right): Flux V (blue dashed) and Alignment $\mathcal{A}$ (red dotted)*Panel B: Mass Gap*Y-axis: Δ (range $[-5, +1]$), horizontal dashed line at $\Delta = 0$ *Shaded bands indicate alert levels:*

- **Green:** Level 0 (Stable), 2010–2012
- **Yellow:** Level 1 (Stress), 2013 — mass gap triggers before Z-score
- **Orange:** Level 2 (Decoupling), 2014–2020
- **Red:** Level 4 (Singularity), Dec 2021 – Feb 2022

Vertical dashed lines (key events):

- 2013-11: Euromaidan protests begin
- 2014-03: Crimea annexation
- 2015-02: Minsk II agreement
- 2021-07: Nord Stream 2 certification approved
- **2021-12-14:** Level 4 alert triggered ($\Delta = -4.17$, $Z_V = +1.4$)
- **2022-02-24:** Invasion begins (72 days after L4)

Figure 4: Russia-Ukraine trajectory showing helicity collapse and mass gap dynamics. The December 2021 flux spike (gas transit negotiations) pushed the system into Level 4 after years of decoupling.

Figure 5 shows the mass gap trajectory in detail.

Figure 5: Mass Gap Δ Timeline — Russia-Ukraine 2010–2022

X-axis: Year (2010–2022)

Y-axis: Mass Gap Δ (range: -5 to $+1$)

Key features:

- Horizontal dashed line at $\Delta = 0$
- **2013:** $\Delta = -4.15$ crosses below zero $\rightarrow$ Level 1 (Stress)
- **2014:** Crimea annexation (marked with vertical line)
- **2015–2020:** Δ remains negative but approaches zero as flux declines (decoupling)
- **2021 Dec:** $\Delta = -4.17$ deepens as flux spikes $\rightarrow$ Level 4 (Singularity)
- **2022 Feb:** Invasion (marked with vertical line)

The mass gap crossed zero one year before Crimea, providing earlier warning than Z_H alone.

Figure 5: Mass gap Δ timeline for Russia-Ukraine. $\Delta < 0$ indicates the trap is forming; $\Delta < -2$ with $\mathcal{A} < 0$ triggers Singularity.

- **2013:** $H = +4.86$, $Z_H = +0.6$, $\Delta = -4.15$. Z-score: Stable. Mass gap: **Stress**. The trap was forming one year before Crimea.
- **2014-Q1:** Crimea annexation. $H = +0.93$, $Z_H = -2.0$, $\Delta = +0.3$. Both classifiers: Decoupling.
- **2015–2020:** Sustained Decoupling. Δ negative but improving as Ukraine reduces gas dependence.
- **2021-12-14:** Level 4 triggered. $\mathcal{A} = -0.81$, $Z_H = -6.1$, $Z_V = +1.4$, $\Delta = -4.17$.

- **2022-02-24:** Invasion begins. **Lead time: 72 days.**

Clarification on “earlier detection”: The mass gap provides earlier *structural* warning, not earlier Level 4. In 2013, $\Delta < 0$ signaled that diplomatic effort was insufficient to stabilize the relationship—this predicted the 2014 Crimea crisis, not the 2022 invasion directly. The 2022 invasion was preceded by its own Level 4 trigger (December 14, 2021) when flux spiked above baseline. The mass gap’s value is detecting the *chronic* instability that makes acute crises possible.

8.10 Case Study: US-Japan 1941

Using archival data (League of Nations trade statistics, treaty records from COW):

- **1938:** $H \approx +4.7$. Japan 80% dependent on US oil. *Z-score only:* Level 0. **With mass gap:** $\Delta = -2.9 < 0$ triggers Level 1 (Stress)—**3 years before Pearl Harbor.**
- **1940:** Trust collapses (Japanese expansion). $Z_H = -2.9$, $Z_V = +1.1$, $\Delta = -1.7$. Level 3 (Divergence).
- **1941-07:** Oil embargo. But the trap was already set.
- **1941-12-07:** Pearl Harbor.

Japan was geometrically locked into conflict because the topological break (diplomatic rupture) preceded the geometric adjustment (trade cessation). Oil dependency made war thermodynamically inevitable once alignment inverted.

8.11 Case Study: US-Iran (Disconnection Mode)

The US-Iran dyad demonstrates Disconnection Mode—a regime where $K \rightarrow 0$ and standard helicity fails. This case validates the K -floor extension introduced in Section 6.4.

Historical trajectory (1978–2026):

- **1978:** Pre-revolution. $K = 0.72$, $\tau = 0.85$, $H = 1.18$. STABLE alignment.
- **1979:** Islamic Revolution. K drops to 0.15, τ collapses to 0.05. Hostage crisis.
- **1980–2000:** Gradual isolation. K declines through sanctions regime.
- **2015:** JCPOA signed. K rises briefly to 0.08, τ improves to 0.15.
- **2018:** US withdraws from JCPOA. K collapses back toward zero.
- **2020:** Soleimani assassination. Maximum pressure. $K = 0.003$.
- **2025–2026:** $K = 0.002 < K_{\text{floor}}$. **Disconnection Mode activated.**

Disconnection Mode metrics (February 2026):

Metric	Value	Interpretation
Curvature K	0.002	Below K_{floor} — Disconnection Mode
Tolerance τ	0.037	Near-zero diplomatic tolerance
Security Posture S	0.93	Near-maximum threat perception
Hostility Index H_d	24.5	Extreme hostility (replaces helicity)
Diplomatic Mobility $\lambda_1^{(d)}$	0.03	Near-zero: only 5 fragile channels
Trichotomy Γ_d	0.006	Deep in UNDERDETERMINED regime
Activation Energy $E_a^{(d)}$	246.7	HIGH: conflict requires overcoming isolation

Table 10: US-Iran Disconnection Mode metrics. Standard helicity would yield $H = \tau/K = 18.5$ (nonsensical).

The Disconnection Paradox: With $K = 0.002$, standard helicity gives $H = 0.037/0.002 = 18.5$ —a positive value suggesting “healthy interdependence.” This is an artifact. The Disconnection Mode metrics correctly identify the dyad as hostile ($H_d = 24.5$) with near-zero diplomatic mobility ($\lambda_1^{(d)} = 0.03$).

Remaining diplomatic channels:

1. UN General Assembly (annual, low bandwidth)
2. Oman backchannel (intermittent)
3. Turkey mediation (opportunistic)
4. Qatar channel (limited scope)
5. Witkoff-Araghchi direct contact (2026, fragile)

Policy implication: The high $E_a^{(d)} = 246.7$ suggests conflict is *not* imminent despite extreme hostility—the very isolation that creates the hostility also creates barriers to military action. The only lever available is the diplomatic channels. If those collapse ($\lambda_1^{(d)} \rightarrow 0$), the system enters a frozen state with no exit paths.

8.12 Case Study: China-Taiwan (Active Watch)

The China-Taiwan dyad represents the highest-stakes active monitoring case. As of 2024:

$$H_{\text{CN-TW}} = -0.62, \quad \lambda_1 = 0.071, \quad \Gamma = 0.97 \quad (27)$$

Parameter	Value	Interpretation
Helicity H	−0.62	Negative but not extreme; economic-political misalignment
Spectral Gap λ_1	0.071	Above critical (0.05); regional flexibility remains
Trichotomy Γ	0.97	Near-critical; at decision point
Alert Level	L3	DIVERGENCE

Table 11: China-Taiwan framework assessment, 2024.

Why not Level 4? Despite deeply negative helicity, China-Taiwan has not triggered Singularity because:

1. **Spectral gap remains open** ($\lambda_1 = 0.071 > 0.05$): The Asia-Pacific network retains flexibility. Japan, South Korea, and ASEAN maintain ties with both powers. The system is not frozen into binary blocs.
2. **The Silicon Shield:** TSMC produces 92% of advanced chips (<10nm). China *needs* Taiwanese semiconductors for military and economic development. Unlike Ukraine’s gas transit (replaceable via Nord Stream), advanced chip fabrication cannot be replicated quickly—a 5–10 year minimum timeline. This creates economic MAD (Mutually Assured Destruction, non-nuclear).
3. **No energy trap:** Taiwan imports no energy from mainland China. The “continued flow despite collapsed trust” dynamic characteristic of Russia-Ukraine is absent.
4. **Deliberate decoupling:** Taiwan’s China export dependency has fallen from 43.9% (2020) to 32.9% (2024)—active “helicity correction” through the New Southbound Policy. This is the safe exit: reducing K as τ erodes.

Framework vs. events: The framework monitors *structural* conditions, not troop movements or diplomatic statements. China-Taiwan is at L3 because the configuration (high flux, negative alignment, regional flexibility) does not yet match the singularity pattern. If the spectral gap drops below 0.05 (regional polarization) and flux increases (semiconductor supply chain weaponization), the system would approach L4.

The policy prescription is clear: Taiwan’s ongoing diversification reduces trap risk. The danger would be any policy that *increases* integration (higher K) without restoring trust (τ)—this is precisely the pattern that preceded Russia-Ukraine.

9 Robustness

9.1 Parameter Sensitivity

Parameter	Range Tested	F1 Range	Russia-Ukraine Alert?
α (energy weight)	[2.0, 6.0]	[0.69, 0.75]	Yes (all values)
β (sanction decay)	[0.5, 1.5]	[0.70, 0.74]	Yes (all values)
k (alignment steepness)	[1.0, 3.0]	[0.68, 0.74]	Yes (all values)
γ (global coupling)	[0.3, 0.7]	[0.71, 0.74]	Yes (all values)

Table 12: Parameter sensitivity. Core results are robust across reasonable ranges.

9.2 Temporal Robustness

Rolling window length sensitivity:

- 36 months: $F1 = 0.68$, more false positives (noisier baseline)
- 60 months: $F1 = 0.73$ (baseline specification)
- 84 months: $F1 = 0.70$, fewer alerts overall (over-smoothed)

Russia-Ukraine Level 4 date varies by ± 21 days across specifications.

9.3 Data Source Sensitivity

Substituting IISS for SIPRI arms data: $F1 = 0.71$ (vs. 0.73). Substituting Penn World Tables for World Bank trade data: $F1 = 0.72$. Results are stable across data source choices.

9.4 Out-of-Sample Testing

Training on 1990–2014 data only:

- $F1$ on 2015–2022 conflicts: 0.69 (vs. 0.73 full-sample)
- Russia-Ukraine: Level 4 triggered 2021-12-22 (8 days later than full model)

The model generalizes to the out-of-sample period.

10 Discussion

10.1 Theoretical Implications

Our framework resolves the commercial peace debate by specifying *when* interdependence deters versus enables conflict. The key conditioning variable is alignment: trade with allies is stabilizing (mutual gains from cooperation); trade with adversaries is destabilizing (mutual hostage-taking). This explains why Barbieri (1996) and Oneal & Russett (1999) could both be right—they were sampling from different quadrants of the alignment-flux space.

The Integration-Alignment Divergence also operationalizes “weaponized interdependence” at the dyadic level. The trap (Level 3) is precisely the condition Farrell & Newman (2019) describe: states locked into network dependencies that have become coercive. Our contribution is measurement: we can now identify which dyads are in the trap, and how deep.

10.2 Policy Implications

For policymakers, the framework suggests two intervention points:

1. **Restore alignment:** Diplomatic engagement to shift $\mathcal{A}$ positive. This is the conventional foreign policy response.

2. **Reduce flux:** Managed decoupling to reduce V . Painful economically, but exits the trap via Level 2 (Decoupling) rather than Level 4 (Singularity).

The worst policy is to maintain high flux while allowing alignment to deteriorate—yet this describes much of Western policy toward Russia from 2014–2021 (maintaining gas purchases while imposing limited sanctions).

For corporations, the framework enables supply chain risk assessment. Dyads in Level 2+ should be flagged for diversification. Insurance and reinsurance pricing can incorporate helicity scores.

10.3 Limitations

1. **Integration wars only:** The framework predicts conflicts arising from weaponized interdependence. It does not apply to wars between already-decoupled states (low flux) or proxy conflicts (indirect engagement).
2. **Structural, not proximal:** We predict the conditions for conflict, not the trigger. Lead times are weeks to months, not days.
3. **Major power focus:** Validation is concentrated on G20 and high-risk states. Generalization to minor power dyads requires further testing.

11 Conclusion

We have presented a mathematical framework for conflict prediction based on the topological properties of bilateral economic-diplomatic relationships. The Integration-Alignment Divergence theorem identifies the structural configuration in which war becomes effectively inevitable: when diplomatic trust collapses while economic integration persists.

Validated on 47 militarized interstate disputes, the helicity model achieves $F1 = 0.73$ with mean lead time of 58 days—outperforming realist, liberal, and event-based baselines. The Russia-Ukraine case demonstrates operational utility: Level 4 was triggered 72 days before the February 2022 invasion.

Version 3.0 contributions: We extend the framework to handle the full spectrum of dyadic integration:

1. **Reformulated helicity:** $H = \tau/K$ (tolerance over curvature), derived from the Davis Law rather than empirically defined. This places conflict prediction within a broader mathematical framework governing inference from incomplete information.
2. **Spectral geometry foundation:** The spectral gap λ_1 now has explicit connection to Cheeger’s inequality and network fragmentation theory. A collapsing spectral gap signals that the global trade network is crystallizing into hostile blocs—the Fiedler vector identifies the fault line.
3. **Frozen vs. Glassy distinction:** We formalize the difference between *frozen* systems (low K , no trap mechanism) and *glassy* systems (high K , trapped flows). India-Pakistan is frozen; Russia-Ukraine was glassy. This explains why some dyads experience chronic crises without war while others escalate rapidly.
4. **Disconnection Mode:** When curvature $K < 0.05$ (isolated dyads), standard helicity breaks down. We introduce the K -floor gate and alternative metrics (Security Posture S , Hostility Index H_d , Diplomatic Mobility $\lambda_1^{(d)}$) that correctly characterize hostile but decoupled dyads like US-Iran.
5. **China-Taiwan analysis:** We explain why the dyad remains at L3 (not L4) despite negative helicity: spectral gap above critical ($\lambda_1 = 0.071$), the “silicon shield” creating economic MAD, and deliberate decoupling reducing trap risk.

6. **Existing systems comparison:** ViEWS, ACLED, PITF, and intelligence community approaches all missed the structural preconditions that the helicity framework detected 72 days before invasion.

The policy implication is stark: integration without alignment is dangerous. High-flux relationships with deteriorating trust must be either diplomatically repaired or carefully decoupled. The alternative is the trap—and the trap ends in war. But for already-isolated dyads (Disconnection Mode), the only lever is diplomatic channels; if those collapse, the system freezes into a state with no exit paths.

*For extended treatment including historical case studies, mathematical foundations, and policy implications, see **The Geometry of War: Predicting Conflict Through Topological Economics** (Davis, 2026).*

Ethics Statement. This research analyzes publicly available aggregate data on state-level behavior. No individual human subjects were involved, and the work was exempt from IRB review per Brown University policy.

We acknowledge potential dual-use concerns. Conflict prediction systems could theoretically be misused for military planning, preemptive strikes, or market manipulation. We advocate for use in diplomatic early warning and humanitarian preparedness, not military targeting. The 72-day mean lead time is designed to enable diplomatic intervention, not operational planning.

We also note the risk of self-fulfilling prophecy: public prediction of conflict could accelerate escalation. For this reason, we recommend that operational deployment include human-in-the-loop review and avoid public release of specific dyad alerts without diplomatic consultation.

Patent Disclosure. Methods described in this paper are the subject of US Provisional Patent Application No. 63/935,782, “Topological Risk Detection System Using Helicity Metrics for Financial and Geopolitical Forecasting,” filed December 2025. The patent covers computational methods for helicity-based prediction in financial markets and international relations, including the K -floor gate, Disconnection Mode metrics, and the Γ -based alert classification system. Academic use for research and education is unrestricted. Commercial licensing inquiries: bee_davis@alumni.brown.edu.

Data and Code Availability: Replication code and processed data available at <https://github.com/nurdymuny/helicity>. Raw data sources are public as cited. The 47 conflict events are listed in Supplementary Table S1.

Appendix A: Technical Details

A.1 Alignment Bound Proof

Lemma 11.1. *The alignment term $\mathcal{A}_{AB} \in [-1, 1]$ for all valid inputs.*

Proof. Let $x = k \cdot \left[\frac{S+R}{2} - \sigma(X) \right]$.

Since $S, R \in [0, 1]$, we have $\frac{S+R}{2} \in [0, 1]$.

Since $\sigma(X) = 1 - e^{-\beta X}$ with $\beta, X \geq 0$, we have $\sigma(X) \in [0, 1]$.

Therefore $\frac{S+R}{2} - \sigma(X) \in (-1, 1]$, and $x \in (-k, k]$.

Since $\tanh : \mathbb{R} \rightarrow (-1, 1)$, we have $\mathcal{A} = \tanh(x) \in (-1, 1) \subset [-1, 1]$. $\square$

A.2 Parameter Calibration

Strategic weight $\alpha = 4.0$: Derived from Hamilton (2003), who estimate that oil price shocks have GDP elasticity 4 $\times$ larger than equivalent trade shocks.

Sanction decay $\beta = 1.0$: Calibrated to the GSDB severity scale such that $\sigma(X) = 0.5$ when $X = 0.69$ (median severity).

Steepness $k = 2.0$: Chosen so that $\tanh(k \cdot 1) = 0.96$, ensuring 95% saturation at boundary conditions.

A.3 Rolling Window Justification

The 60-month window corresponds to typical diplomatic memory: sufficient to capture regime changes (new administrations, treaties) while avoiding noise from quarterly fluctuations. Empirically, 60 months minimizes out-of-sample prediction error in cross-validation.

A.4 Symmetry Verification

Computing directional helicity from asymmetric trade flows ($T_{A \rightarrow B}$ vs $T_{B \rightarrow A}$), we find $\text{Corr}(H_{AB}, H_{BA}) = 0.94$ across all dyad-months. The symmetry assumption is empirically justified.

A.5 Baseline Model Specifications

- **Realist (military balance):** Predicts conflict when CINC ratio $> 2 : 1$ between dyad members (Correlates of War National Military Capabilities v6.0). Alert when the weaker state's CINC $< 0.33 \times$ stronger state's CINC.
- **Liberal (trade/GDP):** Predicts peace when bilateral trade/GDP $> 1\%$ for both states (inverse prediction). Conflict alert when trade/GDP $< 0.5\%$ for either state. Trade data from UN Comtrade; GDP from World Bank WDI.
- **GDELT Goldstein:** 30-day moving average of Goldstein tone scores for dyad-specific events. Alert when $Z_{\text{Goldstein}} < -2.0$ (two standard deviations below 180-day rolling mean).
- **Random baseline:** Uniform random assignment with base rate matching observed conflict frequency ($47/61,776 = 0.076\%$ per dyad-month).

A.6 Historical Data Processing (US-Japan 1930–1945)

For the US-Japan case, we construct proxy variables from archival sources:

- **Trade (T):** League of Nations *International Trade Statistics* (1930–1939); US Department of Commerce *Foreign Commerce and Navigation* (1940–1941). Converted to constant 1940 USD using BLS CPI deflator.

- **Energy (E):** US oil export records to Japan from Hamilton (2003) and US Tariff Commission reports. Expressed as share of Japanese petroleum consumption from Japanese Ministry of Commerce and Industry records.
- **Alignment ($\mathcal{A}$):** No UN voting existed. We proxy using: (1) treaty status from COW Formal Alliances v4.1 (defensive alliance = 1, neutrality pact = 0.5, no treaty = 0, hostile = -0.5); (2) diplomatic representation level (ambassador = 0.2, chargé = 0.1, recall = -0.3); (3) public statements coded from *Foreign Relations of the United States* (FRUS) volumes.
- **Sanctions (X):** Binary coding from State Department records: moral embargo (1938) = 0.3; scrap metal embargo (1940) = 0.6; oil embargo (1941) = 1.0.

The historical case uses annual data interpolated to monthly; modern validation uses true monthly observations.

A.7 Out-of-Sample Validation Details

Training set (1990–2014): $N = 31$ conflict events across 156 dyads.

Test set (2015–2022): $N = 16$ conflict events.

Metric	Training (1990–2014)	Test (2015–2022)
F1 Score	0.75	0.69
AUC-ROC	0.86	0.79
Mean Lead Time	74 days	68 days
Russia-Ukraine L4 Date	—	2021-12-22

Table 13: Out-of-sample validation. Model trained on 1990–2014 data only.

The out-of-sample F1 (0.69) is lower than full-sample (0.73), as expected. Russia-Ukraine Level 4 triggers 8 days later (Dec 22 vs Dec 14) in the out-of-sample model due to slightly different baseline estimates.

Cross-validation: 5-fold temporal CV (non-overlapping 6-year windows) yields mean F1 = 0.71 ± 0.04 (std across folds). This confirms the single train/test split result is representative.

Appendix B: Supplementary Table S1 — Conflict Events

Table S1 lists all 47 militarized interstate disputes (MIDs) in the validation sample.

#	Dyad	Region	Conflict Date	L4 Alert	Lead (d)	Max Lv
1	Russia–Ukraine	Europe	2022-02-24	2021-12-14	72	4
2	Armenia–Azerbaijan	Caucasus	2020-09-27	2020-08-15	43	4
3	India–Pakistan	S. Asia	2019-02-26	2019-01-08	49	4
4	Saudi Arabia–Yemen	M. East	2015-03-26	2015-01-22	63	4
5	Russia–Georgia	Caucasus	2008-08-08	2008-06-12	57	4
6	Israel–Lebanon	M. East	2006-07-12	2006-05-28	45	4
7	Ethiopia–Eritrea	Africa	1998-05-06	1998-03-01	66	4
8	India–Pakistan	S. Asia	1999-05-03	1999-03-15	49	4
9	US–Iraq	M. East	2003-03-20	2002-12-18	92	4
10	NATO–Yugoslavia	Europe	1999-03-24	1999-01-15	68	4
<i>[...37 additional conflicts listed in supplementary materials...]</i>						

Table 14: Supplementary Table S1 (excerpt): 47 MIDs in validation sample. Full table available in online supplement. “L4 Alert” = date Level 4 first triggered (— if never reached L4). “Lead” = days from L4 to conflict. “Max Lv” = maximum alert level reached before conflict.

Selection criteria: All MIDs from UCDP/PRIO (1990–2022) with ≥ 25 battle deaths involving at least one state from our 42-state sample. Excluded: intrastate conflicts, conflicts with non-state actors only, and conflicts where both parties have < 12 months of trade data.

True positives (L4 before conflict): 35 of 47 (74% recall).

False negatives (no L4 before conflict): 12 of 47. Common pattern: low-flux dyads where the trap condition ($Z_V > 1$) was never met (e.g., Ethiopia–Eritrea 2020 flare-up occurred after years of near-zero trade).

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