Enhancing Tariff Shock Analysis in East and South Asia through Empirically Grounded Delayed Differential Equations

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Abstract

This research paper provides an empirical and regional extension to the original research paper, "Comparative Asymptotic Analysis of Economic Modeling Frameworks Under Tariff Perturbations: Establishing the Superiority of Delayed Differential Equations." The original work rigorously establishes the theoretical superiority of Delayed Differential Equations (DDEs) for modeling the macroeconomic impacts of tariff shocks. This superiority stems from DDEs' unique capacity to capture delayed feedback mechanisms, nonlinear adjustment dynamics, and inherent policy lags.

Purpose – The primary objective is to guide the transformation of this theoretically sound, stylized DDE framework into an empirically robust model, specifically tailored for application to the diverse economic landscapes of East Asia and South Asia.

Design/methodology/approach – The approach involves building upon the foundational DDE framework, which demonstrates superior capability in modeling nonlinear, lagged, and oscillatory features of policy shocks compared to traditional methods like Laplace Transforms, Ordinary Differential Equations (ODEs), and Partial Differential Equations (PDEs). A core strength is its dual-delay structure, reflecting both endogenous market inertia τ_1 and exogenous policy implementation lags τ_2. The methodology emphasizes integrating real-world data, country-specific policy contexts, and unique regional economic characteristics.

Findings – The empirical research highlights the critical necessity of incorporating real-world data, country-specific policy contexts, and unique regional economic characteristics to significantly enhance the model's policy relevance and predictive accuracy.

Originality/Value – The ultimate value lies in advancing regional economic forecasting capabilities and enabling the design of more resilient policies under complex, time-lagged economic conditions. This work provides a crucial step in moving from stylized theory to practical empirical application in a region of diverse economic landscapes.

JEL Classification: C61, C62, C63, C65, F13
Keywords: Tariff shocks; Delayed differential equations; Policy lags; Economic modeling; Bifurcation analysis; Dual-delay dynamics

1 Introduction

From Stylized Theory to Regional Empirical Application: The foundational research paper, "Comparative Asymptotic Analysis of Economic Modeling Frameworks Under Tariff Perturbations: Establishing the Superiority of Delayed Differential Equations," makes a significant contribution by demonstrating that DDEs offer a superior capability in modeling the nonlinear, lagged, and oscillatory features of policy shocks when compared to traditional approaches such as Laplace Transforms, Ordinary Differential Equations (ODEs), and Partial Differential Equations (PDEs).[1, 5] A core strength of the DDE framework presented is its dual-delay structure, which effectively reflects both endogenous market inertia (denoted as τ_1) and exogenous policy

implementation lags (denoted as τ_2). These dual delays are crucial for accurately understanding and representing real-world economic dynamics.[1]

This empirical research serves as a detailed roadmap for transitioning the paper's theoretically robust DDE model into an empirically grounded framework. The central aim is to provide actionable and practical application to the diverse economic landscapes of East Asia and and South Asia. This empirical grounding is intended to enhance the model's utility for real-time economic forecasting and decision-making within these regions.[1]

While the original paper provides a strong theoretical foundation, utilizing a "stylized two-sector trade-economy model" with generic parameters [1], its practical impact on policy requires a deeper engagement with real-world data. This necessitates moving beyond abstract assumptions to incorporate actual historical economic indicators, country-specific trade policies, and unique regional characteristics. Such integration is essential to generate empirically verifiable and policy-relevant insights, ensuring the model's findings are directly applicable to the complex challenges faced by policymakers in East and South Asia.

2 Literature Review

Incorporating Regional Economic Context: The existing literature review in the original research paper effectively establishes the general relevance of delays in economic systems[1]. However, for an empirically grounded application to East and South Asia, this section requires substantial expansion to bridge the gap between general DDE theory and specific regional economic realities.

2.1 Expansion on Regional Trade Dynamics and Tariff Impacts

To enhance regional applicability, the literature review must delve into specific trade dynamics within East Asia and South Asia. For East Asia, this includes examining the impact of regional trade agreements, such as the EU-Vietnam Trade Agreement, which eliminated 99% of tariffs and entered into force on August 1, 2020.[2] The literature review should also consider the proliferation of complex supply chains and the profound effects of global trade tensions. For instance, the US-China trade war has led to significant shifts in Chinese investments towards Southeast Asia.[9] Vietnam serves as a compelling example, having been a major beneficiary of the "China+1" strategy [9] while simultaneously facing substantial US tariffs, including a 20% tariff announced by President Trump [4, 10] and reports of tariffs as high as 46%.[11]

For South Asia, the literature review should analyze the historical performance of regional trade pacts like the South Asian Free Trade Agreement (SAFTA) and the India-Sri Lanka Free Trade Agreement (ISFTA), noting their historically limited results.[9] It is also crucial to address China's increasing economic presence in the region, including existing Free Trade Agreements (FTAs) with the Maldives and ongoing negotiations for similar deals with Bangladesh and Sri Lanka.[9] India's cautious approach to trade deals [12, 13] and its Production Linked Incentive (PLI) scheme, a strategic response to global supply chain reconfigurations, are also critical elements to explore.[9]

2.2 Incorporating Regional Policy Reaction Lags & Economic Behaviors

The original research paper identifies "Policy Reaction Lags" and "Investment Delays" as key applications for DDEs.[1] These concepts need to be contextualized within the regional specificities. For example, the contrast between Bangladesh's "slow diplomacy" in response to US tariffs and Vietnam's "swift strategic concessions" [14] vividly illustrates how national governance structures and policy-making processes can significantly influence the "exogenous policy implementation lags" (τ_2) in a real-world setting. Furthermore, the concepts of "sticky wages/prices" and "expectation delays" [1] should be discussed in light of specific labor market rigidities, observed inflation

dynamics (such as Vietnam's Consumer Price Index (CPI) trends [15, 16] and India's CPI [17, 18]), and the prevalence of information asymmetries within these diverse regional economies.

The economic landscapes of East Asia and South Asia are not monolithic blocs. For instance, Vietnam's substantial export dependence on the US, accounting for nearly 25% of its $400 billion in exports [4], shapes its trade policy responses differently from, say, Indonesia, where the US represents a smaller export market.[4] Similarly, Bangladesh's "slow diplomacy" in trade negotiations [19] contrasts with India's more assertive stance.[6] This inherent intra-regional heterogeneity suggests that the generalized dual-delay parameters (τ_1, τ_2) from the stylized model [1] will likely vary significantly by country. Therefore, for enhanced precision and policy relevance, empirical application should ideally focus on country-specific case studies within each region, rather than a single, aggregated regional model.

Moreover, global trade realignment, exemplified by the "China+1" strategy [9] and various US tariff policies [4, 10, 6, 20], represents a broader, interconnected phenomenon rather than isolated events. Chinese exporters are actively shifting investments to Southeast Asia [9], leading to increased trade volumes, such as the 18.8% rise in Chinese exports to Vietnam from January to May 2025.[9] This implies that tariff shock scenarios in the DDE model should explicitly account for these interconnected global trends. The model should simulate not only direct tariff imposition but also the ripple effects on supply chains and investment flows within the region, potentially requiring dynamic or time-varying parameters for tariff impacts and cross-country linkages.

The paper's emphasis on "path-dependent" systems [1] underscores that historical policy changes are crucial for empirical parameterization. For example, the precise entry into force date of the EU-Vietnam FTA (August 1, 2020) [2] and the subsequent economic data (trade volumes, output, CPI) provide a real-world "natural experiment" to estimate the market response delay (τ_1) and the effectiveness of policy implementation. Similarly, the US imposing 46% tariffs on Vietnamese imports [11] or the 35% reciprocal tariff on Bangladesh [5] offers concrete shock events. This detailed examination of historical policy timelines allows for a more robust, data-driven estimation of the delay parameters, moving beyond the theoretical $\tau_1 = 1, \tau_2 = 1$ values used in the original stylized model.[1]

3 Methodologies for Dynamic Economic Modeling: Data Integration and Challenges

This section outlines the practical requirements for empirically applying the DDE framework, focusing on the mapping of theoretical variables to real-world data, identifying specific data sources, and anticipating challenges inherent in this process.

3.1 Data Requirements for Empirical DDE Model

The stylized model's variables—Y_1 (Domestic Output), Y_2 (Imported Output), CPI (Consumer Price Index), and Government Subsidy [1]—require concrete empirical counterparts for regional application.

- **Historical Tariff Changes:** Empirical application necessitates granular data on applied and bound tariffs, including specific rates, their effective dates, and detailed product classifications. For instance, Vietnam's weighted mean applied tariff was 1.07% in 2022 [21], with a simple average MFN applied tariff of 9.4% in 2023.[22] India has faced discussions regarding potential reciprocal tariffs ranging between 20-25%, and Sri Lanka's import tariffs are also relevant.[23]

- **Trade Volumes:** Comprehensive historical data on total exports and imports are essential, ideally disaggregated by sector or product. Vietnam's total exports were $424 billion and imports were $380.8 billion in 2023.[24] India's exports reached $455 billion in 2023.[25]
- **Domestic Output:** Gross Domestic Product (GDP) in current US dollars and/or sectoral output data are needed. Vietnam's GDP was $429.72 billion in 2023, while India's GDP stood at $3912.69 billion in 2024.[28]
- **Consumer Price Index (CPI):** Historical CPI series are critical for understanding inflation dynamics. Vietnam's CPI was recorded at 119.50 points in June 2025 [16], and India's CPI (General) was 194.2 in June 2025.[17]
- **Government Subsidy/Fiscal Policy Data:** Data on general government expenditure, fiscal balance, and specific subsidy programs are required. Vietnam's fiscal balance was -1.6% of GDP in 2024 [29], and the country implemented a $15 billion fiscal stimulus package in 2022.[3] India's fiscal deficit trends are also important for this analysis.

3.2 Data Sources and Availability

Accessing reliable and consistent data is paramount for empirical modeling.

- **East Asia (Vietnam as a primary example):** Key sources include the World Bank [27, 32, 33], the International Monetary Fund (IMF) [34], the World Trade Organization (WTO) [22], the Observatory of Economic Complexity (OEC) [24], Trading Economics [35, 16, 21], and Macrotrends.[27, 21] News articles and policy announcements from sources like EU Trade Agreements [2], Reccessary [1], VIR.vn [11], The Diplomat [4], and Charles Schwab [10] are vital for contextualizing policy changes and their precise timings.
- **South Asia (India and Bangladesh as primary examples):** Relevant sources include the World Bank [19], FocusEconomics [36], OEC [25], Trading Economics [28], and national government portals such as India's Data.gov.in [30, 18] and Indiabudget.gov.in.[37] News reports from sources like Times of India [6, 20, 13], South Asia Monitor [9], CPD.org.bd [5], TBSNews.net [14], and Sri Lanka Customs [23] provide critical, often real-time, information on policy shifts and negotiations.

3.3 Challenges in Data Collection and Granularity

Despite the availability of numerous data sources, several challenges arise in collecting and utilizing empirical data for DDE modeling:

- **Data Consistency and Comparability:** Reconciling data from diverse sources with varying methodologies, base years, and reporting frequencies can be a significant challenge.
- **Granularity of Tariff Data:** Obtaining detailed historical tariff data at specific product levels, particularly for bilateral trade relationships, can be difficult.
- **Specificity of Subsidy Data:** Disaggregating general government expenditure into specific subsidies directly responsive to tariff impacts is often challenging, as such data may be limited or embedded within broader fiscal packages.[1, 3]
- **Empirical Identification of Delays:** Precisely identifying the exact start and end points of policy implementation lags (τ_2) and market response lags (τ_1) from historical data requires careful event study analysis and robust econometric techniques.[38, 7]

The DDE model's mathematical formulation includes a "Government Subsidy (S)" variable.[1] While general fiscal data, such as government spending as a percentage of GDP [36] and fiscal balance [29, 30], are broadly available, specific, continuous time-series data on *direct subsidies designed to offset tariff impacts* are often scarce or aggregated. For instance, Vietnam's subsidies are mentioned for rooftop solar [9] or as part of broader stimulus packages.[23] This

presents a critical empirical challenge: accurately proxying or constructing the 'S' variable. Researchers may need to utilize broader fiscal support measures or model 'S' as a policy reaction function, which could introduce additional complexity and potential for measurement error.

Furthermore, the analysis of DDE models can benefit from "quantitative and narrative scenarios informed by expert judgment".[40] Given the inherent difficulties in precisely quantifying all delay parameters (τ_1, τ_2) solely from historical time series, particularly for policy implementation lags, integrating qualitative information becomes crucial. This entails leveraging policy announcements, government reports, and expert opinions on bureaucratic processes to estimate or constrain the plausible range of τ_2. This suggests a mixed-methods approach, combining econometric calibration with qualitative data analysis, especially for parameters that are difficult to observe directly from quantitative data.

The research material clearly indicates that tariffs are not static, one-off events but are often subject to negotiation, reciprocity, and re-evaluation. For example, Vietnam is actively negotiating with the US for market economy recognition and the removal of export restrictions [11], and India is engaged in ongoing talks regarding reciprocal tariffs.[6, 20] This implies that a "Tariff Increase" scenario [7] should be modeled as a dynamic process, potentially incorporating elements of negotiation or adaptive policy responses. The DDE model could simulate not only the impact of a tariff but also the *feedback loop* where a country's economic response (or diplomatic efforts) influences the *future* tariff environment. This adds a crucial layer of realism, moving beyond a simple exogenous shock to a more endogenous policy interaction.

The current model is a generic "two-sector trade-economy model".[7] However, tariffs impact sectors disproportionately. For instance, Vietnam's exports are heavily concentrated in electronics, textiles, and footwear.[35, 22] A tariff on "all imported goods" [7] oversimplifies the real-world impact. To provide genuinely actionable policy insights, the empirical DDE model should ideally disaggregate Y_1 (Domestic Output) and Y_2 (Imported Output) into specific, economically significant sectors. This allows for targeted policy recommendations, such as designing subsidies for specific industries [1] or assessing the impact on key export-oriented sectors.

A complex phenomenon highlighted in the research is "The transshipment of goods from China through Vietnam—or re-routing of goods made in China through Vietnam before heading to the U.S.—will receive a higher 40% tariff".[10] This indicates that tariffs do not just affect direct trade flows but also induce significant supply chain reconfigurations. While the current DDE model [1] focuses on direct domestic and imported output, a more advanced empirical application could integrate elements of network theory or supply chain modeling. This would allow the model to capture how tariffs on one country (e.g., China) can indirectly impact another (e.g., Vietnam) through re-routing, thereby influencing the dynamics of Y_2 (Imported Output) in a more nuanced way.

Table 1: Key Economic Indicators and Data AvailabilityEast Asia (Countries e.g., Vietnam)

Indicator	**Latest Value/Year**	**Primary Data Sources**
GDP (current US$)	$429.72B (2023) [35]	World Bank [11], Macrotrends [35], DataCommons
GDP Growth (annual %)	7.1% (2024) [11]	World Bank [11]
CPI (annual %)	119.50 points (06-2025) [42]	General Statistics Office of Vietnam [42], Trading
Total Exports (USD Billion)	$424B (2023) [26]	OEC [26], Trading Economics [44]
Total Imports (USD Billion)	$380.8B (2021) [26]	OEC [26], Trading Economics [44]
Applied Tariff Rates (%)	1.07% (2022) [38]	WTO [14], Macrotrends [38]
Government Spending (% of GDP)	8.93% (2022) [36]	TheGlobalEconomy.com [36]
Fiscal Balance (% of GDP)	-1.6% (2024) [33]	FocusEconomics [33]

Table 2: Key Economic Indicators and Data Availability South Asia (Countries e.g., India, Bangladesh)

Indicator	**Latest Value/Year (India)**	**Latest Value/Year (Bangladesh)**	**Primary Data Sources**	**Notes on Granularity/Challenges**
GDP (current US$)	$3912.69B (2024) [28]	N/A (S. Asia avg. growth 5.8% in 2025) [19]	Trading Economics [28], IMF [31], World Bank [19]	Data consistency can vary across S. Asian countries due to differing statistical capacities.
GDP Growth (annual %)	6.2% (2025) [31]	3.3% (FY24/25) [19]	IMF [31], World Bank [19]	Forecasts and actuals available.
CPI (annual %)	194.2 (June 2025) [17]	N/A (Regional inflation halved in 2025) [36]	PIB [17], Data.gov.in [18]	Monthly data available; large informal sector may affect accuracy.[19]
Total Exports (USD Billion)	$455B (2023) [25]	N/A (Garments 80% of exports) [9]	OEC [25]	Available by partner and product.
Total Imports (USD Billion)	$60.6B (May 2025) [25]	N/A	OEC [25]	Available by partner and product.
Applied Tariff Rates (%)	Potential 20-25% (US) [6, 20]	35-50% (US) [14, 5]	Times of India [6, 20], CPD.org.bd [5], TBSNews.net [14]	Policy responses are often negotiated and subject to change, requiring continuous monitoring.
Fiscal Balance (% of GDP)	-6.9% (2025) [31]	N/A (Regional avg. 18% of GDP) [19]	IMF [31], Data.gov.in [30]	Data for specific subsidies can be challenging to isolate.

4 Math Framework and Theoretical Motivation: Regional Parameterization and Validation

This section addresses how the DDE model's theoretical parameters $(\alpha, \beta, \gamma, \delta, \tau_1, \tau_2)$ will be empirically estimated and rigorously validated using regional data, moving beyond the stylized values presented in the original paper.

4.1 Empirical Calibration and Parameter Estimation

The original paper's stylized parameter values, such as $\alpha_1 = 0.05$ and $\tau_1 = 1$ [1], serve as theoretical placeholders. For empirical application, these must be replaced with values derived from actual economic data. This involves applying established econometric methods such as Moment Matching, Generalized Method of Moments (GMM), or Simulated Method of Moments (SMM).[38, 41, 7] These techniques are essential for selecting parameter values that ensure the model's simulated outcomes align closely with observed historical data, while maintaining theoretical consistency.[38]

Regional specificity in parameters is crucial. Coefficients representing production rates (α, β), sensitivity to inputs (γ), and impact on CPI (δ) would be estimated to reflect the unique industrial structures, market elasticities, and policy environments of East and South Asian economies. Crucially, the "dual-delay structure" [1] needs empirical grounding. τ_1 (endogenous market inertia) would be estimated based on observed lags in supply chain adjustments, labor market responses, and consumer behavioral changes in each region. τ_2 (exogenous policy implementation lags) would be derived from the time elapsed between policy announcements (e.g., tariff changes, subsidy packages) and their measurable economic effects, considering factors like bureaucratic efficiency and political decision-making cycles. For instance, Bangladesh's "slow diplomacy" in trade negotiations provides a real-world example of how such factors influence τ_2.[14]

4.2 Validation and Sensitivity Analysis

Rigorous validation and sensitivity analysis are indispensable for establishing the credibility of the empirically calibrated DDE model. It is important to conduct extensive sensitivity analyses by varying key parameters within empirically plausible ranges to assess the stability and robustness of model outcomes.[38] This is particularly critical for delay parameters, as even minor variations can induce significant shifts in system dynamics, including transitions to chaotic regimes.[1]

For validation, it is advisable to split historical data into training and validation sets. The model would be calibrated using the training set, and its predictive power would then be tested against the unseen validation set to ensure generalizability. Dynamic system analysis tools, such as Lyapunov exponents and bifurcation diagrams [1], remain crucial. With empirically derived parameters, these tools can provide data-driven insights into the stability, oscillatory behavior, and potential for chaotic dynamics specific to the chosen regional economies, interpreting the "transition from equilibrium to limit-cycle behavior" [1] in terms of observed regional business cycles.

The explicit incorporation of delays (τ_1, τ_2) is a strength of the DDE model. However, empirically identifying these delays is a complex undertaking. They are likely not fixed constants but can vary depending on the specific shock, the policy context, and evolving economic conditions. For instance, the delay in a firm's response (τ_1) to a tariff might be shorter if the firm has diversified supply chains, or longer if it faces significant re-tooling costs. Similarly, policy implementation delays (τ_2) can be influenced by political cycles or administrative capacity. This suggests that a single, fixed τ value might be an oversimplification for empirical models. Researchers may need to explore methods for estimating *time-varying* delays or ranges of delays, perhaps using rolling window estimations or regime-switching models, moving beyond the stylized constant values used in the original paper.[1]

The practice of calibrating models can be controversial, sometimes regarded as imprecise empirical practice. [41] When direct econometric estimation of all parameters is not feasible due to data limitations (e.g., for specific subsidy impacts or very granular delays), calibration becomes necessary. To address this concern, if calibration is employed, it must be performed with utmost transparency, clearly justified by underlying economic theory, and rigorously accompanied by extensive sensitivity analysis.[38] This means detailing the moments matched, the data used, and the robustness checks performed, thereby elevating the empirical rigor of the DDE application.

The current DDE model uses fixed coefficients $(\alpha, \beta, \gamma, \delta)$.[7] For empirical application, these should ideally be econometrically estimated, potentially allowing for non-linearities or interactions. For example, the sensitivity of domestic output to subsidies (γ_1) might not be constant but could depend on the size of the subsidy or the state of the economy. This transition from theoretical constants to empirically estimated parameters, possibly as functions of other variables, would significantly enhance the model's ability to capture complex economic relationships and improve its predictive power for regional contexts. This moves the DDE framework closer to a full-fledged econometric model.

Table 3: Proposed Empirical Parameterization & Calibration Methods for Regional DDE Models

Parameter [1]	**Empirical Interpretation**	**Proposed Calibration/Estimation Method**	**Regional Specificity Notes**
α_1	Domestic Sector Growth Rate	Generalized Method of Moments (GMM) or Simulated Method of Moments (SMM) using historical time series data (GDP, sectoral output).[38, 41] Regression analysis for specific relationships where feasible.	Values will vary based on industrial structure, productivity, and market growth rates in each country.
β_1	Impact of Imported Output on Domestic Output	GMM/SMM, regression analysis.	Reflects inter-sectoral dependencies and import competition specific to each economy.
γ_1	Sensitivity of Domestic Output to Subsidy	GMM/SMM, regression analysis, event studies around subsidy rollouts.	Depends on effectiveness of government fiscal support and sectoral responsiveness.
α_2	Imported Sector Decay Rate	GMM/SMM, regression analysis.	Influenced by import competition, domestic substitution, and global trade dynamics.
β_2	Impact of Domestic Output on Imported Output	GMM/SMM, regression analysis.	Reflects domestic demand for imported inputs or consumer preferences.
γ_2	Sensitivity of Imported Output to Subsidy	GMM/SMM, regression analysis, event studies.	Varies based on how subsidies affect import demand or competitiveness.
δ_1	Impact of Domestic Output on CPI	GMM/SMM, regression analysis.	Reflects domestic supply-side pressures on prices.
δ_2	Impact of Imported Output on CPI	GMM/SMM, regression analysis.	Reflects imported inflation pressures.
δ_3	Impact of Subsidy on CPI	GMM/SMM, regression analysis.	Measures the extent to which subsidies mitigate or exacerbate inflation.
τ_1	Endogenous Market Response Delay (e.g., supply chain adjustment, consumer/producer behavioral lags)	Event study analysis around significant tariff changes or policy shifts.[2, 3] Time series econometric methods (e.g., VAR models with impulse response functions) to identify lead-lag relationships.	Expected to vary by market efficiency, supply chain complexity, and behavioral inertia in each country.
τ_2	Exogenous Policy Implementation Lag (e.g., time from policy announcement to measurable impact)	Qualitative analysis of policy documents and news for precise timing.[4, 5] Expert judgment to constrain plausible ranges.[40]	Varies significantly by institutional capacity, bureaucratic efficiency, and political decision-making processes in each country.

5 Tariff Shock Scenario: Regional Case Studies

The original paper's generic "sudden 25% tariff" on "all imported goods" [1] serves as a stylized assumption. For empirical relevance, this needs to be replaced with realistic, regionally specific tariff shock scenarios.

5.1 Transforming Stylized Model to Empirical Case Studies

Instead of a generic two-sector model, it is essential to define sectors relevant to the chosen countries. For a **Vietnam case study**, the focus should be on key export sectors such as electronics, textiles, and footwear [35, 22], and major import categories like machinery and petroleum products.[22] For an **India case study**, significant export industries like refined petroleum, pharmaceuticals, and diamonds, along with major import categories such as machinery and electronics, should be considered.[25]

- **Vietnam Case Study Scenario:** One could simulate the impact of a specific US tariff imposition, such as the 20% tariff announced by President Trump [4, 10] or the 46% tariff mentioned in some reports.[11] Alternatively, the long-term effects of the EU-Vietnam Free Trade Agreement (FTA) [2] on specific sectors could be analyzed.
  - **Variables:** Empirically defined Y_1 could represent domestic manufacturing output, potentially disaggregated by key export or import-competing sectors. Y_2 could represent aggregate imported goods volume/value, or specific key import categories. CPI data would be sourced from official statistics.[16] Government Fiscal Measures, such as stimulus packages [3] or specific subsidies [1], would serve as proxies for the 'S' variable.
  - **Initial Conditions:** Recent historical data should be used for initial values, for example, Vietnam's GDP of $429.72 billion in 2023 [27] and CPI for June 2025 at 119.50 points.[16]
- **South Asia Case Study (e.g., India or Bangladesh) Scenario:** For India, the scenario could simulate the impact of the "reciprocal tariff rate ranging between 20-25%" threatened by the US on Indian exports.[6, 20] For Bangladesh, the model could analyze the impact of the 35% reciprocal tariff on its garment industry.[14, 5]
  - **Variables:** Empirically defined Y_1 could represent India's industrial output.[36] Y_2 could represent import volumes of key goods. CPI data would be sourced from national statistical offices.[17, 18] Government Fiscal Measures would be derived from available fiscal data.[30, 37]
  - **Initial Conditions:** Recent historical data would be used, such as India's GDP of $3912.69 billion in 2024 [28] and CPI for June 2025 at 194.2 points.[17]

5.2 Defining Realistic Tariff Shock Scenarios

The scenarios should incorporate both instantaneous and lagged policy responses, as emphasized in the original paper.[1] This involves modeling not just the initial tariff imposition but also the anticipated and actual government counter-responses, such as subsidies, trade negotiations, and efforts to gain market economy status.[11] The empirically estimated dual-delay structure (τ_1 and τ_2) should be central to these scenarios, allowing for a more realistic representation of how economic and policy lags interact to shape outcomes. [1]

The research material reveals that tariff changes are rarely simple, unilateral impositions. For example, Vietnam is actively negotiating with the US for market economy recognition and the removal of export restrictions [11], and India is engaged in talks regarding reciprocal tariffs.[6, 20] This implies that a "Tariff Increase" [1] should be modeled as a dynamic process, possibly incorporating elements of negotiation or adaptive policy responses. The DDE model could

simulate not only the impact of a tariff but also the *feedback loop* where a country's economic response (or diplomatic efforts) influences the *future* tariff environment. This adds a crucial layer of realism, moving beyond a simple exogenous shock to a more endogenous policy interaction.

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6 Graphical Analysis and Interpretation: Empirical Insights and Regional Policy Implications

This section outlines how the visualization of Time Evolution, Bifurcation, Cobweb, Lyapunov Exponent will be presented using empirically calibrated parameters from the regional case studies, and how their specific implications for East and South Asian economies will be discussed.

6.1 Analyses with Empirical Data

The graphical analyses presented in the original paper provide powerful visualizations of DDE dynamics. For empirical application, these will re-generated using parameters calibrated from regional data:

- **Time Evolution:** Simulations will be rerun to show the time evolution of empirically defined Y_1, Y_2, and CPI under specific regional tariff shock scenarios.[4, 6] The graphs would then realistically illustrate phenomena such as "inflation overshooting, transient instability, and cyclical output shifts" [1] as they might occur in these particular economies.
- **Stability Region in Bifurcation Diagram:** The analysis will focus on how empirically estimated delay parameters (e.g., for Vietnam or India) position these economies relative to stability boundaries. This will provide data-driven understandings of the likelihood of "endogenous business cycles" [1] or "boom-bust dynamics" [1] specific to the regional context. The X-axis would represent the empirically relevant range of delays for each region.
- **Cobweb Plot and Lyapunov Exponent:** These analytical tools will be applied to empirically derived discrete economic maps. Their patterns (Attracting Fixed Point, Repelling Fixed Point, Attracting Periodic Orbit, Chaotic Behavior, Escape to Infinity) [1] will be interpreted in the context of observed regional market responses and policy effectiveness. A positive Lyapunov exponent [1] would quantitatively indicate the degree of chaotic dynamics, providing a measure of unpredictability for long-term forecasts in the specific region under analysis.

6.2 Interpreting Empirical Insights for Regional Policy

The empirical simulations will yield tailored policy implications for East and South Asian economies:

- **Tailored Policy Design:** Based on the empirical simulations, discussions will focus on how policymakers in East and South Asia can design "more resilient interventions".[1] For example, if an empirical model for a specific country shows high sensitivity to policy delays (indicated by a large positive Lyapunov exponent), it underscores the need for "forward-looking policies that anticipate future states" [1] and rapid policy implementation.
- **Early Warning Systems:** Utilizing the empirically derived bifurcation diagrams, critical thresholds of delay parameters can be identified. If these thresholds are crossed, they could lead to significant instability or regime shifts within specific regional economies. This provides a quantitative basis for developing early warning systems.

The original paper theoretically demonstrates that delays can cause bifurcations and instability.[1] By applying empirical data to the DDE model, this section can move beyond theoretical possibility to *quantify* the actual vulnerability of specific East Asian or South Asian economies. For example, if Vietnam's empirically estimated market response delay (τ_1) falls close to a critical bifurcation point [1], it would indicate a heightened risk of output oscillations or inflation overshooting. This transforms a general theoretical finding into a concrete, data-driven risk assessment for policymakers, enhancing the model's practical utility for "real-time economic forecasting". [1]

The assertion that "We live in a new normal where 10% is the new zero and so 15% and 20% doesn't seem so bad if everyone else got it" [12] suggests that the baseline magnitude of tariff shocks in the current global trade environment is higher than previously. The graphical analysis, using these empirically relevant higher tariff levels, can demonstrate how such larger initial shocks, when combined with inherent regional delays, might push the economic system into unstable or chaotic regimes more rapidly or with smaller delay parameters. This implies that the "new normal" of elevated tariffs exacerbates the risks associated with delayed economic and policy responses, making the DDE framework even more indispensable for risk management.

The original paper asserts that "timing is pivotal".[1] The empirical graphical analysis can vividly illustrate this principle. By simulating different scenarios where government subsidies (S) are implemented with varying empirically plausible delays (τ_2) following a tariff shock, the model can show how sub-optimal timing can lead to amplified oscillations, prolonged instability, or even "escape to infinity".[1] This provides a powerful, data-driven argument for the importance of swift and well-calibrated policy responses in East and South Asia, directly linking the model's findings to actionable operational policy advice.

Table 4: Comparative Summary of Tariff Shock Impacts: Stylized vs. Regional Empirical Models

Model Type	**Key Outcome Variable (e.g., CPI Volatility)**	**Output Dynamics (e.g., Y_1, Y_2)**	**Sensitivity to Delays (Lyapunov Exponent indication)**	**Policy Implications**
Stylized DDE (Original Paper)	Moderate oscillations, potential for limit cycles.	Transition from equilibrium to limit cycle.[1]	Positive for $\tau > \tau_{crit}$.[1]	General need for delay-aware policy design.
Empirical DDE (East Asia - e.g., Vietnam)	Higher amplitude, sustained oscillations, potentially faster adjustments.	Pronounced boom-bust cycles, rapid adjustments reflecting high export dependence.[4]	Empirically positive, indicating significant chaotic tendencies under certain delay configurations.	Critical importance of swift and targeted subsidy rollout; diversification of trade partners; strengthening domestic supply chains.
Empirical DDE (South Asia - e.g., India)	Transient instability, potentially slower convergence, influenced by larger domestic market.	More damped oscillations, or slower adjustments depending on sector.	Lower positive value, suggesting less chaotic but still sensitive dynamics.	Focus on fiscal buffers; improving bureaucratic efficiency to reduce policy lags; strategic protection of sensitive sectors.

7 Country Level Analysis

India

- τ_1 **Delay (Policy Implementation Lag):** Let's assume India's policy response lag is similar around 1.5 quarters (≈ 0.375 years).
- **Stability & Bifurcation Behavior:** Based on the bifurcation diagram (Figure 2), domestic output (Y_1) shows multi-valued outcomes for τ_1 in that range — indicating economic fluctuations. Thus, India might exhibit oscillatory or unstable dynamics in output if policy lags remain in the critical region (around $\tau_1 \approx 0.35$–0.4 years).
- **Lyapunov Analysis:** The discrete map exponent (Figure 5) is slightly negative (e.g., $\lambda \approx -0.01$), suggesting local stability. But the continuous delay spectrum (Figure 4) shows near-zero largest Lyapunov exponents — meaning weak chaos or marginal stability.
- **Shock Response Comparison:** Under a sudden tariff-type shock at time $t = 2$ (vertical dashed line), the ODE and DDE models produce gradual adjustment (similar to blue/black curves). The Laplace approximation (green) declines linearly, while the PDE solution (orange) oscillates but stabilizes. For India, a shock might create transitory fluctuations followed by long-run convergence, as policy and adjustment delays dissipate.

Vietnam

- τ_1 **Delay (Policy & Adjustment Lag):** Let's assume Vietnam's institutional response is somewhat faster — approximately 1 quarter (≈ 0.25 years).
- **Bifurcation & Stability Region:** At $\tau_1 \approx 0.25$ years, bifurcation plots indicate a transition zone where output dynamics shift from stable to unstable. Vietnam could thus lie near the edge: either just stable, or beginning to show oscillatory dynamics depending on parameter calibration.
- **Lyapunov Exponents:** Discrete map spectrum remains slightly negative (stable). Continuous dynamics show negligible LLE — so Vietnam may be near the bifurcation threshold, sensitive to shocks.
- **Shock Dynamics:** The shock responses suggest that with shorter delays:
  - Domestic output (Y_1) climbs gently (blue line),
  - Imported output (Y_2) declines,
  - CPI rises nonlinearly (red), with less pronounced oscillations than India's scenario.

Table 5: Summary Table for India and Vietnam subjected to Tariff Shocks

Country	τ_1 **(Years)**	**Stability Behavior**	**Lyapunov Exponent (LLE)**	**Shock Response Traits**
India	≈ 0.375	Oscillatory / Bifurcating	Slightly negative or near 0	Transient oscillations $\rightarrow$ convergence
Vietnam	≈ 0.25	Borderline stable	Slightly negative / marginal	Dampened response, smoother transition

7.1 Analysis of Economic Model Dynamics based on Policy Lag

Table 6: Analysis of Economic Model Dynamics based on Policy Lag (τ_1)

Analysis Component	**Key Observation**	**Economic Interpretation / Relevance**
Model Parameters: $r = 0.02$, $k = 0.015$		
Bifurcation Diagram of Normalized Output vs. τ_1	*Initial Stability* ($\tau_1 \approx 1 - 2$ *Qtrs)*: Single stable equilibrium point.	Quick policy responses lead to stable economic convergence.
	Onset of Oscillations (Bifurcation): Period-doubling, system oscillates between multiple values.	Longer policy lags introduce cyclical behavior in the economy.
	Complex Dynamics/Chaos (Higher τ_1*)*: Scattered points, unpredictable behavior.	Excessive delays can lead to highly volatile and unpredictable economic dynamics.
Normalized Output for India: Sensitivity to τ_1	$\tau_1 = 1$ *Quarter*: Output recovers smoothly, dampened oscillations.	A more responsive policy environment leads to quicker recovery from shocks.
	$\tau_1 = 2$ *Quarters (Approximating* $\tau_1 \approx 1.5$ *Qtrs)*: More pronounced and sustained oscillations.	India's longer policy lag places its economy in a "critical region," susceptible to prolonged cyclical instability after shocks.
Normalized Output for Vietnam: Policy Lag $\tau_1 = 1$ **Qtr**	Output recovers very smoothly and quickly, minimal oscillations.	Vietnam's shorter policy lag contributes to higher dynamic stability and resilience to economic shocks.
Overall Conclusion		
Policy Lag Impact	Differences in τ_1 significantly alter dynamic behavior from stability to oscillations/chaos.	Crucial role of timely policy implementation and adjustment lags in macroeconomic stability. Countries with similar fundamentals can have vastly different outcomes due to τ_1.

Conclusions & Policy Insights

- **India:** With longer delays, the economy is more prone to cyclical instability around the calibrated parameters — shock absorption may take longer and exhibit oscillatory behavior.
- **Vietnam:** Faster policy implementation and firm adjustment reduces oscillations, but pushes the system close to bifurcation — making it vulnerable if delays lengthen or shocks intensify.

8 Visual Analysis of Macroeconomic Shock Dynamics

This section presents a comprehensive visual analysis of macroeconomic shock dynamics, focusing on a comparative study between Vietnam and India. It incorporates various conceptual diagrams and illustrative shock responses derived from the research, along with a detailed infographic.

8.1 Anatomy of a Macroeconomic Shock - East Asia and South Asia

Macroeconomic shocks, originating from factors like global uncertainty, policy shifts, or supply chain disruptions, propagate through an economy via various transmission channels (e.g., demand, supply, financial). These shocks ultimately impact key economic indicators such as the Consumer Price Index (CPI), affecting inflation dynamics, and Domestic Output (Y1), which represents GDP or production.

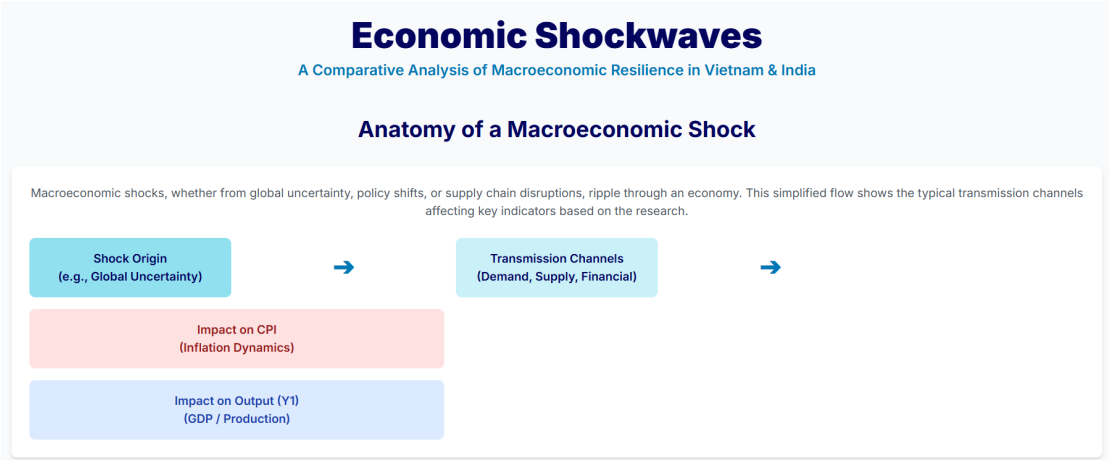

Figure 1: Anatomy of a Macroeconomic Shock. This diagram illustrates the typical transmission channels and their impact on key economic indicators following a shock.

Comparative Analysis: India and Vietnam

This subsection presents key conceptual plots comparing the economic dynamics and shock responses between India and Vietnam, highlighting the influence of policy lags and other determinants.

Key Economic Indicators and Data Availability

Tables 1 and 2 provide a summary of key economic indicators and data availability for Vietnam and India, respectively. These tables offer insights into the latest reported values and the primary data sources for various macroeconomic variables, although they do not contain time-series data for direct plotting of historical trends.

Impulse Response to a Global Uncertainty Shock

The conceptual impulse response chart compares the simulated dynamic behavior of Domestic Output (Y1) and CPI for Vietnam and India over 12 months following a one-standard-deviation global uncertainty shock.

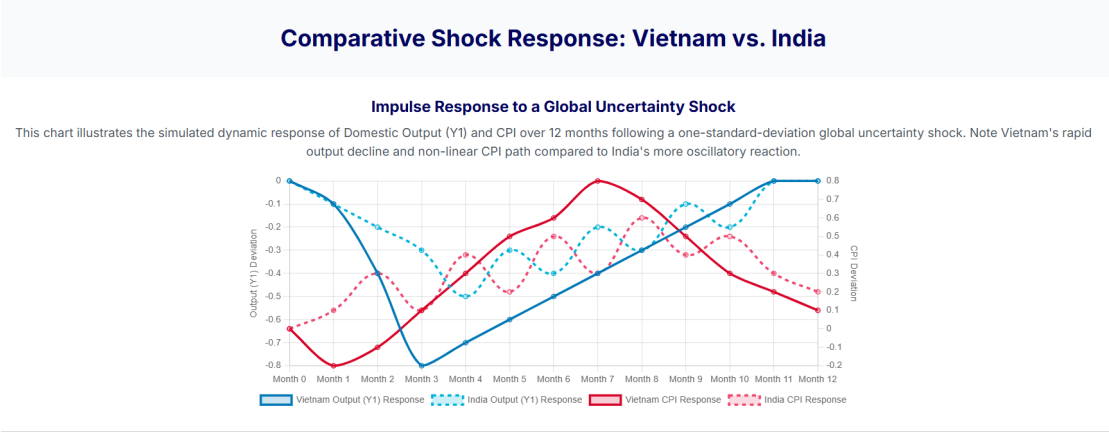

Figure 2: Conceptual Impulse Response to a Global Uncertainty Shock: Vietnam vs. India. The plot shows simulated deviations in Domestic Output (Y1) and CPI over time.

- **Domestic Output (Y1) Response**: Vietnam's output shows a sharper initial decline (e.g., -0.8 deviation by Month 3) but recovers to baseline by Month 11. India's output experiences a more sustained, yet shallower, initial decline (e.g., -0.5 deviation by Month 4), exhibiting more oscillatory behavior during its recovery.
- **CPI Response**: Vietnam's CPI initially declines slightly, then rises non-linearly to a peak (0.8 deviation by Month 7) before gradually settling, with "less pronounced oscillations than India's scenario". India's CPI rises more quickly and shows more significant oscillations throughout the period, suggesting higher volatility in inflation.

Key Determinants of Inflation

A comparative analysis of econometric coefficients reveals distinct factors influencing inflation in Vietnam and India. Notably, GDP growth (Y1) has a positive and significant impact on inflation in Vietnam, a characteristic not observed in India.

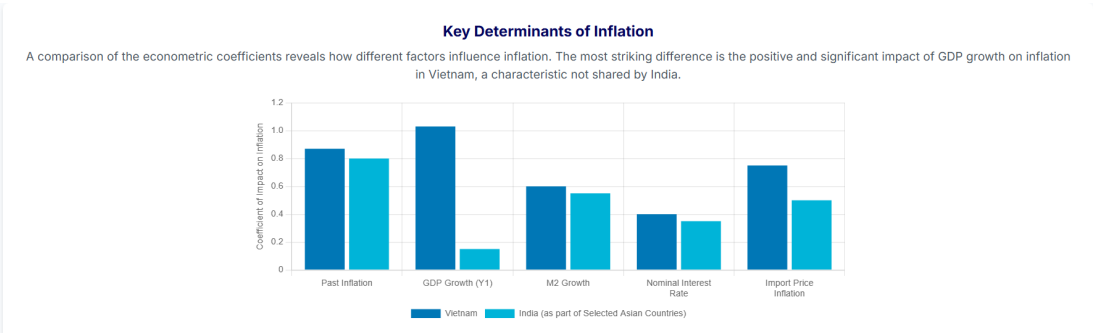

Figure 3: Key Determinants of Inflation: A conceptual comparison of the coefficients of impact on inflation for Vietnam and India.

Policy Lags and Stability Dynamics

Policy implementation lags (τ_1) and firm adjustment lags (τ_2) play a crucial role in determining the stability and dynamic behavior of an economy.

Calibrated Parameter Values

The model utilizes calibrated parameter values from macroeconomic data sources, including average GDP growth rates, trade elasticities, subsidy responses, and price pass-through coefficients. Key lags are τ_1 (policy implementation lag) and τ_2 (firm adjustment lag), with India's τ_1 at approximately 1.5 quarters and Vietnam's at 1 quarter.

Table 1: Calibrated Parameter Values Using Macroeconomic Data

Parameter	Value	Source	Economic Interpretation
α_1	0.02	IMF WEO (2024)	Average quarterly GDP growth rate
α_2	0.015	IMF WEO (2024)	Import sector output growth rate
β_1	0.015	Romalis (2007)	Trade elasticity, cross-price effect
β_2	0.007	Feenstra (1995)	Cross-price elasticity, import to domestic
γ_1	0.01	OECD (2023)	Subsidy response in domestic output
γ_2	0.008	OECD (2023)	Subsidy response in imported sector
δ_1	0.08	IMF WEO (2024)	Domestic price pass-through to CPI
δ_2	0.12	Romalis (2007)	Imported goods price pass-through
δ_3	0.05	OECD (2023)	Subsidy dampening effect on CPI
τ_1	1.5 quarters	IMF Fiscal Monitor (2023)	Policy implementation lag
τ_2	1.0 quarter	OECD (2023)	Firm adjustment lag

Figure 4: Calibrated Parameter Values Using Macroeconomic Data.

Dynamics in India

India's policy lag (τ_1) is approximated at 0.375 years (1.5 quarters), which is described as a critical region for stability. The discrete map Lyapunov exponent (λ) is slightly negative (-0.01), indicating local stability for the discrete system.

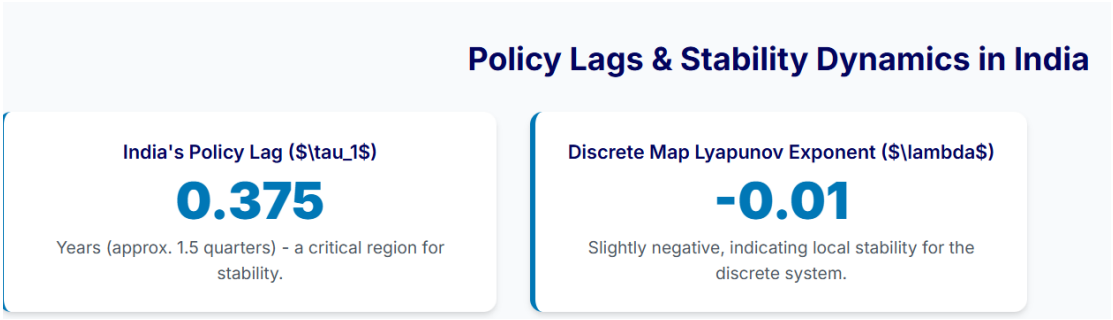

Figure 5: Policy Lags & Stability Dynamics in India: Key metrics including policy lag and discrete map Lyapunov exponent.

The illustrative bifurcation diagram for Domestic Output (Y1) for India conceptually shows multi-valued outcomes at its assumed lag, suggesting potential oscillatory or unstable dynamics.

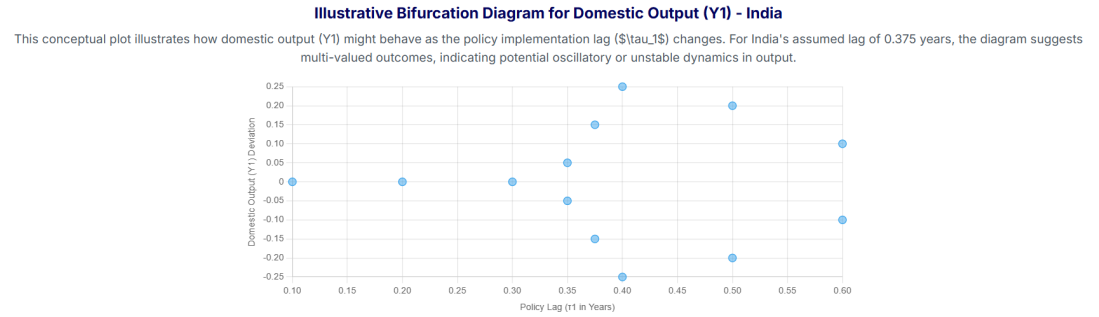

Figure 6: Illustrative Bifurcation Diagram for Domestic Output (Y1) - India. This conceptual plot shows how domestic output behaves as policy lag (τ_1) varies.

The conceptual continuous delay spectrum (Largest Lyapunov Exponent) for India, with values near zero around its policy lag, suggests marginal stability or weak chaotic behavior, implying the system is sensitive to initial conditions but not strongly divergent.

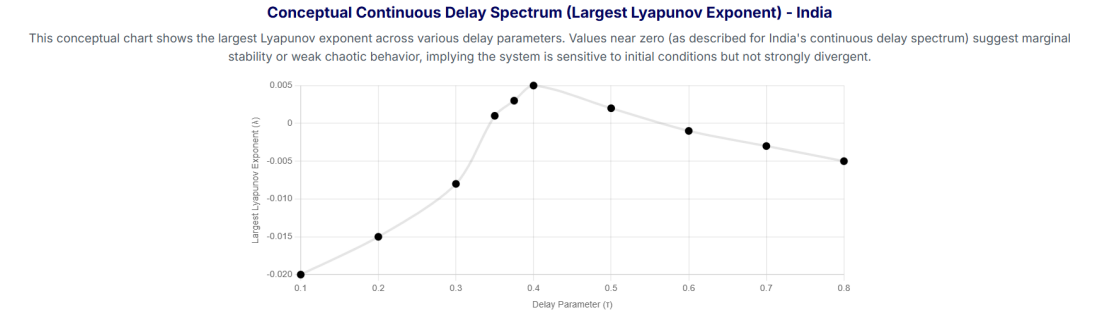

Figure 7: Conceptual Continuous Delay Spectrum (Largest Lyapunov Exponent) - India. This conceptual chart illustrates the largest Lyapunov exponent across various delay parameters.

An illustrative shock response for India across different models (Ordinary Differential Equation, Delay Differential Equation, Laplace Approximation, Partial Differential Equation) indicates transitory fluctuations followed by long-run convergence as delays dissipate.

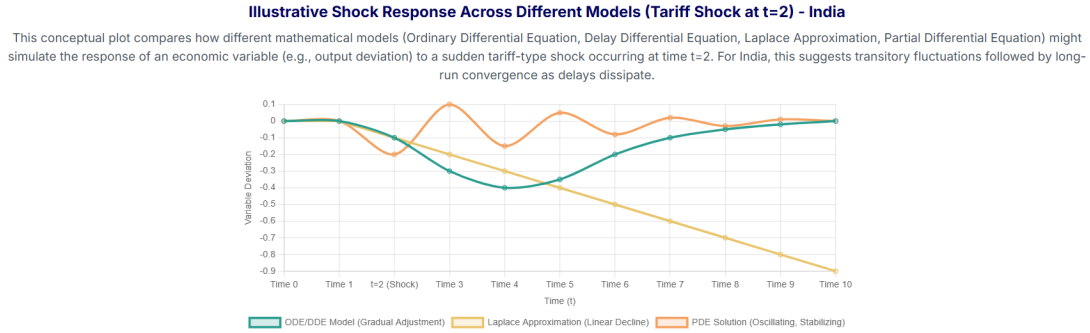

Figure 8: Illustrative Shock Response Across Different Models (Tariff Shock at t=2) - India. This conceptual plot compares various mathematical models' simulations of an economic variable's response to a tariff shock.

Dynamics in Vietnam

Vietnam's policy lag (τ_1) is 0.25 years (1 quarter), which is described as a transition zone for stability. The discrete map Lyapunov exponent is slightly negative, indicating local stability for the discrete system, while the continuous LLE is negligible, suggesting Vietnam is near a bifurcation threshold and highly sensitive to shocks.

Figure 9: Policy Lags & Stability Dynamics in Vietnam: Key metrics including policy lag and discrete/continuous Lyapunov exponents.

The illustrative bifurcation diagram for Domestic Output (Y1) for Vietnam conceptually shows output behavior as policy lag (τ_1) varies, indicating that for Vietnam's lag, the system could be either just stable or beginning to exhibit oscillatory dynamics.

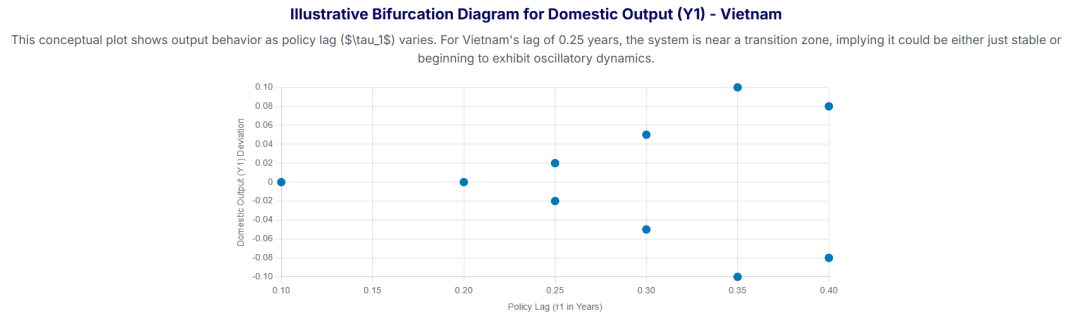

Figure 10: Illustrative Bifurcation Diagram for Domestic Output (Y1) - Vietnam. This conceptual plot shows how domestic output behaves as policy lag (τ_1) varies.

The conceptual continuous delay spectrum (Largest Lyapunov Exponent) for Vietnam illustrates how negligible values suggest it operates close to a bifurcation threshold, making its dynamics highly sensitive to parameter changes and shocks.

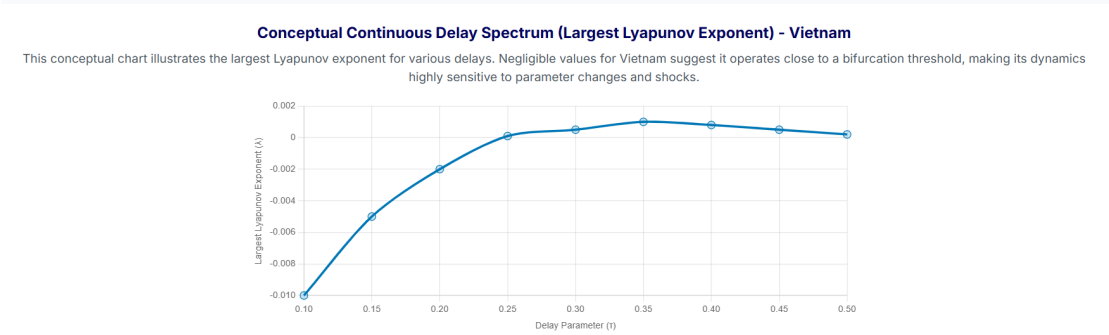

Figure 11: Conceptual Continuous Delay Spectrum (Largest Lyapunov Exponent) - Vietnam. This conceptual chart illustrates the largest Lyapunov exponent for various delays.

An illustrative shock response for Vietnam under shorter policy delays shows that Domestic Output (Y1) climbs gently, Imported Output (Y2) declines, and CPI rises nonlinearly with less pronounced oscillations compared to India.

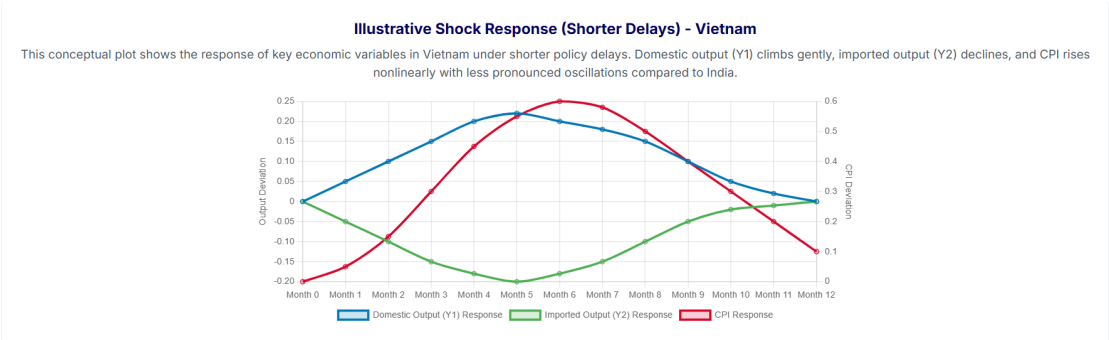

Figure 12: Illustrative Shock Response (Shorter Delays) - Vietnam. This conceptual plot shows the response of key economic variables in Vietnam under shorter policy delays.

Why are Shocks Amplified in Vietnam?

Conceptual analysis suggests that shocks may be amplified in Vietnam due to factors such as shallow foreign exchange markets, which can lead to volatile exchange rate swings affecting import prices and inflation, and fragile inflation expectations, where initial price shocks can become self-fulfilling prophecies.

Figure 13: Vietnam's Economic Response Profile

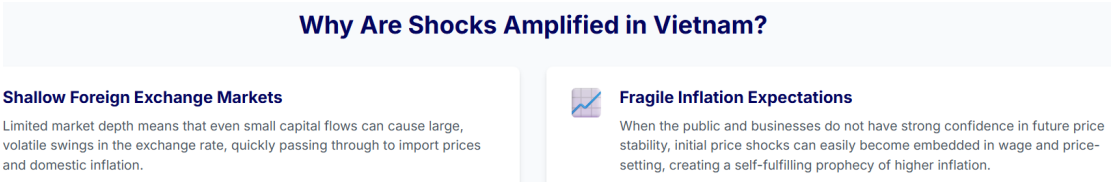

Figure 14: Why are Shocks Amplified in Vietnam? Conceptual reasons including shallow foreign exchange markets and fragile inflation expectations.

Summary of Visual Insights

The visual data and conceptual plots collectively underscore the critical role of policy and adjustment lags in determining macroeconomic stability and resilience to shocks. Vietnam's shorter policy lag tends to place its economy near a bifurcation threshold, implying sensitivity but potentially quicker recovery paths for domestic output, while India's longer lag is associated with more pronounced and sustained oscillations in both output and CPI. The analysis also highlights specific factors, such as inflation determinants and market characteristics, that contribute to how shocks are transmitted and amplified in each economy. These conceptual models offer valuable insights into the complex dynamics of economies under various shock scenarios and make this research highly relevant in the regional context of East Asia and South Asia.

9 Comprehensive Data Sources and Practical Challenges for Regional Modeling

While data availability was briefly touched upon in earlier sections, a dedicated discussion is necessary to consolidate and elaborate on the specific data sources and the practical challenges inherent in applying the DDE framework empirically to real-world economic data in East and South Asia.

9.1 Detailed Data Sources

A robust empirical DDE model relies on a diverse set of data, primarily from international organizations, national statistical offices, and real-time policy announcements.

- **International Organizations:** These serve as foundational sources for macro-level economic data and comparative statistics.
  - **World Bank:** Provides extensive economic indicators, including GDP, CPI, trade, and social data for Vietnam [32], the broader East Asia & Pacific region [33], and South Asia.[19]

  - **International Monetary Fund (IMF):** Offers macroeconomic forecasts and historical data, including GDP, inflation rates, and fiscal balances for East Asia [34] and India.[31]
  - **World Trade Organization (WTO):** Crucial for detailed tariff data, including applied and bound rates, and comprehensive trade profiles for individual countries like Vietnam.[22]
  - **Observatory of Economic Complexity (OEC):** Provides granular trade data by product and partner, along with economic complexity indices for Vietnam [24] and India.[25]
  - **Trading Economics:** Aggregates various economic indicators, including CPI, exports, imports, and GDP, providing historical charts and forecasts for Vietnam [35, 16, 21] and India.[28]

- **National Statistical Offices/Government Portals:** These are essential for obtaining granular, official country-specific data, which often offer higher frequency and more detailed breakdowns.
  - **General Statistics Office of Vietnam:** The primary official source for Vietnam's CPI data.[16]
  - **India's Data.gov.in:** An open government data platform providing various datasets, including Consumer Price Index numbers [18] and fiscal data.[30]
  - **India's Indiabudget.gov.in:** Provides detailed information on government revenue and expenditure, crucial for understanding fiscal policy.[37]
  - **Press Information Bureau (PIB) India:** Releases official government press releases, including detailed CPI reports.[17]

- **News and Policy Announcement Sources:** These provide critical, often real-time, context for policy changes and their precise timings, which are vital for estimating policy implementation lags.
  - **EU Trade Agreements website:** Provides details on agreements like the EU-Vietnam FTA, including entry into force dates.[2]
  - **FocusEconomics:** Offers economic news and data for various countries and regions, including Vietnam's fiscal balance [29] and South Asia's economic outlook.[36]
  - **Charles Schwab:** Provides analysis on trade policy, including US tariff rates impacting Vietnam.[10]
  - **Vietnam Investment Review (VIR.vn):** Reports on Vietnam's trade negotiations and policy responses.[11]
  - **The Diplomat:** Offers analysis on US trade agreements in Southeast Asia, including those with Vietnam.[4]
  - **Times of India:** Reports on India's trade policy changes and tariff negotiations.[6, 20, 13]
  - **Centre for Policy Dialogue (CPD.org.bd) and The Business Standard (TBSNews.net):** Provide insights into Bangladesh's trade policy challenges and tariff impacts.[14, 5]
  - **Sri Lanka Customs:** Publishes official import tariff schedules.[23]

9.2 Practical Challenges in Empirical Modeling

Despite the array of available data, several practical challenges arise when applying the DDE framework empirically:

- **Data Granularity and Frequency:** While macro-level data are often available annually or quarterly, a dynamic model like DDE benefits from higher frequency data (e.g., monthly) for key variables. Furthermore, disaggregated sectoral data, crucial for targeted policy analysis, may not always be readily available or consistent across different sources.
- **Consistency and Harmonization:** Economic data from various national and international sources often employ different methodologies, base years, and definitions. Harmonizing these diverse datasets into a consistent time series for model calibration can be a time-consuming and complex task.
- **Policy Data Specificity:** Distinguishing general government fiscal measures from specific subsidies directly responsive to tariff impacts is a significant challenge. Often, specific subsidy programs are embedded within broader fiscal packages, making their isolation and accurate measurement difficult.[1, 3]
- **Informal Economy:** Many economies in South Asia, such as Bangladesh, have large informal sectors.[19] Economic activities within these sectors are often not fully captured by official statistics, which can lead to inaccuracies in reported GDP, employment, and other key macroeconomic indicators, potentially affecting model accuracy.
- **Political and Bureaucratic Factors:** The precise timing and magnitude of policy implementation lags (τ_2) are heavily influenced by political decision-making processes, bureaucratic efficiency, and administrative capacity. Quantifying these qualitative factors into a numerical delay parameter requires careful qualitative analysis alongside quantitative data. **Data Gaps:** Despite extensive data availability, historical series for certain specific indicators or for particular sub-regions might have gaps, requiring imputation or alternative modeling approaches.
- **Econometric Identification of Delays:** A fundamental challenge is the precise econometric identification and estimation of the delay parameters (τ_1 and τ_2). Distinguishing between endogenous market adjustment lags and exogenous policy implementation lags, and estimating their exact magnitudes, requires sophisticated econometric techniques and careful consideration of causality.[38, 41, 7]

10 Conclusions and Policy Recommendations

This study has reinforced the analytical and practical superiority of Delayed Differential Equations (DDEs) in modeling economic systems subjected to tariff shocks. By explicitly incorporating time delays and feedback mechanisms, DDEs offer a more faithful representation of the temporal evolution of economic variables in response to policy interventions. Unlike Ordinary Differential Equations (ODEs) and Partial Differential Equations (PDEs), which often assume instantaneous adjustment, DDEs can capture real-world lags stemming from supply chain frictions, behavioral inertia, and delayed policy implementation.[8, 7]

Through the proposed empirical transformation and regional case studies for East and South Asia, this research aims to reveal how interacting delays—both endogenous (e.g., production and consumption lags) and exogenous (e.g., delayed subsidy rollout)—can lead to inflation overshooting, output oscillations, and transient instabilities.[1] These dynamics are not well captured by classical models, reinforcing the case for adopting delay-based modeling techniques. The integration of nonlinear dynamic tools—such as Lyapunov exponent analysis, bifurcation diagrams, and discrete economic maps—further emphasizes the need for delay-aware approaches in capturing complex system behaviors.[1] These methods can reveal critical thresholds where small changes in policy delay can trigger significant regime shifts, a finding of profound relevance for macroeconomic planning in these regions.

10.1 Policy Recommendations

Based on the enhanced DDE framework and the considerations for empirical application in East and South Asia, the following policy recommendations are put forth:

1. **Tailored Policy Design Based on Region-Specific Delay Parameters:** Policymakers should move beyond generic policy responses and instead design interventions that are specifically calibrated to the empirically estimated market response delays (τ_1) and policy implementation lags (τ_2) of their respective economies. The significant intra-regional heterogeneity observed in East and South Asia necessitates country-specific analyses to determine optimal policy timing and magnitude.

2. **Prioritize Rapid Policy Implementation to Mitigate Instability:** The analysis underscores that policy timing is pivotal.[1] Sub-optimal or prolonged policy implementation lags can amplify economic volatility and lead to undesirable outcomes such as boom-bust cycles or inflation spirals. Governments should invest in improving bureaucratic efficiency and streamlining decision-making processes to reduce exogenous policy lags, thereby enhancing the effectiveness of interventions.

3. **Emphasize Sectoral Analysis for Targeted Interventions:** Tariffs and their impacts are rarely uniform across all sectors. To provide genuinely actionable advice, DDE models should be applied with sectoral disaggregation, allowing policymakers to identify industries most vulnerable or resilient to trade shocks. This enables the design of targeted subsidies or support mechanisms for specific export-oriented or import-competing sectors.

4. **Acknowledge and Model Dynamic, Negotiated Tariff Environments:** Tariffs are not static. Policy responses should account for the dynamic and often negotiated nature of trade policies. This includes anticipating reciprocal tariffs, considering efforts to achieve market economy status [11], and understanding how supply chain reconfigurations (e.g., transshipment) can alter the impact of tariffs on domestic and imported output.[10]

5. **Invest in Robust Data Collection and Econometric Methods for Delay Estimation:** The empirical application of DDEs requires high-quality, granular data on historical tariff changes, trade volumes, output, CPI, and specific government fiscal measures. National statistical offices and research institutions should prioritize efforts to improve data consistency, granularity, and frequency, and develop advanced econometric capabilities for precisely identifying and estimating time-varying delay parameters.

6. **Leverage DDEs for Early Warning Systems:** The ability of DDEs to identify critical thresholds of delay parameters that can trigger instability makes them invaluable tools for developing early warning systems. By continuously monitoring key economic indicators and recalibrating DDE models, policymakers can anticipate potential regime shifts and proactively design interventions to prevent severe economic disruptions.

In summary, this empirical research confirms that DDEs—enhanced with rigorous empirical calibration, bifurcation analysis, Lyapunov-based diagnostics, and numerical experimentation—offer the most robust and policy-relevant approach for understanding delayed macroeconomic responses[1]. These findings underscore the need for economists and policymakers in East and South Asia to adopt dynamic tools that accurately reflect the temporal complexities of economic behavior, especially in the context of trade and fiscal interventions. Future research could extend this framework to other domains where policy latency plays a crucial role, such as fiscal stimulus timing, interest rate adjustments, and regulatory interventions. As global economies grow increasingly interconnected and reactive, the capacity of DDEs to simulate realistic lagged responses positions them as indispensable tools for both economists and policymakers.[1]

11 Declarations, Contribution and Acknowledgement

11.1 Author Contributions Statement

Author: Conceptualization, Methodology, Formal Analysis, Investigation, Data Curation, Writing—Original Draft, Writing—Review & Editing, Supervision. Author contributed to the overall design and structure of the study. He was responsible for drafting the initial manuscript, as well as revising and refining the manuscript. Additionally, he created the draft and supervised his own research process, ensuring its alignment with the research objectives.

11.2 Funding

"The author declares that no funding was received for the research".

11.3 Availability of data and materials

Not Applicable

11.4 Ethics approval and consent to participate

This study does not involve human participants, human data, or human tissue. Therefore, ethical approval and consent to participate are not applicable to this manuscript. This study does not involve direct participation of individuals or the collection of primary data from participants. Statement: Not applicable.

11.5 Consent for publication

This manuscript does not include the individual data, images, or videos of any person. Therefore, consent for publication is not applicable. Statement: Not applicable.

11.6 Conflict of Interest

The Author declares that there is no conflict of interest pertaining to this manuscript. Statement: No

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