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Data-Driven Modeling and Simulation of Strategic Interactions Between Major Powers

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Abstract
Strategic interactions among major powers are characterized by complex interdependencies, conflicting national interests, and dynamically evolving international environments. Traditional quantitative approaches, including multiple regression and time-series analysis, primarily focus on statistical relationships among political and economic variables, limiting their ability to characterize adaptive decision-making and reciprocal strategic responses. To address these limitations, this study proposes a data-informed multi-agent deep reinforcement learning framework for modeling and simulating strategic interactions between major powers, using Sino–U.S. relations as a representative case. First, a multidimensional strategic state representation is constructed by integrating bilateral trade, economic capabilities, exchange rates, diplomatic interactions, and geopolitical security indicators. Historical diplomatic records are processed through event extraction, semantic categorization, and quantitative relationship scoring to characterize both accumulated strategic influences and short-term interaction dynamics. Second, a multi-agent stochastic game model is developed to represent major powers as autonomous decision-making agents with interdependent strategic objectives. A multidimensional reward mechanism incorporating economic benefits, security interests, diplomatic gains, and confrontation costs is formulated to support adaptive strategic behavior modeling. Third, a deep reinforcement learning mechanism is introduced to enable agents to optimize their policies through repeated strategic interactions and environmental feedback. Furthermore, a scenario-based simulation framework is designed to investigate strategic behavior evolution under alternative conditions, including economic cooperation, trade competition, diplomatic negotiation, and security confrontation. Historical consistency assessment, comparative baseline analysis, and parameter sensitivity evaluation are incorporated to examine model credibility and behavioral robustness.

Index Terms
Major-Power Strategic Interactions; Strategic Behavior Modeling; Stochastic Games; Multi-Agent Reinforcement Learning; Scenario-Based Simulation

I. Introduction
The international political landscape has undergone profound transformations with the continuous redistribution of economic capabilities, technological resources, and strategic influence among major powers. As the international system becomes increasingly interconnected and competitive, strategic interactions between major powers have emerged as an important determinant of regional stability, global governance, and international economic development. In particular, the evolving relationship between China and the United States represents a complex form of strategic interaction characterized by economic interdependence, geopolitical competition, diplomatic coordination, and differences in national security priorities. Although bilateral cooperation has generated substantial economic and political benefits, increasing strategic competition in trade, technology, security, and regional affairs has introduced considerable uncertainty into the development of Sino–U.S. relations. Zhang [1] emphasized that the historical evolution of Sino–U.S. relations reflects the interaction of changing national capabilities, strategic perceptions, and international circumstances. Understanding how major powers formulate strategic decisions, respond to external actions, and adjust their behavioral strategies under evolving international conditions is therefore essential for investigating the mechanisms underlying international strategic competition and cooperation.

Strategic interactions between major powers are inherently dynamic, interdependent, and influenced by multiple dimensions of national interests. Unlike isolated decision-making problems, international strategic behavior is determined not only by the internal economic and political conditions of individual countries but also by their expectations regarding the intentions and potential responses of other actors. A strategic decision made by one country may alter the perceived security environment, economic expectations, and diplomatic preferences of another, thereby triggering subsequent strategic

adjustments. Such reciprocal interactions may generate cooperation, competitive escalation, negotiation, or confrontation depending on the prevailing strategic conditions. Furthermore, differences in strategic perception and uncertainty regarding the intentions of other actors can amplify the consequences of individual decisions and produce unexpected patterns of interaction. Consequently, major-power relations cannot be adequately understood as a simple combination of independent economic and political variables. Instead, they should be examined as an evolving system in which national actors continuously interact, evaluate strategic outcomes, and adapt their decisions in response to changing environmental conditions.

Existing quantitative studies of international relations have provided important foundations for analyzing political interactions, identifying influential factors, and characterizing the evolution of bilateral relationships. Statistical approaches, including multiple regression analysis, vector autoregressive models, and time-series analysis, have been widely adopted to investigate associations between economic indicators, diplomatic relations, and international political developments. In addition, event-based quantitative analysis has enabled researchers to transform qualitative political interactions into structured observations. Goldstein [2] proposed a conflict–cooperation scale for international event data, providing a quantitative approach to representing the intensity and direction of interstate interactions. Schrodt [3] reviewed advances in political event data analysis and demonstrated the importance of systematic event coding in the computational study of international relations. Subsequently, Leetaru and Schrodt [4] introduced the Global Database of Events, Language, and Tone (GDELT), which provides a foundation for extracting structured international event information from large-scale textual sources. These studies have contributed to the development of empirical and computational approaches for investigating international political behavior.

Despite these advances, conventional quantitative approaches exhibit several limitations when applied to strategic behavior modeling. First, regression-based methods primarily focus on statistical associations among observed variables and generally do not explicitly represent the reciprocal decision-making processes of strategic actors. Although time-series models can capture temporal dependencies and responses to shocks, they do not necessarily explain how competing countries select actions according to their strategic objectives. Second, many quantitative approaches represent bilateral relations through aggregated indicators, potentially overlooking differences between individual strategic actions, their underlying motivations, and their subsequent consequences. Third, traditional statistical forecasting methods often provide limited mechanisms for examining hypothetical strategic decisions and counterfactual interaction scenarios. As a result, identifying the factors associated with changes in bilateral relations does not automatically reveal how strategic behavior emerges, how national policies adapt to the actions of other countries, or under what conditions bilateral interactions evolve toward cooperation or confrontation.

Game theory provides a theoretical foundation for investigating strategic interdependence among rational decision-making actors. However, conventional game-theoretic models frequently rely on predefined strategy sets, simplified utility functions, and assumptions about information availability or actor rationality. These assumptions can restrict their ability to describe adaptive strategic behavior under complex and changing international conditions. Stochastic games extend sequential decision-making frameworks by allowing multiple agents to interact within a shared dynamic environment. Littman [5] established an important foundation for multi-agent reinforcement learning using Markov games, in which the outcomes of individual decisions depend on the combined actions of multiple agents. Building upon this formulation, deep reinforcement learning offers a computational approach for approximating decision-making policies through repeated interaction and accumulated rewards. Lowe et al. [6] introduced a multi-agent actor–critic framework capable of addressing mixed cooperative and competitive environments, while Gronauer and Diepold [7] systematically examined the methodological challenges and developments of multi-agent deep reinforcement learning. Yu et al. [8] further demonstrated the effectiveness of proximal policy optimization in cooperative multi-agent environments. These advances provide useful computational foundations for investigating adaptive decision-making and interaction dynamics, although their applicability to international strategic behavior requires careful consideration of domain-specific assumptions, data limitations, and model validation.

To address these challenges, this study proposes a data-informed multi-agent stochastic game framework for modeling and simulating strategic interactions between major powers, with Sino–U.S. relations serving as the primary case study. The proposed framework integrates historical political event analysis, multidimensional strategic state representation, game-theoretic modeling, and multi-agent deep reinforcement learning into a unified computational structure. Specifically, political and diplomatic information extracted from historical records is combined with economic indicators, including bilateral trade, gross domestic product, and exchange rates, to characterize the evolving strategic environment. An event-based bilateral relationship score is introduced to represent historical accumulation and short-term changes in diplomatic interactions. Textual records from diplomatic yearbooks are further analyzed through keyword extraction and strategic event categorization to support the identification of representative interaction patterns. The resulting indicators provide the observational foundation for constructing the strategic state space, while strategic actions are separately defined according to their behavioral meanings and institutional contexts.

II. Multiple Regression Model

Strategic interactions among major powers involve complex interdependencies, competing interests, and continuously changing political, economic, and security conditions. Con-

ventional multiple regression models primarily identify statistical associations among explanatory variables; they do not, by themselves, represent the reciprocal decisions of competing national actors. Accordingly, this study outlines a multi-agent stochastic game framework incorporating deep reinforcement learning to examine how major powers might adjust their strategies over repeated interactions. China and the United States are represented conceptually as autonomous agents operating in a shared, dynamically evolving environment. The strategic state includes economic interdependence, bilateral trade relations, national security, geopolitical tensions, and diplomatic interactions. Each agent selects actions according to a decision policy, while joint actions affect subsequent environmental states and the strategic outcomes experienced by both countries. The proposed reward structure considers economic benefits, security interests, diplomatic gains, and the costs of confrontation, allowing the framework to represent trade-offs between immediate preferences and longer-term consequences. Repeated interactions and policy optimization would permit adaptive strategic choices to be investigated in a simulated environment. As an empirical point of comparison, the conventional autoregressive time-series specification is introduced in Eq. (1); this equation is a statistical baseline and should not be mistaken for the stochastic-game transition or reward function, which is discussed conceptually in the preceding description.

$$y_t = \phi_0 + \phi_1 y_{t-1} + \cdots + \phi_p y_{t-p} + \varepsilon_t. \tag{1}$$

A related specification for testing time-series properties, including the contribution of lagged levels and differences, is given in Eq. (2). Its practical interpretation depends on the precise definitions of the parameters and the selected lag order:

$$\Delta x_t = \alpha + \beta_t + (\rho - 1)x_{t-1} + \sum_{i=1}^{p} \theta_t \Delta x_{t-1} + \varepsilon_t. \tag{2}$$

For an evaluation horizon of s periods, forecast performance can also be assessed using the mean squared error (MSE) between predicted and observed values of y_t, as defined in Eq. (3):

$$\mathrm{MSE} = \frac{1}{s}\sum_{i=1}^{s}(\hat{y}_{t+i} - y_{t+i})^2. \tag{3}$$

The corresponding bivariate vector autoregressive (VAR) specification, with p denoting the selected lag order, is represented in the general matrix form of Eq. (4). The original coefficient notation is retained here and should be checked for indexing consistency before statistical replication:

$$\begin{pmatrix} y_t \\ x_t \end{pmatrix} = \begin{pmatrix} \phi_{10} \\ \phi_{20} \end{pmatrix} + \begin{pmatrix} \phi_{11}^{(1)} & \phi_{12}^{(1)} \\ \phi_{21}^{(2)} & \phi_{22}^{(1)} \end{pmatrix} \begin{pmatrix} y_{t-1} \\ x_{t-1} \end{pmatrix} + \begin{pmatrix} \phi_{11}^{(2)} & \phi_{12}^{(2)} \\ \phi_{21}^{(2)} & \phi_{22}^{(2)} \end{pmatrix} \begin{pmatrix} y_{t-2} \\ x_{t-2} \end{pmatrix} + \cdots + \begin{pmatrix} \phi_{11}^{(\rho)} & \phi_{12}^{(\rho)} \\ \phi_{21}^{(\rho)} & \phi_{22}^{(\rho)} \end{pmatrix} \begin{pmatrix} y_{t-\rho} \\ x_{t-\rho} \end{pmatrix} + \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{pmatrix}. \tag{4}$$

A conventional approach to assessing whether lagged values of one variable have explanatory value for the other is a joint F-test of the relevant lag coefficients. Under the null hypothesis, those coefficients are jointly equal to zero, as stated in Eq. (5):

$$H_0 : \phi_{12}^{(q)} = 0, \quad q = 1, 2, \cdots, p. \tag{5}$$

Under the alternative hypothesis, H_1, at least one lag coefficient satisfies $\phi_{12}^{(q)} \neq 0$. The manuscript reports the corresponding test statistic in Eq. (6); its numerator and denominator notation requires verification before the statistic can be interpreted or reproduced:

$$S_1 = \frac{RSS_0 - RSS_{1/P}}{RSS_{2/T-2P-1}} \sim F(p, T - 2P - 1). \tag{6}$$

The restricted model used to obtain the residual sum of squares is represented by Eq. (7). It should be estimated with the same dependent variable and comparable observation window as the unrestricted model:

$$y_t = \phi_{10} + \phi_{11}^{(1)} y_{t-1} + \phi_{11}^{(2)} y_{t-2} + \cdots + \phi_{11}^{(p)} y_{t-\rho} + \widetilde{\varepsilon}_{1t}. \tag{7}$$

When performing a Granger-causality test, the chosen lag length must be justified because the outcome can be sensitive to the number of included lags, the integration properties of the series, and any transformations applied to nonstationary variables. Stationarity diagnostics and a clearly specified lag-selection procedure are therefore necessary for a reliable interpretation of the reported test results.

III. Research Methods

A. Data Selection

The modeling and simulation of strategic interactions between major powers require a systematic representation of the multidimensional factors influencing national decision-making. To characterize the evolving strategic relationship between China and the United States, this study incorporates political, economic, diplomatic, and security-related indicators into a unified state representation framework. In particular, an event-based bilateral relationship score is introduced to quantify the dynamics of Sino–U.S. relations. This indicator is based on the assumption that bilateral relations evolve through the accumulation of individual political and diplomatic events, whose impacts may vary according to their significance, direction, and temporal characteristics. Accordingly, the relationship score is characterized by two complementary dimensions: historical accumulation, which reflects the lasting effects of previous interactions, and current event flows, which capture short-term changes in bilateral relations.

Building upon this event-based quantification approach, the selected variables are organized into a multidimensional strategic state space to support the proposed multi-agent stochastic game model. Economic indicators, including bilateral exports, imports, gross domestic product, and exchange rates, characterize economic interdependence and relative

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economic conditions. The bilateral relationship score represents the overall diplomatic interaction environment, while supplementary indicators related to national defense, geopolitical security, and high-level political exchanges can be incorporated to characterize strategic competition and cooperation when reliable observations are available. Through temporal alignment, data normalization, and event-based feature construction, these indicators form the observable state representation used by national agents to evaluate strategic conditions and select corresponding actions. The overall process of data preparation and strategic state construction is illustrated in Figure 1.

The study considers monthly observations over the 2010–2020 period, during which Sino–U.S. relations experienced substantial changes in economic cooperation, diplomatic interactions, and strategic competition. The collected indicators are organized into temporally aligned observation sequences to characterize the evolution of the bilateral strategic environment. After data cleaning, temporal synchronization, and feature standardization, the resulting dataset provides the initial state information required for multi-agent strategic decision-making and dynamic interaction simulation. The selected variables and their corresponding representations are summarized in Table 1.

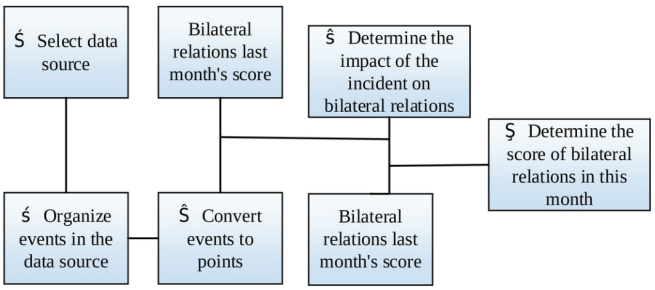


Figure 1: Workflow of data preparation and strategic state construction

Table 1: Summary of the Variables and Their Representations

Variable	Symbol
Exports to the United States	Export
Imports to the United States	Import
Relationship score	Relation
China's GDP	CHNGDP
U.S. GDP	USAGDP
U.S. dollar–renminbi exchange rate	e

Building upon the historical records of high-level political exchanges between China and the United States, this study develops an event-driven strategic behavior quantification framework to characterize the evolution of bilateral strategic interactions. A quantitative event-scoring mechanism is introduced to transform diplomatic activities, economic cooperation, trade disputes, and security-related interactions into structured indicators of strategic behavior. Specifically, historical events are classified according to their strategic attributes, including cooperation, competition, confrontation, and diplomatic negotiation, while their potential influences are characterized through event frequency, interaction intensity, and temporal characteristics. To construct the multidimensional strategic state representation, textual information from diplomatic yearbooks is systematically processed through keyword extraction, semantic categorization, and event identification. These event-based indicators are subsequently integrated with standardized economic and political statistics to establish temporally aligned strategic observation sequences. Unlike conventional regression-based approaches that primarily examine statistical correlations, the proposed framework treats strategic indicators as environmental observations and uses explicitly defined action categories to support the analysis of adaptive decision-making and reciprocal interactions between national agents [9].

To account for the historical evolution of Sino–U.S. strategic interactions, this study considers the foreign policy orientations and strategic decision-making characteristics observed across different presidential administrations. In particular, the administrations of George W. Bush and Barack Obama provide historical contexts for examining changes in bilateral cooperation, strategic competition, and diplomatic engagement. Their foreign policy records and international relations literature offer useful information for identifying representative strategic behaviors and understanding variations in national strategic preferences. However, these historical cases are distinguished from the primary monthly observation period of 2010–2020 to maintain temporal consistency in the empirical dataset. By incorporating historical contextual knowledge into the design of strategic action categories and interaction scenarios, the proposed framework aims to improve the interpretability of the modeled strategic decision-making process. Furthermore, the multi-agent stochastic game formulation provides a computational mechanism for examining how national strategic choices interact with changing political and economic conditions, thereby supporting scenario-based analysis of bilateral strategic dynamics.

For strategic variable selection and behavioral feature construction, this study employs Python-based text analysis of the "China–U.S. Relations" chapter of the Diplomatic Yearbook. The textual records are processed through word-frequency analysis, keyword filtering, semantic grouping, and event classification to identify recurring diplomatic topics and strategic interaction patterns. High-frequency expressions, such as cooperation, dialogue, meeting, trade, national defense, and consultation, provide preliminary evidence of the major thematic dimensions underlying Sino–U.S. relations. These terms are further organized into strategic categories associated with diplomatic engagement, economic interaction, security competition, and political coordination. Because word frequency alone cannot determine strategic intentions or the direction of an interaction, contextual interpretation and event-level coding are required before the extracted information can be incorporated into the multi-agent simulation framework. The resulting thematic indicators are intended to support strategic

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state construction and the identification of candidate action categories, rather than serving directly as learned behavioral policies. The preliminary word-frequency statistics are summarized in Table 2.

Table 2: Frequency Distribution of Strategic Interaction Keywords Extracted From Diplomatic Yearbooks

Rank	Keyword	Count	Frequency
4	Cooperation	412	0.93%
7	Minister	356	0.82%
8	Chairman	348	0.78%
10	President	308	0.68%
17	Dialogue	210	0.47%
18	Meeting	204	0.45%
20	Meeting	187	0.43%
26	Taiwan	173	0.38%
27	Secretary of State	171	0.39%
30	Trade	162	0.35%
31	Economics	157	0.35%
39	Consultations	126	0.29%
40	Prime Minister	128	0.28%
46	Congress	121	0.27%
48	Human rights	118	0.26%
56	Religion	110	0.24%
66	Investment	101	0.22%
67	National defense	101	0.23%
71	Meet	98	0.23%
73	Ministry of Foreign Affairs	95	0.22%
75	Peace	92	0.21%
76	Stable	92	0.22%
78	Science and technology	91	0.22%
89	State Councilor	82	0.18%
91	Deputy Minister	78	0.18%

B. Research Hypotheses

The historical trade figures cited in this study indicate that total bilateral imports and exports increased from US$81.77 billion in 2000 to US$634.32 billion in 2019. The source manuscript also reports growth measures of 346% and 12.7%; these percentages are retained pending verification because their calculation methods and denominators are not identified. The expansion of trade is commonly associated with opportunities for production, exchange, employment, and household consumption in both countries, although the distribution of those benefits and their net economic effects vary by industry and over time. Figure 2 illustrates the reported movement in bilateral trade volumes and the associated surplus, providing background for the first research hypothesis.

On one hand, Sino–U.S. economic relations have been shaped by a sustained expansion of bilateral trade and increasingly complex commercial interdependence. As cooperation deepened, institutional differences and limitations in existing trade-management mechanisms became more apparent. The governments developed several channels of high-level dialogue and negotiation intended to address disputes, coordinate policy positions, and maintain communication during periods of economic uncertainty. Figure 3 presents the trade timeline used to contextualize these exchanges and to situate diplomatic engagement alongside changes in trade conditions.

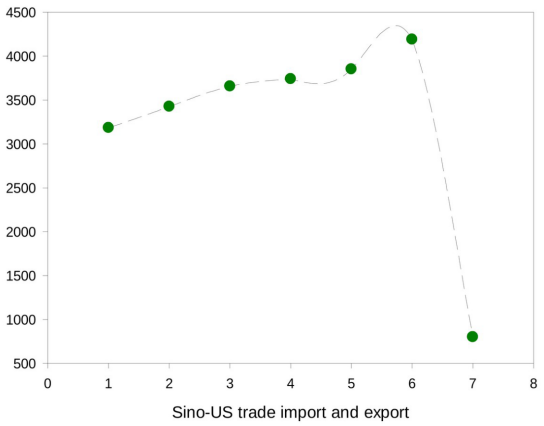


Figure 2: Sino–U.S. Bilateral Trade, Imports, Exports, and Trade Surplus



Figure 3: Timeline of Sino–U.S. Bilateral Trade

On the other hand, the growth of bilateral trade has occurred alongside recurring political disagreement and economic friction. From China's perspective, a substantial bilateral trade surplus has been an important feature of the relationship; the source manuscript reports a 743% increase in that surplus over a 17-year period, although the exact base year and calculation require confirmation. Following the global financial crisis, the United States made greater use of trade-remedy instruments, including investigations conducted under Section 301, and disputes intensified concerning market access, intellectual property, and industrial policy. Meanwhile, China's shift toward higher-value manufacturing increased competition in technologically intensive industries. U.S. political institutions raised concerns about technology transfer and intellectual-property protection, while Chinese officials disputed particular U.S. restrictions and criticized their economic consequences. These disagreements illustrate how trade interdependence can coexist with strategic competition. Diplomatic consultations and mechanisms associated with the World Trade Organization offer avenues for managing disputes, although

their effectiveness depends on the nature of each disagreement and the willingness of both governments to negotiate. On the basis of these competing tendencies, the study formulates its first empirical hypothesis concerning the relationship between high-level exchanges and bilateral trade.

Hypothesis 1. The frequency and intensity of high-level political exchanges are positively associated with the development of Sino–U.S. trade relations, controlling for relevant economic conditions.

The Taiwan issue has remained an important and sensitive component of relations among China, the United States, and Taiwan. The governments involved have adopted differing interpretations of sovereignty, security commitments, and the appropriate forms of diplomatic engagement. Developments involving Taiwan can influence the intensity and content of high-level bilateral communication, even when other economic and diplomatic channels remain active. The study therefore examines whether changes in the status of U.S.–Taiwan relations coincide with changes in high-level exchanges between China and the United States. Such a correlation would not establish a causal relationship, but it could indicate whether bilateral dialogue changes during periods of heightened political sensitivity. This consideration motivates the second hypothesis.

Hypothesis 2. The frequency and intensity of high-level China–U.S. political exchanges are positively correlated with the measured status of U.S.–Taiwan relations, subject to the definition and direction of the relationship index.

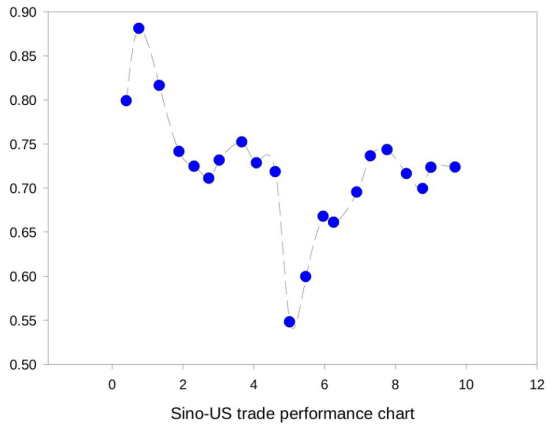


Figure 4: Reported Trade-Related Performance During the Event Window

The event-window discussion in the source manuscript suggests that stock returns for firms in affected industries were negative on the event date, whereas the broader window showed positive performance for some listed companies. Because the underlying event definition, sample, and return estimation procedure are not supplied, this observation should be interpreted as a descriptive claim rather than as a verified causal effect. Figure 4 presents the reported event-window trade-performance pattern, which requires confirmation against the original market data.

The overall logic of the keyword-extraction process and the related regression-based analytical workflow is summarized in Figure 5. The diagram connects historical diplomatic text processing to the quantitative indicators used in the subsequent analyses:

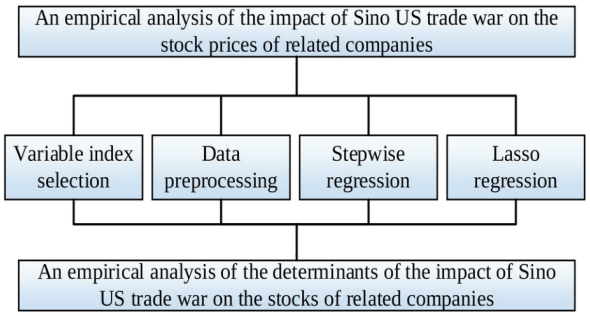


Figure 5: Keyword Extraction and Regression Analysis Workflow for Sino–U.S. Trade Disputes

This study also considers the possibility that conventional geopolitical explanations do not fully reflect the distinctive policy priorities and historical experiences of China and the United States. Interpretations of U.S. foreign policy sometimes emphasize exceptionalism, security commitments, and intervention abroad, while other analyses stress domestic institutional constraints and the changing balance between engagement and competition. Chinese foreign-policy statements frequently emphasize territorial sovereignty, noninterference, and peaceful development, although scholars differ over how these principles are implemented in particular regional disputes. These competing interpretations suggest that international security concerns cannot be understood through geography alone. Issues associated with the South China Sea and Taiwan, for example, may be assigned different levels of strategic significance by the parties involved, and the likelihood of disagreement depends on perceived sovereignty interests, military capabilities, and diplomatic expectations. Conversely, issues concerning global economic governance, climate policy, and selected international institutions can generate opportunities for limited cooperation despite persistent security competition. A balanced analysis should therefore distinguish geopolitical disputes, claims concerning territorial sovereignty, and questions of national security, rather than assuming that either confrontation or cooperation follows automatically from the international positions of the two states. This distinction motivates further examination of how strategic perceptions enter the proposed explanatory framework.

IV. Case Study

A. SPSS-Based Regression Analysis Test

Table 3 presents the reported regression coefficients together with a separate model summary. The table lists several conditional variables intended to represent differences in strategic

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strength, ideology, sovereignty interests, geographic security, judgments about intentions, and strategic reasoning. However, the significance statistics and several test values are absent, so the table does not by itself establish which individual variables are statistically significant. The summary also reports an exact model fit, which requires an audit of the underlying coding, specification, and dependent-variable construction before substantive conclusions can be drawn. From the perspective of international relations, the analysis nevertheless identifies a relevant question: whether sustained communication channels help governments manage differences in strategic interpretation across historical periods. Such mechanisms may support dialogue, clarify intentions, and reduce some opportunities for misunderstanding, but their effects cannot be inferred directly from the incomplete regression output. Figure 6 provides the associated descriptive scores of high-level political exchanges, which should be evaluated against a documented event-coding protocol.

Table 3: Regression Coefficient Estimates and Model Summary

Predictor	B	Std. error	Standardized B	t	p
Constant	.000	.000	.000	—	—
Strength comparison	.000	.000	.000	—	—
Ideology	.000	.000	.000	—	—
Sovereign interests	.000	.000	.000	—	—
Geopolitical security	.000	.000	.000	—	—
Intention judgment	1.000	.000	1.000	—	—
Strategic thinking	.000	.000	.000	—	—

Model summary (as reported):

Model	R	R^2	Adjusted R^2	SE of estimate	R^2 change	F change	df1	df2	p
1	1.000	1.000	1.000	.000	1.000	—	7	14	—

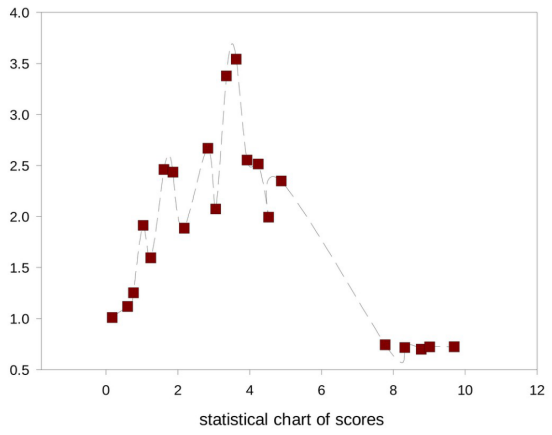


Figure 6: Scores of High-Level Political Exchanges

Concerns about espionage, intellectual-property protection, and technology transfer have also shaped debates over U.S.–China scientific and educational exchanges. Public commentary attributed to Peter Brookes and reports associated with the Heritage Foundation have raised concerns about the protection of U.S. research and technology, while Chinese officials and other observers have criticized broad restrictions on educational collaboration and research mobility. Similarly, statements associated with Peter Navarro in 2018 portrayed some international academic exchanges as potential channels for unauthorized technology transfer; such assertions should be attributed to their speakers and supported by independently verifiable sources rather than adopted as established findings. Policy measures involving export controls, technology access, student visas, and research cooperation may affect bilateral scientific exchange in different ways. To examine potential empirical links, this study considers the number of Chinese students enrolled in U.S. higher education (IS) and China's expenditure on research and experimental development (RD) as possible indicators of the scientific and educational dimension of bilateral relations. Table 4 presents related historical economic, defense, and education indicators, while their statistical relationships with diplomatic exchanges require separate specification and testing.

Table 4: Historical Economic, Defense, and Education Control Variables

Year	China GDP (US$ trillion)	U.S. GDP (US$ trillion)	Relative share	China GDP growth	China military (US$ million)	China military share GDP	U.S. military (US$ million)	U.S. military share GDP	R&D (100m yuan)	Students studying
2000	1.212	10.253	11.82%	8.51%	22929.76463	1.88%	301698	2.94%	895.8	59938
2001	1.338	10.581	12.65%	8.30%	27875.38725	2.06%	312745	2.95%	1042.6	63212
2001	1.472	10.936	13.44%	9.11%	32.137.73567	2.19%	356721	3.26%	1287.5	64758

B. Model Optimization Results

The reported variance inflation factors (VIFs) in Table 5 are below 10, suggesting that the model does not exceed this commonly used screening threshold for multicollinearity. Nevertheless, values below 10 do not demonstrate that multicollinearity has been eliminated. In the displayed regression output, the coefficient for arms sales to Taiwan (AC) has a significance value above 0.05, so it does not meet the conventional 5% criterion for statistical significance. The source text also refers to a statistically significant U.S. GDP control variable (GA), but that variable is not included in the displayed coefficient table and its claimed significance cannot be checked from the evidence presented. Accordingly, Table 5 should be interpreted only as a partial summary of the optimized specification until the full regression output is supplied.

Table 5: Results of the Optimized Regression Specification

Variable	B	Std. error	Beta	t	p	Tolerance	VIF
Constant	7.381	2.438	—	3.028	.012	—	—
China–U.S. total trade (TV)	1.363E-7	.000	.018	.047	.964	.232	4.328
Growth rate (SI)	.026	.025	.236	1.029	.325	.583	1.718
U.S. direct investment (DI)	-.001	.001	-.778	-2.236	.048	.252	3.985
Phase change (0C)	.424	.323	.243	1.312	.218	.897	1.115
Arms sales to Taiwan (AC)	-.432	.343	-.245	-1.257	.235	.812	1.235

Stationarity and dynamic stability are relevant to the interpretation of the vector autoregressive model for exports and imports. The reported autoregressive root diagnostics are provided in Figures 7 and 8; the locations of the characteristic roots relative to the unit circle should be examined before treating the resulting impulse responses as those of a stable VAR model.

The export equation's impulse-response results are presented in Figure 9. Interpretation requires the shock normal-

ization, forecast horizon, identification scheme, and uncertainty intervals, none of which can be reconstructed from the LaTeX text alone.

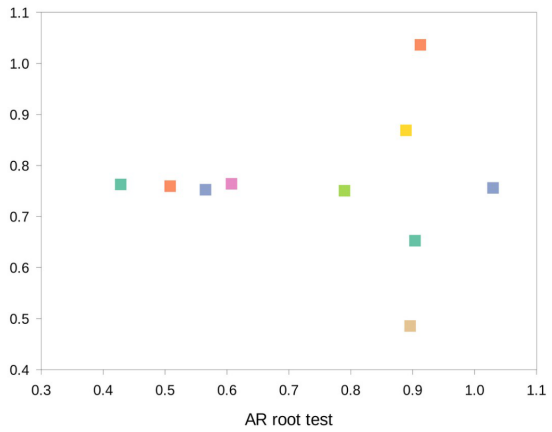


Figure 7: Autoregressive Root Diagnostic, Panel 1

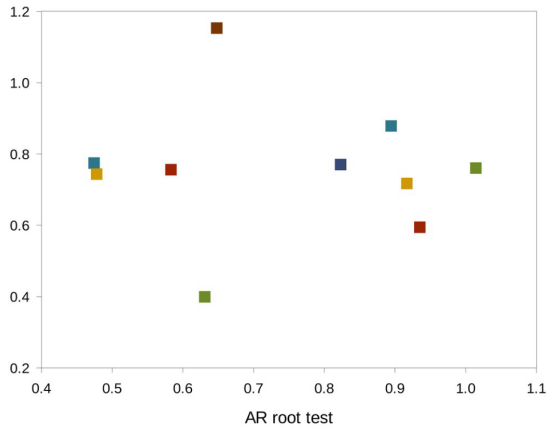


Figure 8: Autoregressive Root Diagnostic, Panel 2

The import equation's impulse-response results are presented in Figure 10. As in the export analysis, conclusions about persistence, direction, and economic magnitude should depend on the reported identification assumptions and the confidence intervals.

The text reports that the coefficient of determination (R^2) and the adjusted coefficient of determination are both greater than 0.5, suggesting that the estimated model may account for a substantial share of the variation in the dependent variable. However, a high fit statistic alone does not establish the validity of a causal interpretation or the adequacy of the model specification, particularly when sample size, variable construction, and residual diagnostics have not been fully documented.

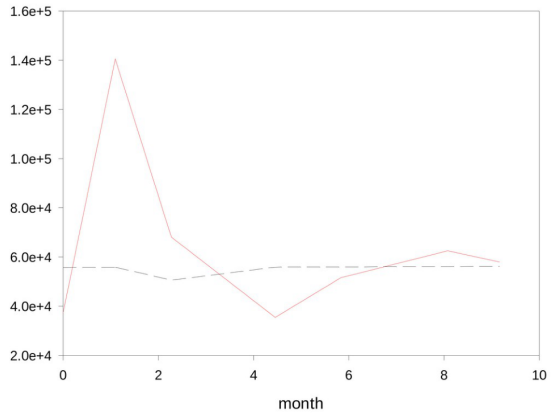


Figure 9: Impulse Response of the Export Equation

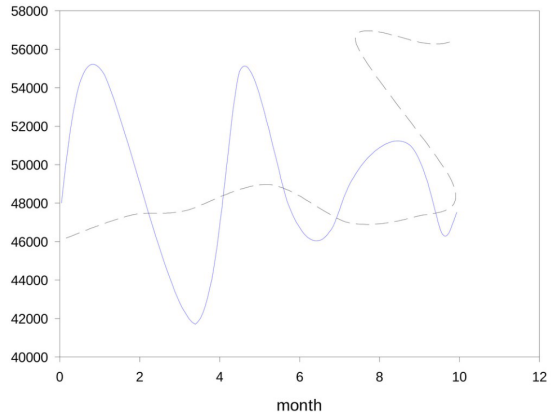


Figure 10: Impulse Response of the Import Equation

V. Conclusion

This study presents a data-informed multi-agent deep reinforcement learning framework for modeling and simulating strategic interactions between major powers, with Sino–U.S. relations serving as a representative case. To overcome the limitations of conventional regression-based approaches in characterizing reciprocal strategic responses and adaptive decision-making, the proposed framework integrates multi-dimensional strategic state representation, stochastic game theory, and multi-agent reinforcement learning into a unified computational architecture. By incorporating economic indicators, diplomatic interactions, geopolitical security factors, and historical political events, a structured representation of the evolving strategic environment is established. An event-based quantification mechanism is further introduced to characterize the accumulated effects of historical interactions and short-term variations in bilateral relations, providing a data-informed foundation for dynamic strategic behavior modeling.

Within the proposed framework, major powers are represented as autonomous agents whose strategic decisions influence both their individual objectives and subsequent envi-

ronmental conditions. A multidimensional reward mechanism incorporating economic benefits, security interests, diplomatic gains, and confrontation costs is formulated to characterize the trade-offs underlying national strategic behavior. Through repeated interactions and adaptive policy optimization, the multi-agent learning mechanism is designed to investigate strategic responses, behavioral adjustment, and cooperation–competition dynamics. Furthermore, a scenario-based simulation approach is established to examine potential interaction trajectories under different economic, diplomatic, and security conditions, providing a computational basis for exploring strategic interdependence and alternative decision-making outcomes.

The principal contribution of this study lies in establishing an integrated methodological framework that connects empirical international relations analysis with adaptive strategic decision-making and dynamic simulation. Nevertheless, the reliability of its applications depends on the quality of historical event coding, the validity of assumed reward structures, and the calibration of environmental transition mechanisms. Limited historical observations and uncertainty regarding actual national preferences also constrain the interpretation and generalizability of simulated outcomes. Future research will focus on implementing and empirically validating the proposed framework, incorporating richer geopolitical event datasets, improving reward-function interpretability, and extending the model to multi-country strategic interactions. These developments are expected to strengthen the framework's capacity to support systematic analysis of strategic behavior evolution, interaction stability, and international cooperation–competition mechanisms.

Author Contributions

Both authors contributed equally to the conception, development, analysis, and preparation of this manuscript. Both authors reviewed the manuscript, approved its final version, and agreed to its submission for publication.

Conflict of Interest

The authors declare that they have no financial or non-financial conflicts of interest in relation to the research presented in this manuscript.

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Data Availability

The data underlying the analyses described in this manuscript are available from the corresponding author upon reasonable request.

References

[1] Zhang, B. (2020). Understanding changes in Sino-U.S. relations from a historical perspective. *China International Strategy Review, 2*(1), 1–13. https://doi.org/10.1007/s42533-020-00048-6

[2] Goldstein, J. S. (1992). A conflict-cooperation scale for WEIS events data. *Journal of Conflict Resolution, 36*(2), 369–385. https://doi.org/10.1177/0022002792036002007

[3] Schrodt, P. A. (2012). Precedents, progress, and prospects in political event data. *International Interactions, 38*(4), 546–569. https://doi.org/10.1080/03050629.2012.697430

[4] Leetaru, K., & Schrodt, P. A. (2013, April). *GDELT: Global data on events, location and tone, 1979–2012* [Conference presentation]. International Studies Association Annual Convention, San Francisco, CA, United States.

[5] Littman, M. L. (1994). Markov games as a framework for multi-agent reinforcement learning. In W. W. Cohen & H. Hirsh (Eds.), *Machine learning proceedings 1994* (pp. 157–163). Morgan Kaufmann. https://doi.org/10.1016/B978-1-55860-335-6.50027-1

[6] Lowe, R., Wu, Y., Tamar, A., Harb, J., Abbeel, P., & Mordatch, I. (2017). Multi-agent actor-critic for mixed cooperative-competitive environments. In *Advances in neural information processing systems* (Vol. 30). Curran Associates. https://proceedings.neurips.cc/paper/2017/hash/68a9750337a418a86fe06c1991a1d64c-Abstract.html

[7] Gronauer, S., & Diepold, K. (2022). Multi-agent deep reinforcement learning: A survey. *Artificial Intelligence Review, 55*, 895–943. https://doi.org/10.1007/s10462-021-09996-w

[8] Yu, C., Velu, A., Vinitsky, E., Gao, J., Wang, Y., Bayen, A., & Wu, Y. (2022). The surprising effectiveness of PPO in cooperative multi-agent games. In *Advances in neural information processing systems* (Vol. 35, pp. 24611–24624). Curran Associates. https://proceedings.neurips.cc/paper_files/paper/2022/hash/9c1535a02f0ce079433344e14d910597-Abstract.html

[9] Beieler, J. (2016). Generating politically-relevant event data. In *Proceedings of the first workshop on NLP and computational social science* (pp. 37–42). Association for Computational Linguistics. https://doi.org/10.18653/v1/W16-5605