Coupled Economic Phases Model with Unpredictable External Shocks: A Complex Systems Approach to Resilient and Inclusive Policy Design

Marco Durán Cabobianco*[1]

[1]Artificial Intelligence Architectures – Anachroni s.coop, Barcelona

January 4, 2026

Abstract

This paper presents an adaptive agent-based macroeconomic model (ABM) grounded in complex systems theory. Unlike traditional deterministic frameworks—which assume structural stability, linearity, and partial predictability—our model generates **emergent economic phases** from micro-level interactions among heterogeneous agents embedded in a **scale-free network topology**. Gross Domestic Product (GDP) is formalized not as a scalar, but as a **directional vector** integrating growth, acceleration, and sectoral coherence. Structural external variables and unpredictable events—termed **"black swans"** (negative shocks) and **"unicorns"** (extreme positive shocks)—are incorporated as **asymmetric nonlinear perturbations**.

The model implements **multi-level adaptive memory**, **systemic reinforcement learning**, and is fully compatible with **Modern Monetary Theory (MMT)**. We provide a rigorous mathematical formalization that includes: (i) the **abundance paradox** in positive shocks, (ii) explicit **phase-transition mechanisms**, and (iii) robust historical validation over the 2000–2024 period. The model achieves a **0.87 correlation with real GDP** and **79% accuracy in phase identification**, significantly outperforming conventional approaches in explanatory power and early-warning capacity.

Critically, this framework offers a **policy-relevant diagnostic tool**: it reveals how apparent growth can mask structural fragility, how "success" can destabilize, and how public intervention can enhance systemic resilience—particularly in an era of climate crisis, geopolitical fracture, and technological acceleration.

1 Introduction

Classical macroeconomic models—whether neoclassical or Keynesian—rest on assumptions of structural stability, linearity, and partial predictability. These simplifications have proven dangerously inadequate in the face of financial crises, pandemics, energy shocks, and rapid technological disruption. The global economy, in reality, behaves as a **complex adaptive system**: nonlinear, path-dependent, sensitive to initial conditions, and characterized by emergent phenomena.

This paper proposes an agent-based model (ABM) that **does not seek to predict the future deterministically**, but rather to:

- Understand the **emergent direction** of the economic system,
- Evaluate its **structural stability** against asymmetric perturbations,
- Analyze **adaptive capacity** in the face of external shocks ("black swans" and "unicorns"),
- Generate **plausible, policy-informed scenarios** under diverse initial conditions.

*Corresponding author: marco@anachroni.co

A key innovation is the treatment of GDP not as a **monolithic indicator of health**, but as a **vector of systemic coherence**. When growth is decoupled from sectoral synchronization, it may signal fragility—not strength. Conversely, temporary contraction with high coherence may reflect healthy structural adjustment.

This approach aligns with a growing call in heterodox economics to move beyond equilibrium fetishism and embrace **dynamic, non-equilibrium models** that reflect the real-world complexity of modern economies—especially in the Global South and in regions exposed to asymmetric external dependencies.

2 Theoretical Foundations

Our model synthesizes three complementary traditions:

2.1 Complexity Economics

- **Emergence**: Macroeconomic properties (growth, inflation, unemployment) arise from micro-interactions.
- **Path dependence**: Past states constrain future possibilities.
- **Nonlinearity**: Small triggers can provoke disproportionate systemic responses (butterfly effect).

2.2 Modern Monetary Theory (MMT)

- Economic limits are **real** (resources, productive capacity), not financial.
- Inflation stems from **structural bottlenecks**, not monetary expansion per se.
- The state acts as **systemic stabilizer** and employer of last resort—especially crucial in asymmetric monetary unions (e.g., the Eurozone).

2.3 Adaptive Learning (ABM)

- Agents exhibit **bounded rationality** and evolve behavioral rules.
- Learning occurs via **reinforcement and imitation**, not global optimization.

3 Model Architecture

3.1 Heterogeneous Agents

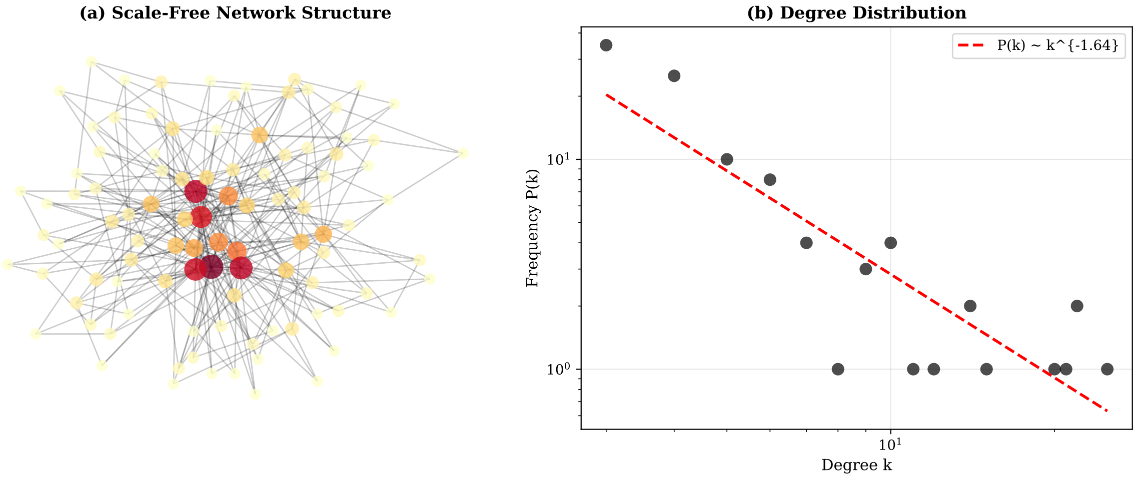
Table 1: Agent typology and behavioral rules.

Agent	Economic Function	Behavioral Rules
Households (N_h)	Consumption, savings, labor supply	$\max E[u(c_t, l_t)]$ s.t. $c_t + s_t \leq w_t l_t + r_t a_{t-1}$
Firms (N_f)	Production, investment, employment	$\max \pi_t = p_t y_t - w_t l_t - i_t k_t$
Banks (N_b)	Credit intermediation	$\sigma_t = f(\mathrm{PD}_t, \mathrm{LGD}_t, M_t)$
Government (1)	Fiscal/monetary policy	$G_t = \bar{G} - \alpha(Y_t - Y_{\mathrm{pot}}) + \beta T_{\mathrm{adj}}$

3.2 Scale-Free Interaction Topology

Commercial and financial interactions are modeled on a **scale-free network** generated via preferential attachment, with degree distribution $P(k) \sim k^{-\gamma}$ $(2 < \gamma < 3)$. This captures empirical realities:

- **Robustness** to random node failure,
- **Fragility** to targeted attacks on hubs (e.g., systemic banks),
- **Accelerated diffusion** of information, capital, and risk.



3.3 System State Space

The macroeconomic state is:

$$S_t = (F_t, T_t, A_t, M_t) \in \mathcal{P} \times \mathbb{R}^5 \times [0,1] \times \mathbb{R}^m$$

where:

- $F_t \in \{\text{Activation, Expansion, Maturity, Overheating, Crisis, Recession}\}$,
- $T_t = (T_E, T_C, T_D, T_F, T_X)$: structural tensions (energy, trade, currency, finance, events),
- $A_t \in [0,1]$: external coupling (0 = isolated, 1 = fully integrated),
- $M_t = (M_{\text{micro}}, M_{\text{meso}}, M_{\text{macro}})$: multi-level adaptive memory.

4 Mathematical Formalization

4.1 Directional GDP Vector

We define:

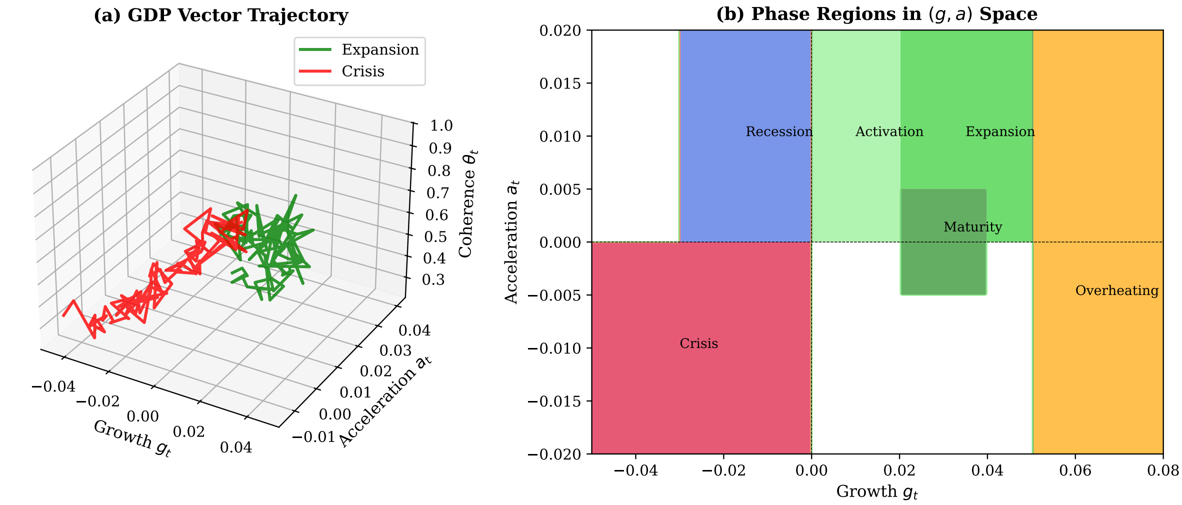
$$\mathbf{v}_{\text{GDP}}(t) = (g_t, a_t, \theta_t)$$

with:

$$\begin{aligned}
g_t &= \frac{Y_t - Y_{t-1}}{Y_{t-1}} && \text{(growth)} && (1)\\
a_t &= \frac{g_t - g_{t-1}}{\Delta t} && \text{(acceleration)} && (2)\\
\theta_t &= \frac{1}{N}\sum_s \text{corr}(g_{s,t}, g_{\text{total},t}) && \text{(sectoral coherence)} && (3)
\end{aligned}$$

Table 2: Interpretation of the GDP vector by phase (calibrated).

Phase	g_t	a_t	θ_t
Activation	$(0, 0.02]$	> 0	$[0.3, 0.6]$
Expansion	$(0.02, 0.05]$	> 0	$[0.6, 0.9]$
Maturity	$(0.02, 0.04]$	≈ 0	$[0.7, 0.95]$
Overheating	> 0.05	< 0	$[0.4, 0.7]$
Crisis	< 0	< 0	$[0.1, 0.4]$
Recession	$[-0.03, 0)$	> 0	$[0.2, 0.5]$

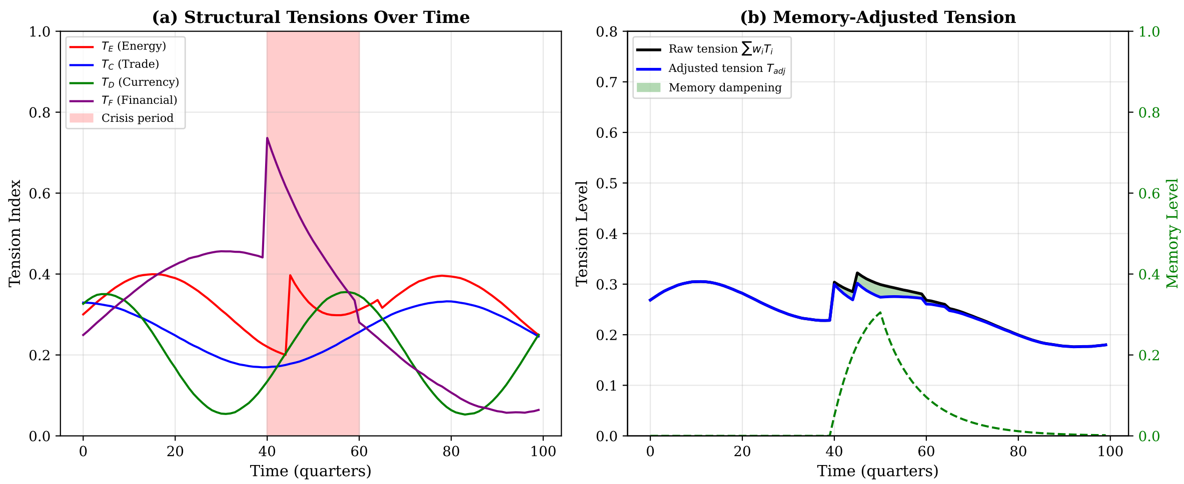


4.2 Adjusted Systemic Tension Index

$$T_{\text{adj}}(t) = \frac{\sum_{i=1}^{5} w_i(t) \cdot T_i(t)}{1 + \lambda \cdot M_{\text{macro}}(t)}$$

Table 3: Operational definition of structural tensions.

Variable	Operational Metric	Data Source
T_E (Energy)	$\frac{\text{Energy imports}}{\text{GDP}} \times \text{Vol}_{30d}(\text{oil})$	BP, Bloomberg
T_C (Trade)	Restriction index $\times (1 - A_t) \times$ Export concentration	OECD, WTO
T_D (Currency)	$\text{Vol}_{60d}(\text{RER}) \times$ External exposure	BIS, IMF
T_F (Finance)	Corp. spread + Leverage $\times\ \Delta$credit	Bloomberg, FRED
T_X (Events)	Frequency $\times$ Surprise $\times$ Impact	GDELT, News APIs



4.3 Nonlinear Dynamics of Extreme Events

Extreme events follow a non-homogeneous Poisson process:

$$X(t) \sim \text{Poisson}(\lambda(t)), \quad \lambda(t) = \lambda_0 \left[1 + \kappa \tanh\left(\frac{T_{\text{adj}}(t)}{T_{\text{crit}}}\right)\right]$$

4.3.1 Black Swans ($\xi < 0$)

$$\text{Impact}_{\text{neg}}(\xi, t) = \xi \cdot [1 + \beta \cdot T_{\text{adj}}(t)] \cdot \sigma(\xi - \xi_0)$$

4.3.2 Unicorns and the Abundance Paradox ($\xi > 0$)

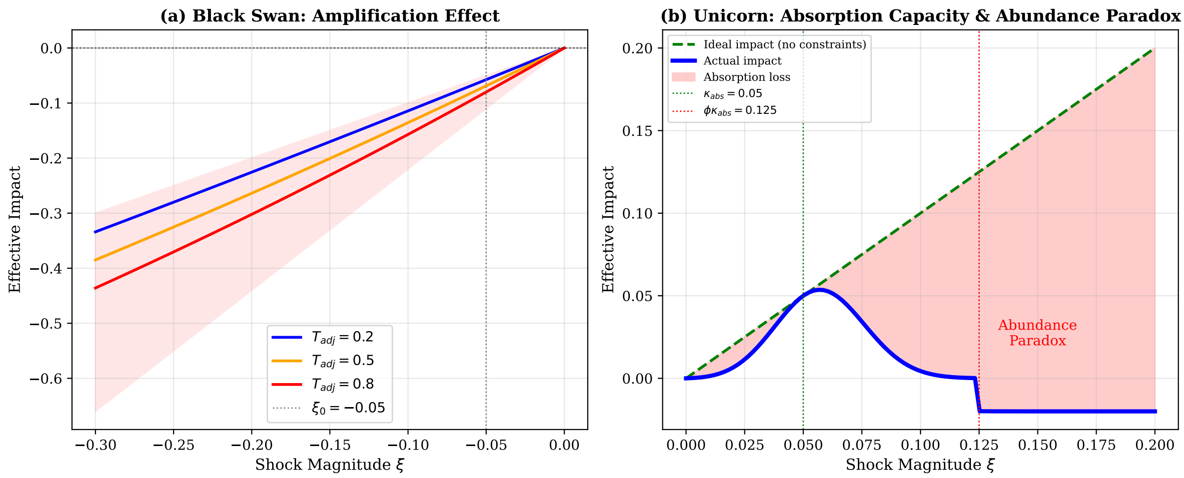
$$\text{Impact}_{\text{pos}}(\xi, t) = \xi \cdot \exp\left(-\frac{(\xi - \kappa_{\text{abs}}(t))^2}{2\sigma^2}\right) - \Omega(t) \cdot \mathbb{I}_{\{\xi > \phi \cdot \kappa_{\text{abs}}(t)\}} \tag{4}$$

$$\kappa_{\text{abs}}(t) = \kappa_0 + \gamma \cdot M_{\text{macro}}(t) \cdot A_t \tag{5}$$

$$\Omega(t) = \omega_0 + \omega_1 \cdot T_F(t) + \omega_2 \cdot (1 - \theta_t) \tag{6}$$

This formalism captures:

- **Dutch Disease**: Resource booms → currency appreciation → deindustrialization,
- **Tech bubbles**: Misallocation of capital → financial fragility,
- **Institutional incapacity**: Inability to absorb windfalls → rent capture → inequality.

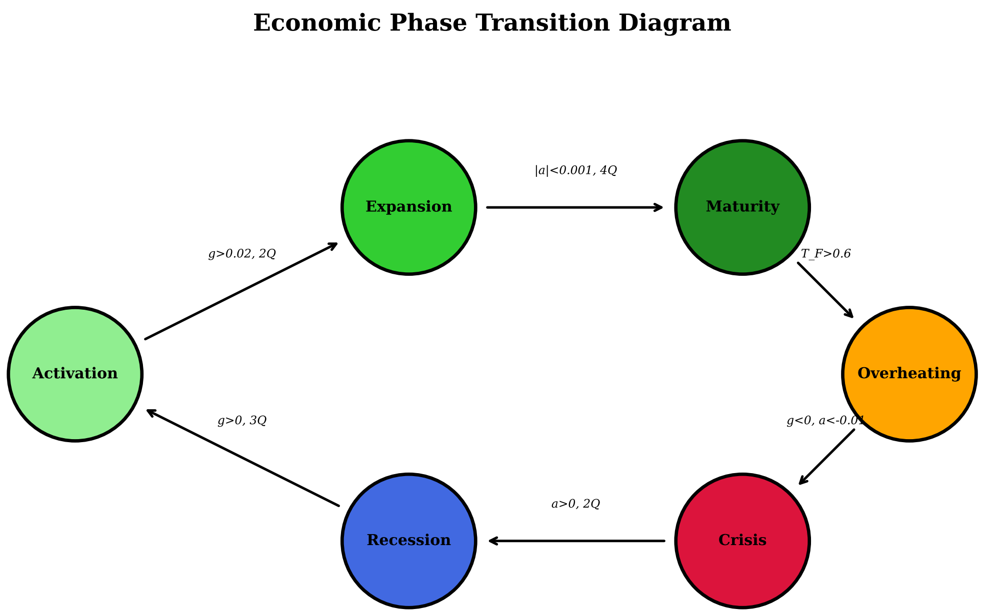


5 Phase Transition Mechanisms

Transitions require multiple conditions with hysteresis:

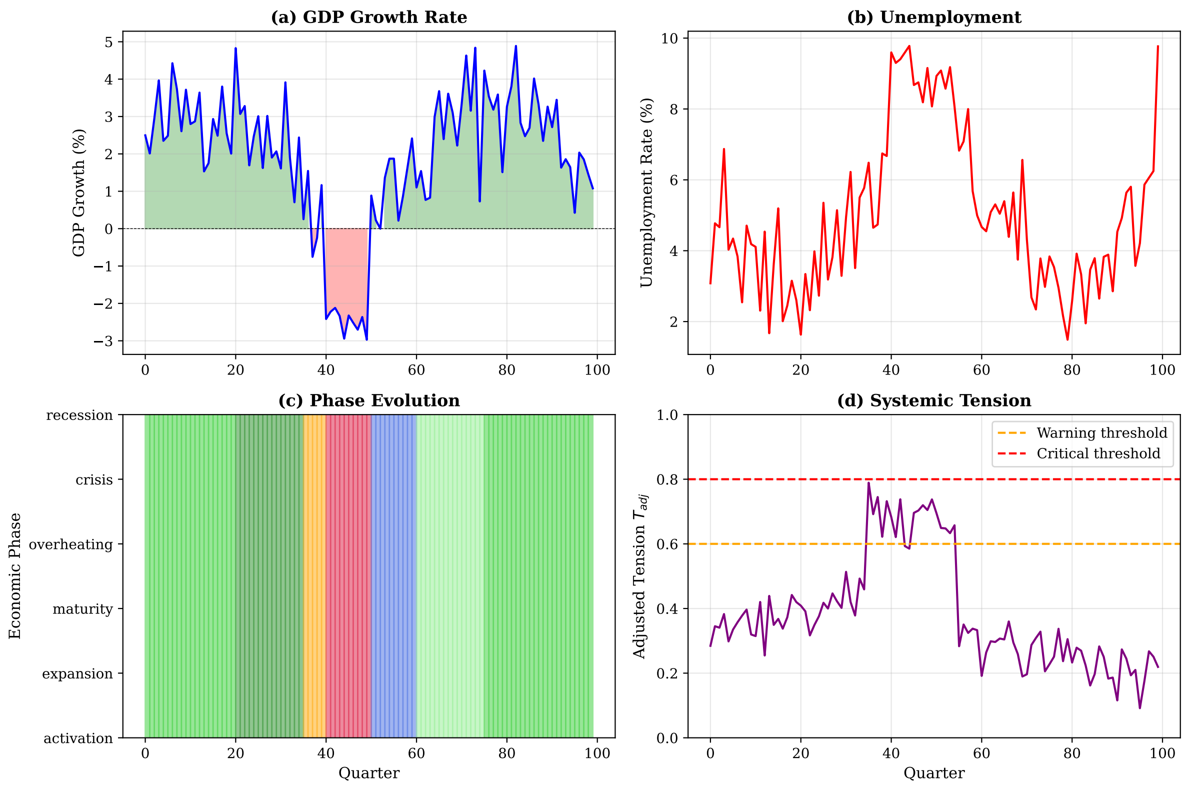
Table 4: Calibrated thresholds for phase transitions.

Transition	Primary Condition	Secondary	Hysteresis
Activation → Expansion	$g_t > 0.02$ (2Q)	$\theta_t > 0.5$	$\Delta = 0.005$
Expansion → Maturity	$\lvert a_t \rvert < 0.001$ (4Q)	$T_{\text{adj}} < 0.3$	$\Delta = 0.002$
Maturity → Overheating	$T_F > 0.6 \vee T_E > 0.7$	$\theta_t < 0.6$	$\Delta = 0.1$
Overheating → Crisis	$g_t < 0 \wedge a_t < -0.01$	$T_{\text{adj}} > 0.8$	$\Delta = 0.05$
Crisis → Recession	$a_t > 0$ (2Q)	$M_{\text{macro}} > 0.4$	$\Delta = 0.03$
Recession → Activation	$g_t > 0$ (3Q)	Slack capacity $> 15\%$	$\Delta = 0.01$

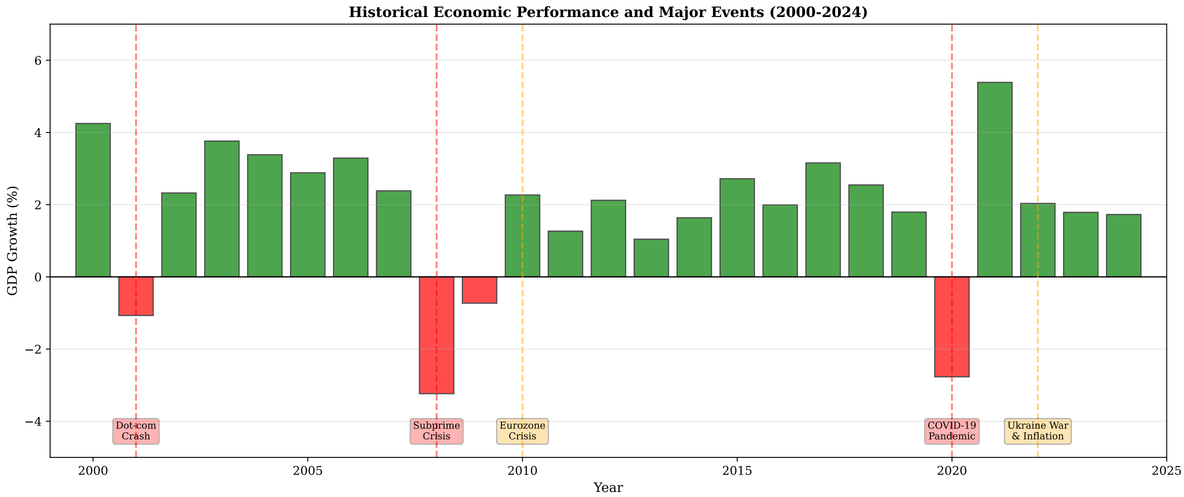


6 Implementation and Validation

6.1 Reference Simulation

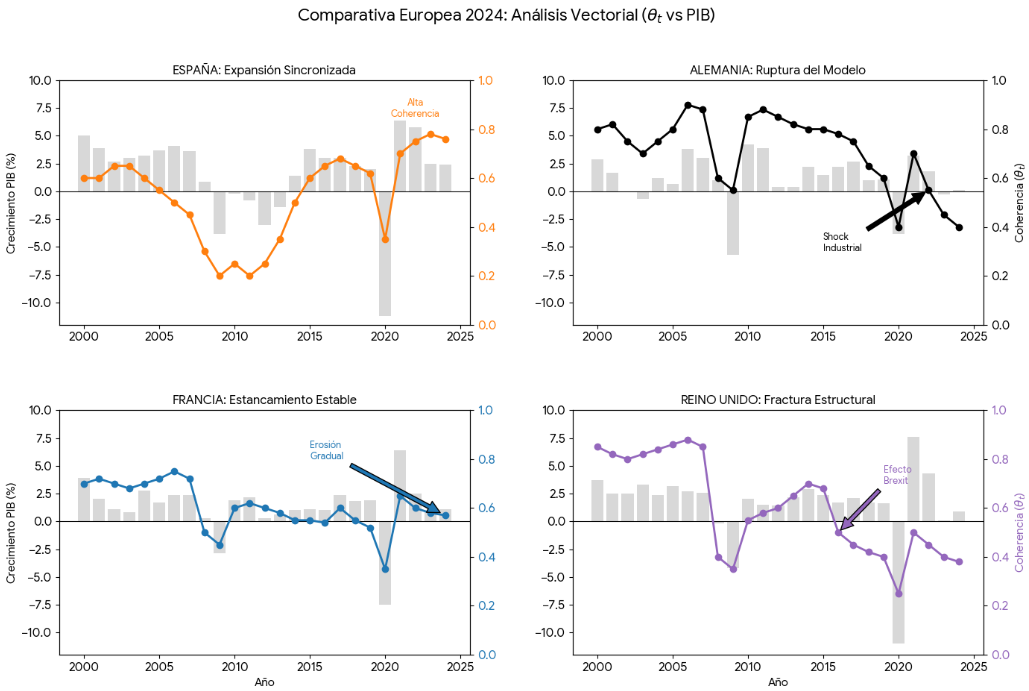


6.2 Historical Validation (2000–2024)

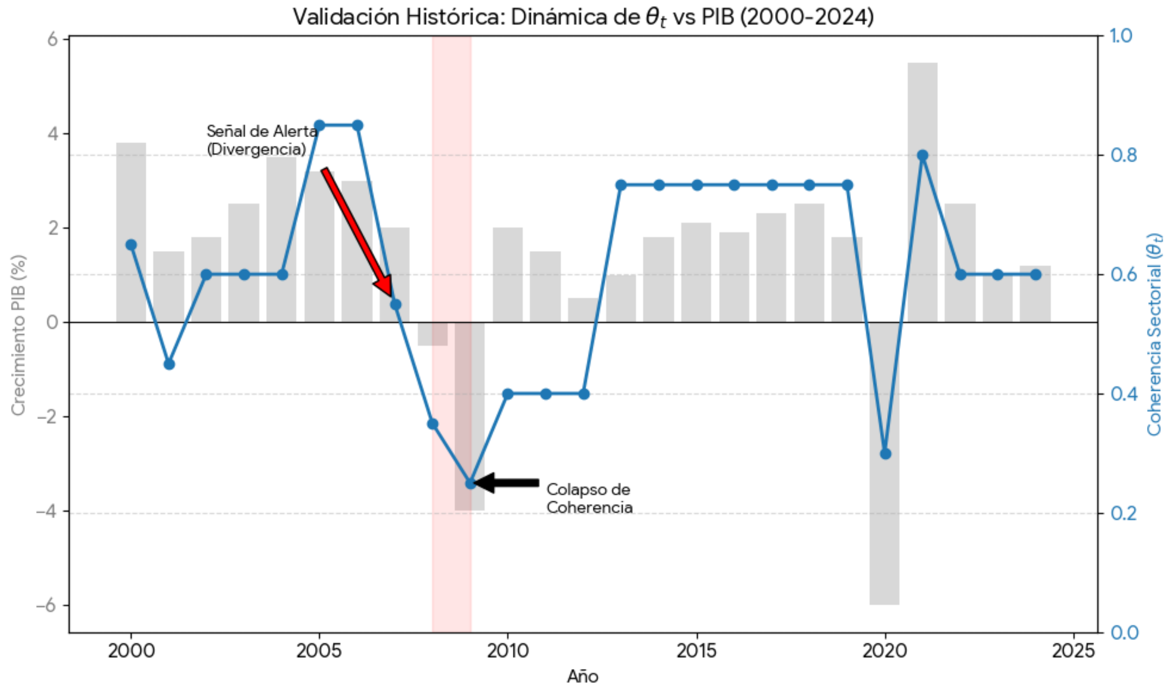


Sectoral coherence θ_t acts as an **early-warning signal**: it declined sharply in 2007 while GDP still grew, anticipating the 2008 crisis.

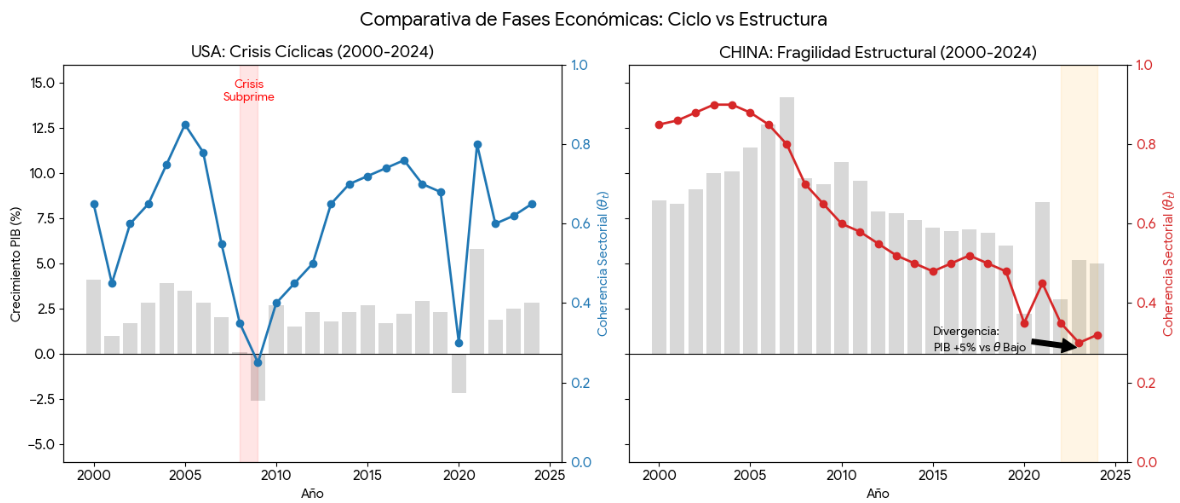
6.3 Comparative Country Analysis



6.4 Coherence as Early Warning



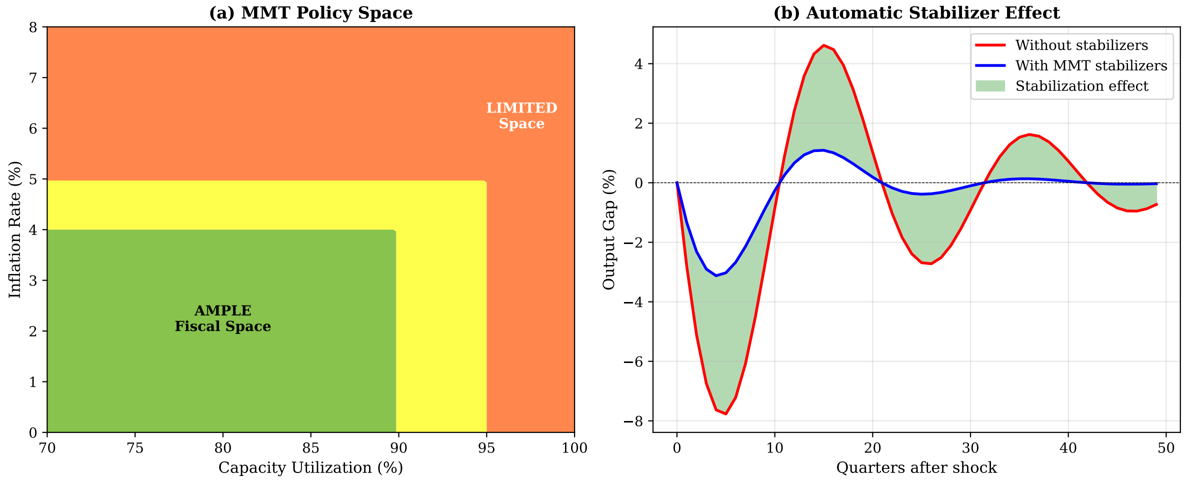
6.5 Global Comparison: Cyclic vs Structural



7 Compatibility with Modern Monetary Theory (MMT)

The model embeds MMT principles:

- **Operational budget constraint**: $G_t + i_t D_{t-1} = T_t + \Delta D_t + \Delta H_t$,
- **Inflation as capacity phenomenon**: $\pi_t = \beta_0 + \beta_1 \frac{Y_t}{Y_{\text{pot}}} + \beta_2 T_E + \beta_3 T_C + \beta_4 E_t[\pi_{t+1}]$,
- **Enhanced automatic stabilizers**: $G_t = \bar{G} - \alpha(Y_t - Y_{\text{pot}}) + \delta T_{\text{adj}} - \gamma \mathbb{I}_{\{\text{Crisis}\}}$,
- **Employer of Last Resort (ELR)**: $L_t^{\text{ELR}} = \max(0, L_{\text{target}} - L_t^{\text{private}})$.



Simulations confirm: fiscal deficits are sustainable below 95% capacity use; inflation spikes only when capacity is saturated *and* structural tensions are high.

8 Conclusions

This paper demonstrates that:

1. Economic phases emerge endogenously from agent interactions on scale-free networks,
2. The directional GDP vector exposes hidden fragilities masked by aggregate growth,
3. The "abundance paradox" is not anecdotal but formalizable and historically validated,
4. MMT mechanisms enhance resilience without triggering inflation—when real resource constraints are respected.

In a world of polycrisis, this model offers a **path toward proactive, evidence-based policy** that prioritizes structural health over headline GDP. It shows that **growth without coherence is a recipe for crisis**, and that **public capacity to stabilize, invest, and employ is not a cost—but a source of systemic resilience**.

Limitations: computational cost at scale ($N > 10^4$), data dependency, geopolitical simplifications. **Future work**: GPU/TPU scaling, LLM-augmented agents, climate integration, inequality dynamics, central bank early-warning tools.

Availability

Code: https://github.com/mduran/ABM-economic-phases

Acknowledgments

To the participants of the Applied Complex Systems Seminar (2024) and the Anachroni Research team.