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Energy Trade and Welfare Effects of the 2025 US–China Tariff Shocks: A Recursively Updated GTAP Analysis

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Abstract

The 2025 tariff escalation between the United States (US) and China generated uneven macroeconomic and energy-trade effects. Using a Global Trade Analysis Project (GTAP) model updated recursively to a common 2023 benchmark, we analyze five independent cumulative-tariff scenarios, a sequential experiment, and five Armington-elasticity settings. Under the peak 145% common-baseline scenario S4, China's equivalent variation falls by USD 203.59 billion and real GDP by 0.59%, whereas US welfare rises by USD 41.43 billion despite a 0.19% GDP decline. China incurs allocative-efficiency and terms-of-trade losses, while the US terms-of-trade gain exceeds its allocative-efficiency loss. These S4 macroeconomic directions remain robust across the elasticity settings. Energy responses are heterogeneous: China's natural-gas output falls by 11.21%, US electricity output rises by 17.32%, China's electricity imports increase by 97.62%, and US coal imports increase by 108.32%. All S4 energy-import responses remain positive across the elasticity settings, although some output and export responses change direction. Third-party energy-trade increases are more frequent than decreases but vary across products and economies. In the sequential S5 experiment, reducing the tariff shock from 145% to 30% raises real GDP in both countries relative to S4 but reverses the welfare pattern: China gains, whereas the US loses. Overall, tariff de-escalation eases output losses without producing symmetric welfare gains.

Keywords: US–China tariffs; energy trade; GTAP; welfare decomposition; terms of trade; Armington elasticity; sequential tariff shocks

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1. Introduction

The US–China trade dispute began in 2018 and escalated again in 2025, when successive measures raised the cumulative additional US tariff on many Chinese goods to 145%. As major energy producers, consumers, and importers, both economies can transmit bilateral tariff shocks to energy markets through production costs, final demand, and supplier substitution. Table 1 summarizes the policy events used to construct the model scenarios.

Subsequent negotiations provided the basis for the lower-tariff S5 scenario, whose implementation under the common-baseline and sequential simulations is detailed in Section 3.4.

This study addresses four questions. First, how does tariff intensity affect welfare and real GDP in China, the United States, and third-party economies? Second, which allocation and terms-of-trade mechanisms explain differences between welfare and GDP

outcomes? Third, how do the shocks alter the output, exports, and imports of coal, crude oil, natural gas, and electricity? Fourth, which conclusions remain directionally robust under alternative Armington elasticities and under a sequential rather than common-baseline comparison? We address these questions with five tariff scenarios, welfare decomposition, product-level energy results, and systematic elasticity tests.

Table 1. Timeline of the 2025 US–China tariff measures used in the scenario design.

Round	Date	Policy Development
First round	1 February 2025	The United States announced an additional 10% tariff on all imports from China in connection with the fentanyl emergency, effective 4 February 2025.
	4 February 2025	China announced its first countermeasures: additional tariffs of 15% on US coal and liquefied natural gas and 10% on US crude oil, agricultural machinery, large-displacement automobiles, and pickup trucks, effective 10 February 2025. China also introduced export controls on selected critical minerals and added designated US entities to relevant control lists.
Second round	3 March 2025	The United States announced a further 10-percentage-point increase in the fentanyl-related tariff on imports from China, raising the cumulative additional tariff to 20%, effective 4 March 2025.
	4 March 2025	China announced a second set of countermeasures: additional tariffs of 15% on US chicken, wheat, corn, and cotton and 10% on sorghum, soybeans, pork, beef, aquatic products, fruit, vegetables, and dairy products, effective 10 March 2025.
Third round	2 April 2025	The United States announced a 34% reciprocal tariff on imports from China. Together with the existing 20% fentanyl-related tariff, this produced a cumulative additional tariff of 54%.
	4 April 2025	China announced an additional 34% tariff on all imports from the United States, effective 10 April 2025.
Fourth round	9 April 2025	China announced that its additional tariff on US goods would rise from 34% to 84%, effective 10 April 2025. The United States announced that its reciprocal tariff on Chinese goods would rise to 125%; together with the 20% fentanyl-related tariff, the cumulative additional US tariff reached 145%, effective 10 April 2025.
	11 April 2025	China announced that its additional tariff on all imports from the United States would rise from 84% to 125%, effective 12 April 2025.
Truce and extension	12 May 2025	China and the United States issued the Geneva Joint Statement. Both sides agreed to remove the tariff increases introduced after 2 April and to suspend 24 percentage points of the 34% reciprocal tariff for an initial 90-day period while retaining the remaining 10%. The previously imposed 20% US fentanyl-related tariff remained in effect. The arrangement was scheduled to take effect on 14 May 2025.
	14 May 2025	The tariff-reduction arrangement under the Geneva Joint Statement took effect. The cumulative additional US tariff setting on imports from China fell from 145% to 30%, comprising the 20% fentanyl-related tariff and the retained 10% reciprocal tariff.
	28–29 July 2025	China and the United States held a new round of economic and trade talks in Stockholm to discuss an extension of the existing tariff suspension. The lower-tariff arrangement established under the Geneva Joint Statement remained in effect during the talks.

Note: Percentage-point changes refer to the additional tariff measures introduced in 2025. The cumulative US tariff figures combine the fentanyl-related tariff and the reciprocal tariff where applicable. **Source:** Authors' compilation based on official policy announcements issued by the US and Chinese governments and relevant news reports.

The study contributes in four respects. First, it combines common-baseline and sequential stage-to-stage simulations to distinguish the cumulative effects of tariff escalation from the incremental adjustments associated with successive tariff changes. Second, it decomposes welfare changes into allocation, terms-of-trade, and investment–savings effects, thereby clarifying the sources of the divergent welfare outcomes in China and the United States. Third, it traces changes in output, exports, and imports across coal, crude oil, natural gas, and electricity, including the associated trade spillovers to third-party economies. Fourth, it evaluates the robustness of the principal results across five Armington-elasticity settings.

2. Literature Review

Research on the US–China trade dispute has developed along several related strands.

One strand examines aggregate trade and welfare effects. Using monthly data from January 2017 to October 2022 and a difference-in-differences (DID) design, Yang et al. [1] find that the trade war substantially reduced Chinese exports to the United States, primarily through higher tariffs. Ju and Hou [2] characterize the transition from Trade War 1.0 to Trade War 2.0 as a new stage of global economic competition. Benguria [3] documents declines in revenue, profits, and capital stocks among firms worldwide with export exposure to China. Li and Pan [4] find welfare losses in both countries, with larger losses in the United States, and attribute most third-country welfare losses to US tariff increases. Evidence from the 2018 tariff rounds documents near-complete pass-through to prices paid by US importers and substantial incidence on US firms and consumers [5–7]. Studies that quantify the associated welfare or real-income effects report losses [5,6]. A broader review concludes that the conflict generated aggregate losses alongside pronounced distributional effects [8].

A second strand examines sectoral heterogeneity. Using a GTAP model, Nantembelele et al. [9] find that the trade war reduced bilateral trade and economic growth in China and the United States while generating trade-diversion effects that created both opportunities and challenges for Sub-Saharan Africa. Agricultural, food, and oil and gas exports benefited, whereas minerals, metals, and services were adversely affected. Deng et al. [10] show that US trade-policy uncertainty increased soybean prices but reduced corn, wheat, and rice prices in China.

A third strand explores the mitigating role of regional trade agreements. Zhang et al. [11] argue that the Regional Comprehensive Economic Partnership (RCEP) can partly offset the adverse effects of the trade war by enabling trade to be rerouted through member economies. Using a gravity model, Yan and Zhang [12] find adverse effects on bilateral imports, exports, GDP, and welfare and conclude that deeper cooperation with Belt and Road Initiative countries could lessen these effects. Product-level evidence also shows that the conflict reallocated trade beyond the two directly involved economies, with substantial cross-country heterogeneity [13].

A fourth strand links trade-policy uncertainty to innovation. Cao and Hu [14] find that greater uncertainty significantly constrains green innovation. Using a DID approach, Zheng et al. [15] show that the trade war increased Chinese firms' applications for key digital technology patents and that KDI helped mitigate the adverse effects of the conflict on firms' market performance.

A fifth strand examines other outcomes, including global-value-chain participation, tariff evasion, and the relative performance of multinational and domestic firms. Meng et al. [16] find that regions situated upstream in China's global value chains suffer greater losses from the trade war. Che et al. [17] find that, after the trade war, a one standard deviation increase in local demand was associated with a 1.312-fold increase in tariff evasion for affected products. Using panel data on Chinese firms from 2011 to 2019, Lee

and Nguyen [18] find that multinational corporations outperformed domestic firms in revenue by approximately 8% following the trade war.

Existing studies document aggregate trade, welfare, sectoral, innovation, and global-value-chain effects of the US–China trade conflict. Energy-security research identifies import-source diversification and supplier concentration as important dimensions of exposure to external supply shocks [19,20]. Related research on energy and climate policy has employed multiregion, multisector CGE models to assess the economy-wide efficiency and distributional effects of policy interventions, including border carbon adjustments [21]. Less attention has been paid to the joint adjustment of energy output, imports, and exports during the 2025 escalation, to the welfare mechanisms behind divergent GDP and equivalent-variation results, or to the difference between common-baseline and sequential comparisons. This study addresses those gaps within a consistent multiregional framework. The remainder of the article presents the model and scenarios, reports the macroeconomic and energy-market results, compares robustness across elasticities and simulation designs, and concludes with policy implications and limitations.

3. Materials and Methods

3.1. Theoretical Foundations of the GTAP Model

The GTAP framework is well suited to this analysis because the Version 11 database represents 160 countries or regions and 65 sectors within a consistent global social-accounting system. It captures intersectoral input linkages, bilateral trade, factor markets, and economy-wide resource constraints. The welfare analysis follows the equivalent-variation decomposition developed for GTAP [22].

3.1.1. General Equilibrium Conditions

GTAP is solved as a large system of nonlinear equations subject to Walrasian general-equilibrium conditions. The equilibrium satisfies the following three conditions:

(1) Zero-profit condition: In each industry, revenue equals cost under constant returns to scale.
(2) Market-clearing condition: Supply equals demand in every commodity and factor market.
(3) Income-balance condition: Total income equals total expenditure in each region.

Mathematically, this is equivalent to finding a price vector P such that the excess-demand function $Z(P) = 0$, satisfying Walras's law:

$$\sum_i p_i Z_i(p) = 0.$$

The recursive updating procedure draws on the general solution logic of dynamic GTAP [23], while factor supplies and macroeconomic aggregates are updated exogenously between annual equilibria in this study.

3.1.2. Production Structure

(1) Nested Production Function

GTAP represents production technology through a multilevel nested constant-elasticity-of-substitution (CES) production function.

At the first level, output is a Leontief combination of intermediate inputs and value added:

$$Q = \min\left(\frac{\mathrm{IC}_1}{a_1}, \frac{\mathrm{IC}_2}{a_2}, \cdots, \frac{\mathrm{VA}}{a_{\mathrm{VA}}}\right)$$

At the second level, value added is a CES composite of primary factors, including capital, labor, land, and natural resources:

$$\mathrm{VA} = A\left[\sum_i \delta_i X_i^{-\rho}\right]^{-1/\rho}$$

where $\sigma = \frac{1}{1+\rho}$ is the elasticity of substitution, and A is the technology parameter.

(2) Returns to Scale and Market Structure

The standard GTAP model assumes perfect competition and constant returns to scale (CRS). Price therefore equals marginal cost, the zero-profit condition holds, and firms earn no excess profits.

3.1.3. Armington Trade Specification

The Armington assumption [24], introduced by Paul Armington in 1969, is central to the GTAP trade specification. It treats otherwise identical products from different origins as imperfect substitutes.

The CES aggregation function takes the following form:

$$U = \left(\sum_i a_i^{1/\sigma} \cdot q_i^{(\sigma-1)/\sigma}\right)^{\sigma/\sigma-1}$$

For a simplified two-source case:

$$Q = \left[\alpha \cdot D^{(\sigma-1)/\sigma} + (1-\alpha)\cdot M^{(\sigma-1)/\sigma}\right]^{\sigma/(\sigma-1)}$$

where Q is the composite commodity supply, D is the domestic product, M is the imported product, α is the domestic share parameter, and σ is the Armington elasticity of substitution.

3.1.4. Welfare Decomposition

Following the GTAP welfare-decomposition framework developed by Huff and Hertel [22], the change in equivalent variation (EV) is decomposed into the following components:

EV = Allocative Efficiency + Terms of Trade + Endowment Effect + Investment–Savings Effect

Expressed mathematically:

$$\mathrm{EV} = \sum_i P_i \cdot \mathrm{d}Q_i + \sum_i \mathrm{d}P_i^{\omega} \cdot T_i + \sum_j \mathrm{d}V_j \cdot W_j + \mathrm{d}P_{\mathrm{Sav/Inv}} \cdot S$$

where P_i is the price of commodity i, Q_i is the quantity of commodity i, P_i^{ω} is the world price, T_i is the trade volume, V_j is the endowment of factor j, W_j is the price of factor j, and S is savings.

3.2. Model Specification

This study uses the GTAP Data Base Version 11, which contains 160 countries or regions, 65 sectors, and five factors of production. For tractability, the database is aggregated into four countries (Australia, China, the United States, and Russia), two regions (the European Union and OPEC), and four aggregate regions (Other North America, ASEAN-10, Japan and South Korea, and Rest of World). The sectors are aggregated into crude oil, natural gas, coal, electricity, agriculture, manufacturing, metals and metal products, petrochemicals, and other activities. The retained factors are land, labor, capital, and natural resources. Monetary welfare results are reported as changes in equivalent variation (USD

million, at 2023 prices), while quantity results are reported as percentage deviations from the recursively updated baseline.

The GTAP model represents import demand through a two-level Armington structure. ESUBD governs substitution between domestic and imported goods, whereas ESUBM governs substitution among foreign sources. Table 2 reports the baseline values for coal, crude oil, natural gas, and electricity. These sector-specific elasticities are common across all countries, regions, and aggregate regions. To assess parameter uncertainty under unusually large tariff shocks, we rerun all five scenarios after changing both ESUBD and ESUBM for the four energy commodities simultaneously by −50%, −25%, +25%, and +50%, while holding all other settings fixed. The corresponding sensitivity profiles for all modeled countries, regions, and aggregate regions are provided in Supplementary Materials S1 and S2. The sensitivity exercise is motivated by the recognized importance of trade-elasticity uncertainty in CGE assessments and of systematic parameter testing in simulation models [25,26].

Table 2. Armington elasticities used in the baseline and sensitivity analysis.

Energy Sector	Elasticity	−50%	−25%	Baseline	+25%	+50%
Coal	ESUBD	1.525	2.2875	3.05	3.8125	4.575
Coal	ESUBM	3.05	4.575	6.10	7.625	9.15
Crude oil	ESUBD	2.60	3.90	5.20	6.50	7.80
Crude oil	ESUBM	5.20	7.80	10.40	13.00	15.60
Natural gas	ESUBD	6.555	9.8325	13.11	16.3875	19.665
Natural gas	ESUBM	17.055	25.5825	34.11	42.6375	51.165
Electricity	ESUBD	1.795	2.6925	3.59	4.4875	5.385
Electricity	ESUBM	4.30	6.45	8.60	10.75	12.90

Note: The same five elasticity settings are applied to S1–S5. Within each sensitivity run, ESUBD and ESUBM for coal, crude oil, natural gas, and electricity are varied simultaneously by −50%, −25%, +25%, or +50% relative to their baseline values. All other model settings remain unchanged. Source: GTAP 11C database; authors' calculations using RunGTAP 3.75 with the standard GTAP model.

3.3. Model Closure and Macroeconomic Balances

Each simulation employs the standard comparative-static general-equilibrium closure of the GTAP model. Regional factor endowments are fixed within each simulation period, implying full employment, whereas factor prices and the sectoral allocation of factors adjust endogenously in accordance with the GTAP factor-mobility assumptions. The global primary-factor price index serves as the numeraire. Regional saving prices and trade balances are determined endogenously, global investment equals global saving, and the regional trade balance satisfies the following identity:

$$TB_r = S_r - I_r$$

where the subscript r denotes the region, and S, I, and TB denote saving, investment, and the trade balance, respectively. Tariff revenue accrues to regional household income and is allocated among private consumption, government consumption, and saving. In constructing the recursively updated 2017–2023 baseline, factor endowments, including capital stocks, are fixed within each annual equilibrium and updated exogenously between years. The tariff scenarios applied to the common 2023 benchmark are solved using the comparative-static closure. The complete closure settings are reported in Table L3 of Supplementary Material S1 and Table L3 of Supplementary Material S2.

3.4. Scenario Design

Table 3 defines five tariff scenarios corresponding to the principal stages of the 2025 US–China tariff escalation and subsequent truce. It distinguishes successive policy adjustments from cumulative tariff shocks measured against the pre-escalation baseline.

Table 3. Tariff scenario settings.

Scenario	Corresponding Policy Stage	Successive Adjustment in US Tariff Shock on Chinese Goods	Cumulative US Tariff Shock on Chinese Goods	Successive Adjustment in Chinese Tariff Shock on US Goods	Cumulative Chinese Tariff Shock on US Goods
S1	Rounds 1 and 2	+20 percentage points relative to the pre-escalation baseline	+20%	+20 percentage points relative to the pre-escalation baseline	+20%
S2	Round 3	+34 percentage points relative to S1	+54%	+34 percentage points relative to S1	+54%
S3	Round 4 escalation	+50 percentage points relative to S2	+104%	+50 percentage points relative to S2	+104%
S4	Round 4 full escalation	+41 percentage points relative to S3	+145%	+41 percentage points relative to S3	+145%
S5	Tariff truce and lower-tariff setting	−115 percentage points relative to S4	+30%	−115 percentage points relative to S4	+30%

Note: The successive-adjustment columns report the tariff changes used in Section 4.6: S1 is measured relative to the pre-escalation baseline, whereas S2–S5 are measured relative to the immediately preceding scenario. The cumulative tariff-shock columns report the shocks applied independently relative to the same pre-escalation baseline in Sections 4.1–4.5. For comparability and implementation within the GTAP framework, the shocks are applied symmetrically to bilateral US–China trade.

Sections 4.1–4.5 use independent scenario simulations. S1–S5 are each simulated from the same model economy and baseline tariff structure prevailing before the 2025 tariff escalation, with bilateral tariff shocks of 20%, 54%, 104%, 145%, and 30%, respectively. Because all five scenarios share the same starting point, their results measure the effects of different cumulative tariff levels relative to the same pre-escalation baseline and can therefore be compared directly.

Section 4.6 uses comparative-static simulations under sequential tariff shocks, with each adjustment applied to the equilibrium obtained from the preceding scenario. S1 applies a 20-percentage-point bilateral tariff shock relative to the pre-escalation baseline. S2, S3, and S4 then introduce additional increases of 34, 50, and 41 percentage points, respectively. S5 reduces the cumulative tariff shock from 145% in S4 to 30%, a decrease of 115 percentage points. Accordingly, the "successive adjustment" columns in Table 3 report the changes used in Section 4.6, whereas the "cumulative tariff shock" columns report the independent scenario settings used in Sections 4.1–4.5.

S5 represents the tariff truce and lower-tariff setting. Under the Joint Statement on the US–China Economic and Trade Meeting in Geneva, issued on 12 May 2025, the United States suspended 24 percentage points of the 34% reciprocal tariff while retaining the remaining 10%. The previously imposed 20% fentanyl-related additional tariff remained in effect. The cumulative tariff shock underlying S5 is therefore specified as:

$$20\% \text{ fentanyl-related additional tariff} + 10\% \text{ retained reciprocal tariff} = 30\%.$$

In Sections 4.1–4.5, S5 is implemented as an independent scenario with a cumulative tariff shock of 30% relative to the pre-escalation baseline. In Section 4.6, S5 represents a reduction in the cumulative tariff shock from 145% in S4 to 30%, equivalent to a decrease of 115 percentage points:

$$145\% - 115 \text{ percentage points} = 30\%.$$

S5 therefore reaches the same final tariff-shock level under both simulation approaches, but the comparison bases differ. The independent scenario simulation measures the overall effect of a cumulative 30% tariff shock relative to the pre-escalation baseline, whereas the sequential simulation measures the changes in economic variables associated with the reduction from 145% to 30% relative to the S4 equilibrium.

In practice, the tariff measures and countermeasures implemented by China and the United States differed across products in both coverage and tariff rates. To ensure comparability across scenarios and facilitate implementation within the GTAP framework, the tariff levels at each stage are represented as uniform and symmetric bilateral tariff shocks. The simulation results should therefore be interpreted as model responses under the specified tariff scenarios rather than as a product-by-product replication of the tariff rates applied in practice.

The tariff shocks are applied exclusively to bilateral trade between China and the United States. No direct tariff shock is imposed on Other North America or any other third-party economy or regional aggregate; their simulated responses arise endogenously through general-equilibrium channels, including trade diversion, relative-price adjustments, and terms-of-trade effects.

3.5. Data Processing and Recursive Updating

The benchmark year of the GTAP Data Base Version 11 is 2017. We update the baseline recursively to 2023 using annual changes in population, labor, capital, and GDP from the Centre d'Études Prospectives et d'Informations Internationales (CEPII) and applied-tariff data from the World Integrated Trade Solution (WITS). The HS4 products are mapped to GTAP commodities and subsequently aggregated into nine model sectors. To update the GTAP tariff structure, the corresponding HS-level applied tariff rates from WITS are aggregated within each GTAP commodity using a simple arithmetic mean. The concordance between HS4 headings, GTAP commodities, and the nine model sectors, together with the condensed HS4 coverage, is reported in Table L1 of Supplementary Materials S1 and S2. At each annual step, the updated equilibrium becomes the benchmark for the following year. The five independent tariff scenarios are then applied to the common 2023 baseline; the explicitly sequential experiment in Section 4.6 instead applies each stage to the preceding equilibrium.

4. Results

Sections 4.1–4.5 report independent simulations relative to the common 2023 baseline. Section 4.6 uses sequential comparisons, with S1 evaluated relative to the pre-escalation benchmark and S2–S5 relative to the preceding equilibrium. Thus, the former measure cumulative tariff effects, whereas the latter capture incremental stage-to-stage adjustments. Supplementary Materials S1 and S2 provide the complete results for the common-baseline and sequential experiments, respectively, across all modeled countries, regions, and aggregate regions, including welfare and its decomposition, real GDP, energy-sector output, imports and exports, terms of trade, and Armington-elasticity sensitivity analyses.

4.1. Macroeconomic and Welfare Effects

Table 4 summarizes the real GDP and welfare effects of the five tariff scenarios across China, the United States, and the reported third-party economies. Under S4, China records the largest welfare loss, at USD 203.59 billion, while the United States records the largest gain, at USD 41.43 billion. Australia, Russia, ASEAN-10, Other North America, Rest of World, and OPEC also gain, whereas the European Union and Japan and South Korea lose welfare. GDP effects are much smaller: China and the United States contract by 0.59% and 0.19%, respectively, while most third-party economies record small positive changes.

Table 4. Macroeconomic effects of the US–China tariff shocks.

Country, Region, or Aggregate Region	Real GDP Change (%)					Equivalent Variation (EV, USD Million)					Impact Category (S4)
	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5	
United States	−0.03	−0.09	−0.16	−0.19	−0.05	650.3	1710.0	12,056.5	41,428	851.3	Significant gains
Australia	0.01	0.02	0.05	0.09	0.01	376.6	1331.8	4630.3	11,387	604.3	Significant gains
Russia	0.01	0.02	0.03	0.06	0.01	431.7	1435.0	4020.4	8105	686.2	Moderate gains
ASEAN-10	0.00	0.00	0.00	0.00	0.00	808.5	2113.9	4339.6	7623	1197.7	Moderate gains
Other North America	0.01	0.04	0.07	0.10	0.02	1558.2	3881.3	6227.7	6954	2288.7	Moderate gains
Rest of World	0.00	0.01	0.02	0.03	0.01	1822.5	4323.9	6044.3	5086	2644.4	Moderate gains
OPEC	−0.01	−0.02	−0.05	−0.07	−0.01	204.6	926.8	2624.9	4256	370.1	Slight gains
European Union	0.01	0.01	0.02	0.03	0.01	653.6	1085.3	−490.4	−4203	879.2	Adverse effect
Japan and South Korea	0.00	0.01	0.01	0.01	0.01	140.8	−318.4	−3638.2	−10,058	110.5	Adverse effect
China	−0.02	−0.08	−0.25	−0.59	−0.04	−15,260.6	−43,237.4	−104,318.0	−203,589	−23,065.9	Adverse effect

Note: Scenarios S1–S5 are independently simulated relative to the common 2023 baseline. Impact categories are based on S4 equivalent variation: EV < 0 indicates an adverse effect; $0 \leq$ EV < 5000 indicates slight gains; 5000 $\leq$ EV < 10,000 indicates moderate gains; and EV $\geq$ 10,000 indicates significant gains. Source: Authors' GTAP simulations.

Figure 1 compares the effects of the five tariff scenarios on real GDP, each of which is simulated independently relative to the common 2023 baseline. Real GDP declines in both China and the United States under all scenarios. From S1 to S4, China's GDP loss increases from 0.02% to 0.59%, while the corresponding US loss increases from 0.03% to 0.19%. The difference between the two countries becomes particularly pronounced under S4, indicating that China experiences the larger output contraction at the highest tariff level. Under S5, the GDP losses fall to 0.04% in China and 0.05% in the United States. Because S5 is independently evaluated against the common baseline, these smaller effects reflect the lower cumulative tariff rate rather than an economic recovery from S4.

Figure 2 decomposes the welfare changes into allocation, terms-of-trade, and investment–savings effects. China's welfare loss increases from USD 15.26 billion in S1 to USD 203.59 billion in S4. Under S4, the allocation and terms-of-trade effects amount to losses of USD 104.32 billion and USD 97.93 billion, respectively, while the investment–savings effect contributes a further loss of USD 1.33 billion. These components therefore reinforce one another. In the United States, the allocation effect is negative in every scenario, but it is offset by improvements in the other welfare components. Under S4, the allocation loss of USD 40.77 billion is more than offset by a terms-of-trade gain of USD 68.94 billion and an investment–savings gain of USD 13.27 billion, producing a total welfare gain of USD 41.43 billion. The contrasting welfare outcomes therefore arise mainly from the opposing terms-of-trade effects: China experiences both lower output and welfare, whereas the US welfare gain occurs despite a decline in real GDP. Under S5, the welfare effects are considerably smaller, with a loss of USD 23.07 billion in China and a gain of USD 0.85 bil-

lion in the United States, consistent with the lower tariff intensity in this independently simulated scenario.

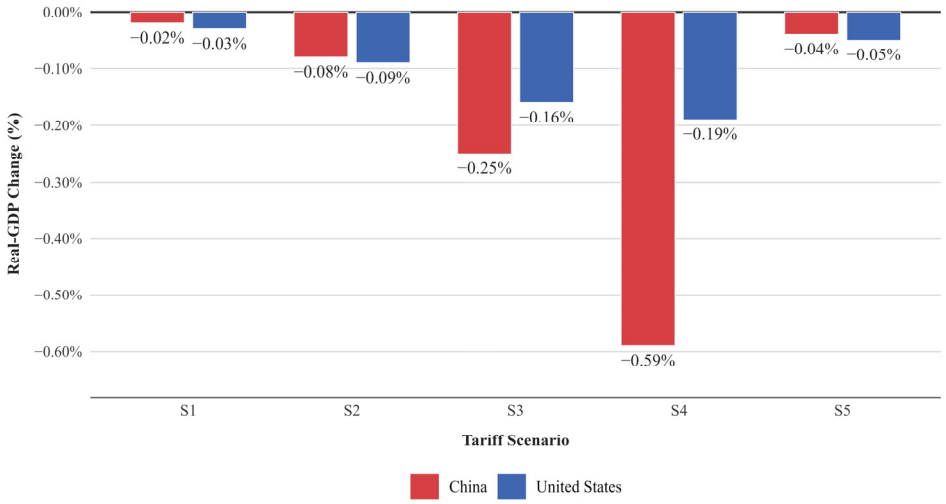


Figure 1. Real-GDP effects in China and the United States across tariff scenarios. Note: Results use the baseline Armington-elasticity setting. S1–S5 are independently simulated relative to the common 2023 baseline and do not represent a recursive time path. Source: Authors' GTAP simulations.

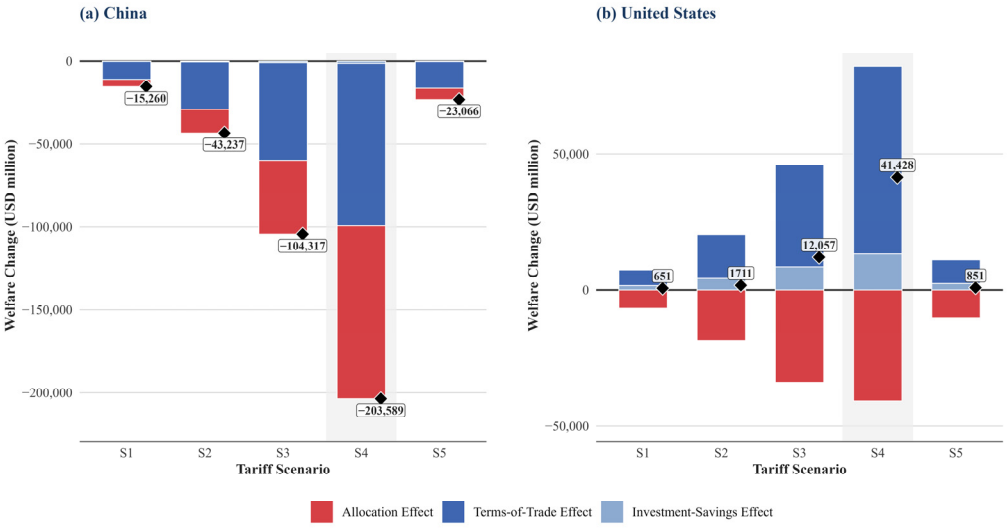


Figure 2. Welfare decomposition in China and the United States across tariff scenarios. Note: Bars report the allocation, terms-of-trade, and investment–savings effects. Black diamonds report total welfare. The shaded area identifies Scenario S4, which represents the period with the highest tariff shock and is central to the paper's core findings. The China and US panels use different vertical scales. Source: Authors' GTAP simulations.

Figure 3 confirms the relative-price mechanism. China's baseline terms of trade deteriorate from −0.26% in S1 to −2.35% in S4, whereas the US terms of trade improve from 0.23% to 2.77%. Both effects become smaller in S5. The elasticity bands widen as the tariff shock increases, but they preserve the negative direction for China and positive direction for the United States, supporting the interpretation that terms-of-trade redistribution is central to the welfare divergence.

Figure 4 summarizes the macroeconomic sensitivity results for China and the United States. Across all five elasticity settings, China's welfare and real GDP changes remain negative in every common-baseline scenario, and the US real GDP change also remains negative. For the headline S4 scenario, US welfare remains positive while Chinese welfare

remains negative, so the central welfare asymmetry is directionally robust even though its magnitude changes substantially.

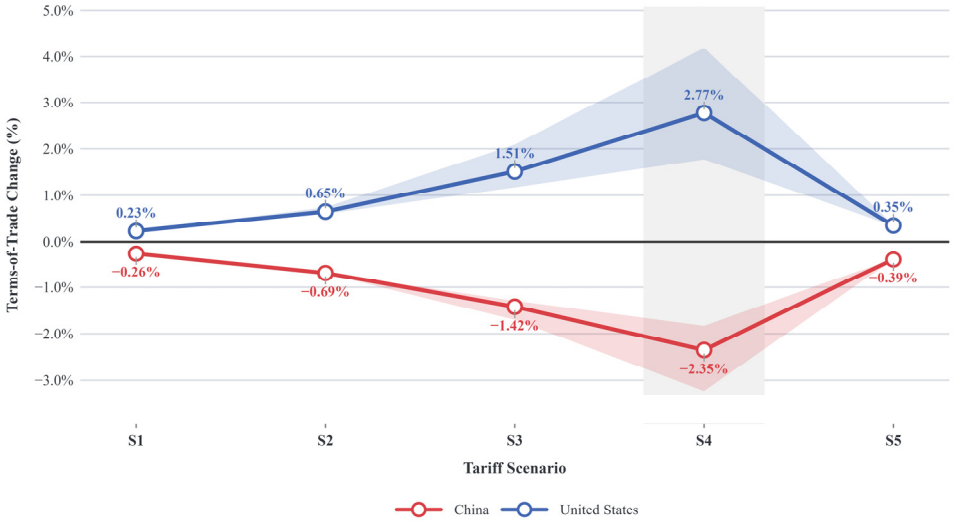


Figure 3. Terms-of-trade effects in China and the United States across tariff scenarios. *Note: Solid lines and points report baseline-elasticity results. Shaded bands report the minimum and maximum across the −50%, −25%, baseline, +25%, and +50% elasticity settings. S1–S5 are independently simulated relative to the common 2023 baseline*; the shaded vertical area identifies Scenario S4, which represents the period with the highest tariff shock and is central to the paper's core findings. Source: Authors' GTAP simulations.

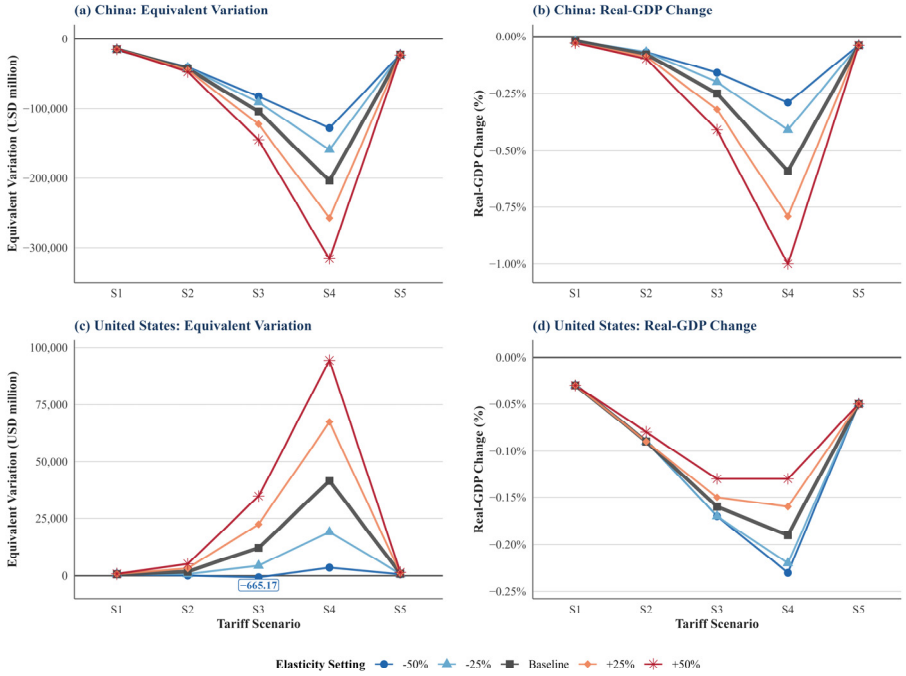


Figure 4. Armington-elasticity sensitivity of welfare and real GDP in China and the United States. Note: Lines connect independently simulated scenario results for visual comparison and do not represent a recursive time path. The five series vary the energy-sector Armington elasticities by −50%, −25%, 0%, +25%, and +50% relative to the baseline values. Source: Authors' GTAP simulations.

Robustness is not universal across every scenario and outcome. At S3, US equivalent variation becomes slightly negative (USD −665.17 million) under the −50% elasticity setting, while it is positive under the other settings. The output, export, and import ranges in Figures 5–7 likewise show sign reversals in selected commodity–scenario cells. The

appropriate conclusion is therefore that the principal S4 macroeconomic signs and the China–US terms-of-trade divergence are robust, whereas exact magnitudes and several sectoral effects remain conditional on the substitution assumptions.

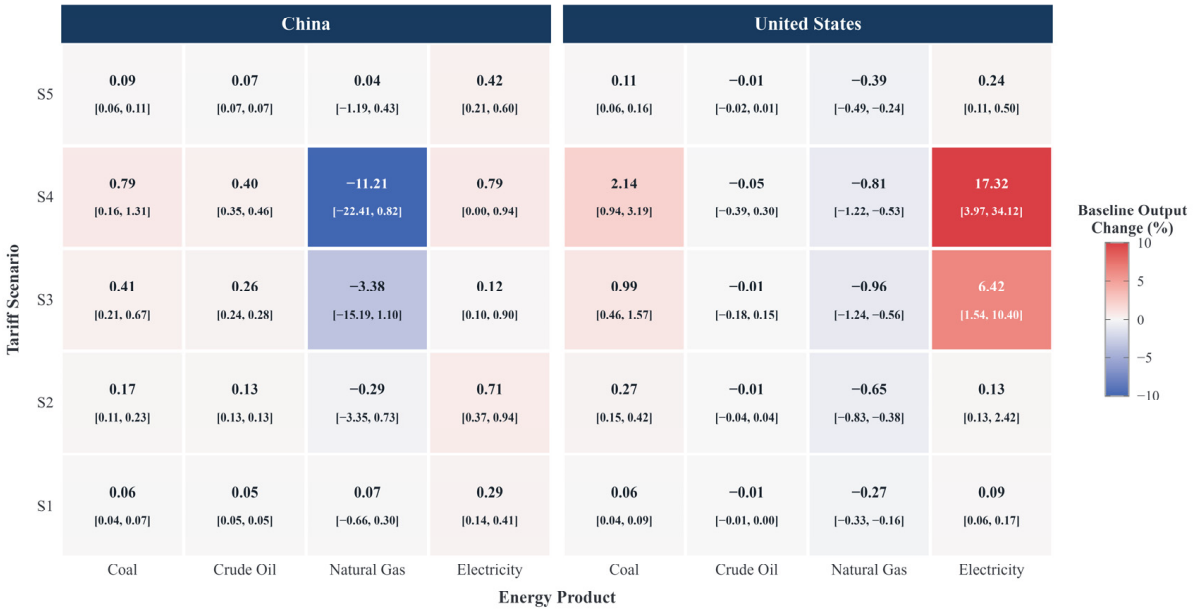


Figure 5. Energy-output responses and Armington-elasticity sensitivity ranges in China and the United States. Note: The first line in each cell is the baseline-elasticity output change. Brackets report the minimum and maximum across the −50%, −25%, baseline, +25%, and +50% elasticity settings. All values are percentage changes from the common 2023 baseline; colors are determined by the baseline result. Source: Authors' GTAP simulations.

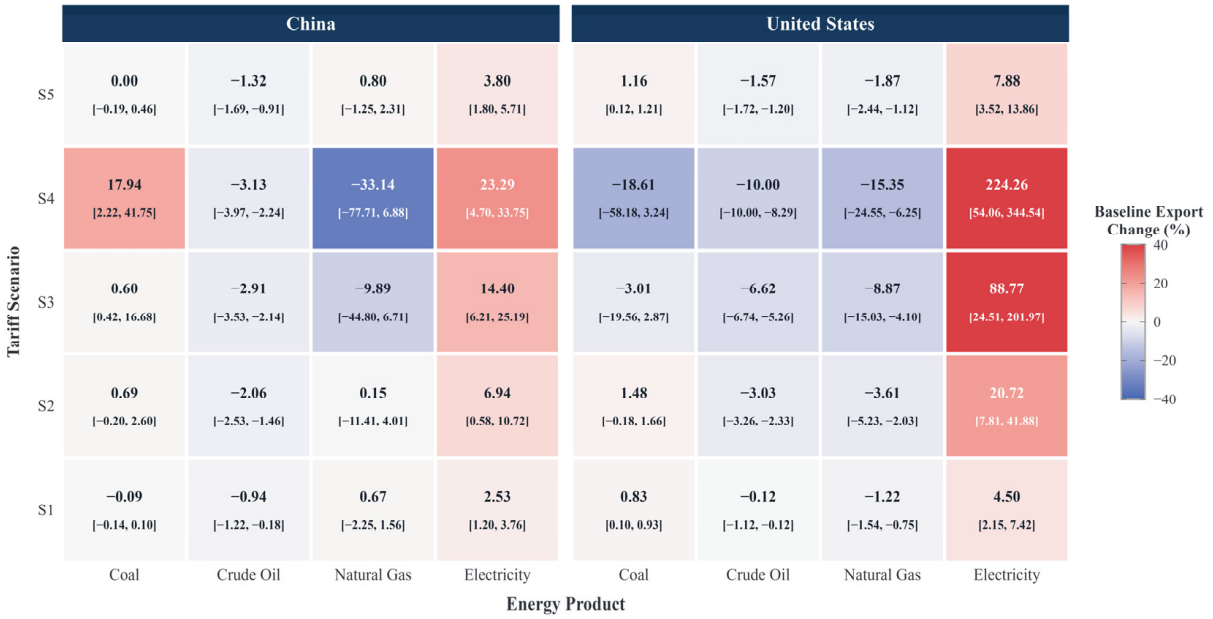


Figure 6. Energy export responses and Armington-elasticity sensitivity ranges in China and the United States. Note: The first line in each cell is the baseline-elasticity export change. Brackets report the minimum and maximum across the −50%, −25%, baseline, +25%, and +50% elasticity settings. All values are percentage changes from the common 2023 baseline; colors are determined by the baseline result and scaled within this figure. Source: Authors' GTAP simulations.

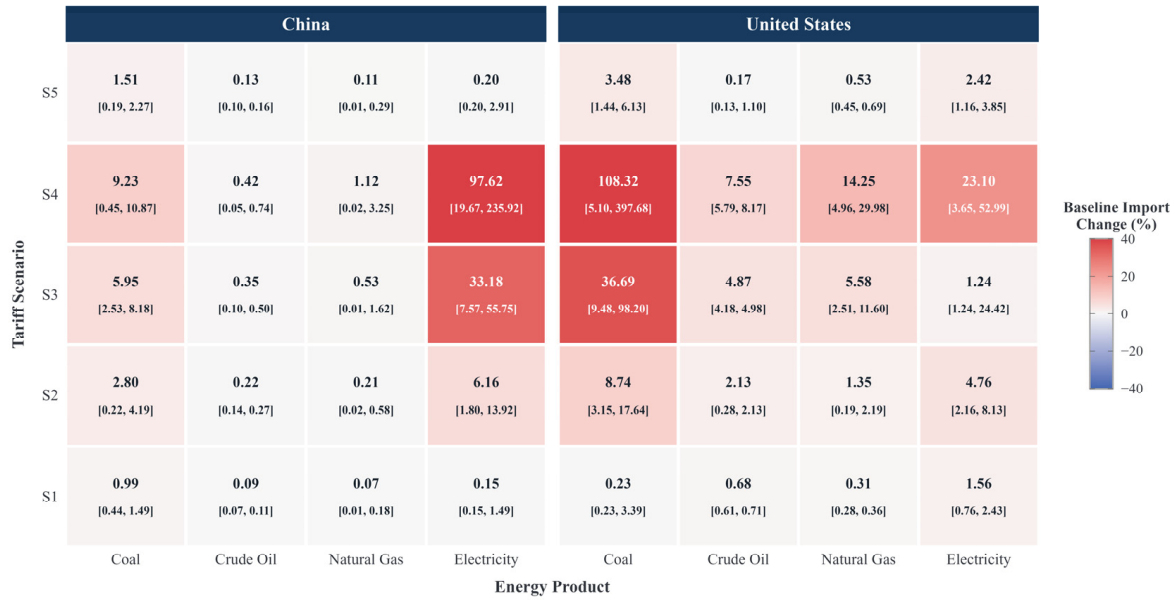


Figure 7. Energy import responses and Armington-elasticity sensitivity ranges in China and the United States. Note: The first line in each cell is the baseline-elasticity import change. Brackets report the minimum and maximum across the −50%, −25%, baseline, +25%, and +50% elasticity settings. All values are percentage changes from the common 2023 baseline; colors are determined by the baseline result and scaled within this figure. Source: Authors' GTAP simulations.

4.2. Energy-Output Effects

Figure 5 presents the baseline energy-output changes and their ranges across the five Armington-elasticity settings. The responses vary considerably across energy products. Under S4, China's coal, crude-oil, and electricity output increases by 0.79%, 0.40%, and 0.79%, respectively, while its natural-gas output decreases by 11.21%. In the United States, coal and electricity output increases by 2.14% and 17.32%, whereas crude-oil and natural-gas output decreases by 0.05% and 0.81%.

The sensitivity analysis preserves the direction of most S4 responses. China's coal and crude-oil output remains positive and its electricity output remains non-negative, while US coal and electricity output remains positive and natural-gas output remains negative. US electricity output ranges from 3.97% to 34.12%. However, the ranges for Chinese natural gas (−22.41% to 0.82%) and US crude oil (−0.39% to 0.30%) cross zero, indicating greater parameter sensitivity. Overall, the results indicate product-specific energy-output adjustments, with most principal directions remaining robust across the elasticity settings.

4.3. Energy Export Effects

Figure 6 presents the baseline energy export changes and their ranges across the five Armington-elasticity settings. Under S4, China's coal and electricity exports increase by 17.94% and 23.29%, while its crude-oil and natural-gas exports decrease by 3.13% and 33.14%, respectively. US coal, crude-oil, and natural-gas exports decline by 18.61%, 10.00%, and 15.35%, whereas electricity exports increase by 224.26%. Because the figure reports percentage rather than absolute changes, the increase in US electricity exports should be interpreted alongside its initial export value.

Most S4 export responses retain their direction across the elasticity settings. US electricity exports remain positive across all five settings, with changes ranging from 54.06% to 344.54%. However, the ranges for Chinese natural gas (−77.71% to 6.88%) and US coal (−58.18% to 3.24%) cross zero, indicating greater sensitivity to the elasticity assumptions. Under S5, US electricity exports also remain positive across all five settings,

ranging from 3.52% to 13.86%, although the response is substantially smaller than under S4. Overall, the export adjustments are heterogeneous across energy products, while the directions of most responses remain robust to the alternative elasticity assumptions.

4.4. Energy Import Effects

Figure 7 presents the baseline energy import changes and their ranges across the five Armington-elasticity settings. Under S4, imports of all four energy products increase in both countries. China's coal, crude-oil, natural-gas, and electricity imports rise by 9.23%, 0.42%, 1.12%, and 97.62%, respectively. In the United States, the corresponding increases are 108.32%, 7.55%, 14.25%, and 23.10%. Because the figure reports percentage rather than absolute changes, the large increases in Chinese electricity imports and US coal imports should be interpreted alongside their initial import levels.

All S4 import responses remain positive across the five elasticity settings. However, the magnitudes of the largest responses vary considerably: Chinese electricity imports range from 19.67% to 235.92%, while US coal imports range from 5.10% to 397.68%. Under S5, the import responses also remain non-negative across the elasticity settings but are substantially smaller; the corresponding ranges narrow to 0.20–2.91% and 1.44–6.13%, respectively. These results show that the direction of the import response is robust, while its magnitude—particularly for Chinese electricity and US coal—depends strongly on the elasticity assumptions.

4.5. Third-Party Energy-Trade Spillovers

Figure 8 summarizes the baseline-elasticity changes in third-party energy trade under S4. Increases in trade volumes are more common than decreases across the reported third-party groups, particularly for coal exports and electricity imports. Coal and crude-oil exports increase in all eight groups, while natural-gas exports increase in seven. Electricity exports, by contrast, decline in most groups, with the largest reductions occurring in Australia (−22.63%) and Japan and South Korea (−22.32%). On the import side, coal imports increase in six of the eight groups, and electricity imports increase in all groups. Natural-gas imports decline throughout, whereas crude-oil import responses are comparatively small and mixed. Overall, increases in trade volumes outnumber decreases, indicating a substantial reallocation of third-party energy trade under S4. The direction and magnitude of this adjustment nevertheless vary across energy products and between export and import flows. These simulated responses are conditional on the assumption that third-country tariff structures remain unchanged; they reflect endogenous trade reallocation under the bilateral US–China tariff shock rather than the effects of additional trade-policy changes by third parties.

4.6. Sequential Tariff-Shock Results

The sequential experiment complements the common-baseline analysis by changing the reference equilibrium for each tariff shock. In the common-baseline simulations, S1–S5 are evaluated independently against the common 2023 baseline. In the sequential experiment, S1 is evaluated relative to the pre-escalation benchmark, while S2–S5 are evaluated against the equilibrium generated by the preceding stage. The resulting values therefore capture incremental stage-to-stage adjustments and are not directly comparable with the cumulative common-baseline results. Although the tariff escalation unfolded over a relatively short calendar period, the simulations indicate that each successive tariff round can produce a distinct equilibrium adjustment. The sequence should be understood as a modeling framework rather than as evidence that the actual economy fully adjusted between policy announcements or as a representation of a dynamic time path.

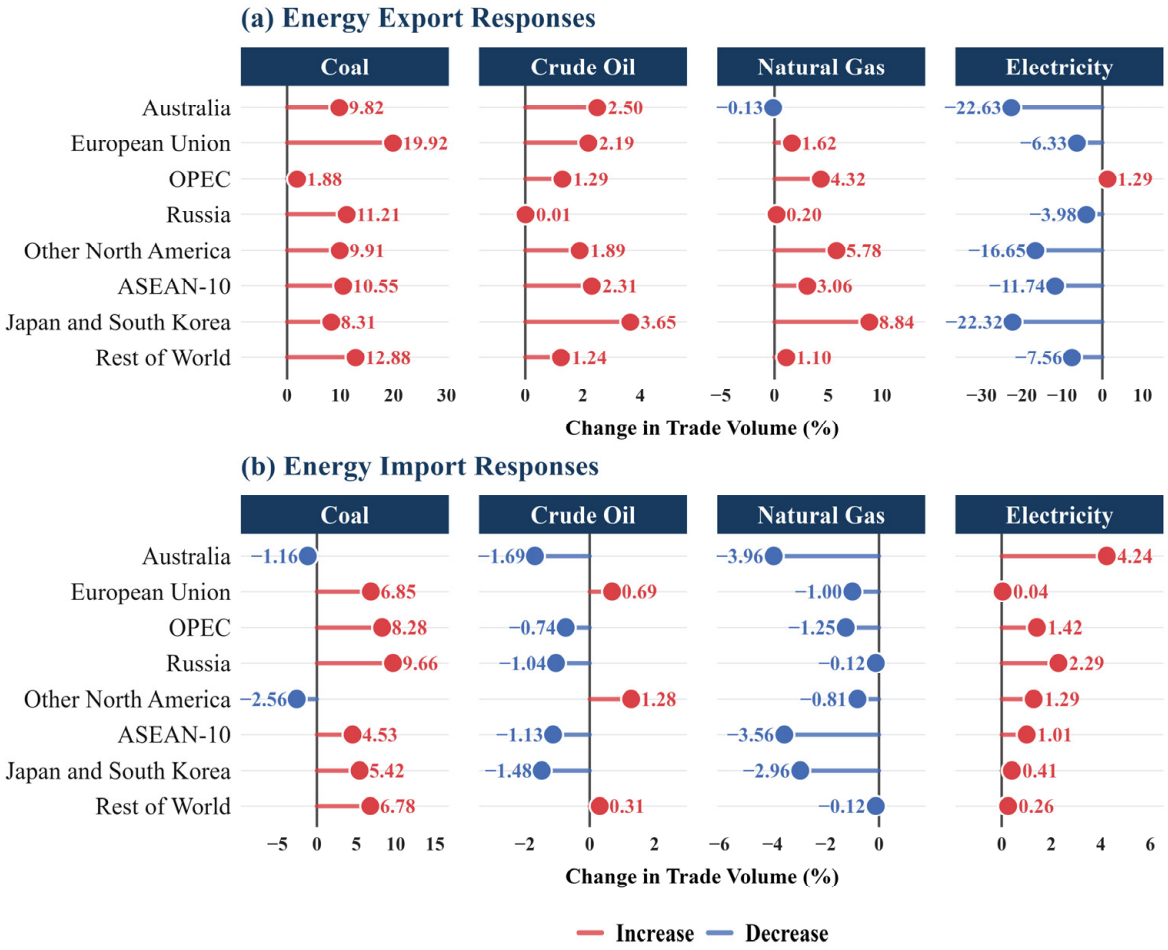


Figure 8. Third-party energy-trade spillovers under the peak tariff scenario (S4). Note: Panel (**a**) reports export changes and Panel (**b**) reports import changes. Red indicates increases and blue indicates decreases. Product panels use independent horizontal scales. Values are percentage changes relative to the common 2023 baseline. Source: Authors' GTAP simulations.

Figure 9 presents the effects on welfare and real GDP under the baseline Armington-elasticity setting. During the escalation stages S1–S4, real GDP declines in both China and the United States. China records stage-specific welfare losses of USD 15.26, 26.26, 39.66, and 31.98 billion, respectively, whereas the United States records welfare gains of USD 0.65, 0.94, 1.49, and 1.12 billion. China therefore bears substantial welfare losses throughout the escalation stages, while the United States records modest gains. Despite using different reference equilibria, the common-baseline and sequential experiments produce the same welfare pattern during S1–S4: China experiences welfare losses, whereas the United States records welfare gains. This consistency supports the robustness of the central directional finding that tariff escalation produces asymmetric welfare effects between the two countries.

Following the peak tariff in S4, the S5 de-escalation increases real GDP by 0.13% in China and 0.10% in the United States. The welfare effects move in opposite directions: China gains USD 100.62 billion, whereas the United States loses USD 37.53 billion relative to the S4 equilibrium. The tariff rollback therefore increases real GDP in both countries but produces an asymmetric welfare response. These S5 results measure the stage-to-stage effects of moving from the 145% tariff setting in S4 to the 30% setting in S5; they do not represent the effects of the S5 tariff setting relative to the common 2023 baseline.

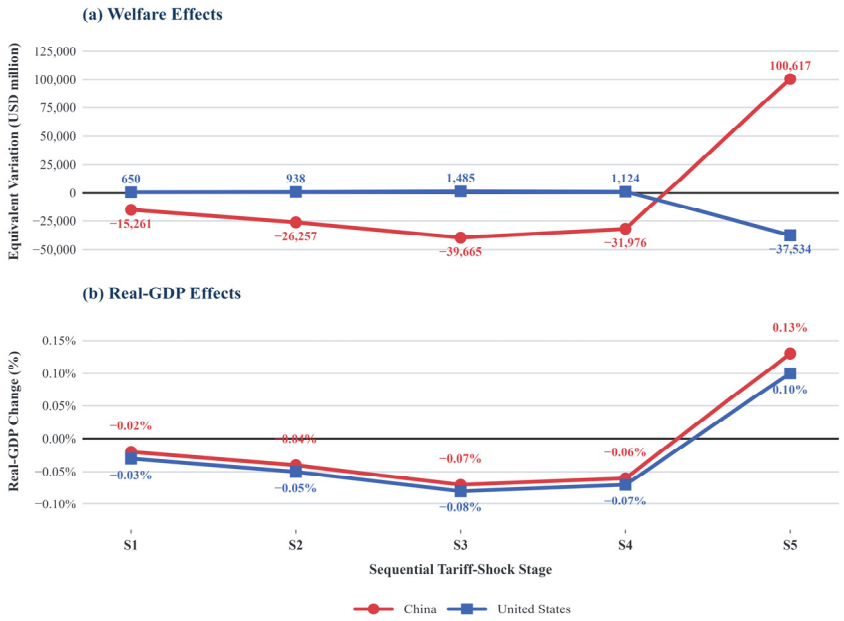


Figure 9. Sequential welfare and real-GDP Effects in China and the United States. Note: Results use the baseline Armington-elasticity setting. S1 is measured relative to the pre-escalation benchmark; S2–S4 apply additional tariff increases relative to the preceding equilibrium; S5 measures the tariff rollback from 145% to 30% relative to the S4 equilibrium. Source: Authors' GTAP simulations.

5. Discussion

Tariff shocks do not affect real GDP and economic welfare in parallel. Under S4, real GDP declines in both China and the United States, whereas the welfare effects move in opposite directions. The welfare decomposition shows that China incurs both allocative-efficiency losses and a deterioration in its terms of trade. The United States also experiences an allocative-efficiency loss, but this is more than offset by its terms-of-trade gain. The increase in US welfare therefore arises primarily from the improvement in the relative price of exports to imports, which raises real purchasing power, rather than from an expansion in domestic output. Across the five Armington-elasticity settings, the main S4 results remain unchanged in direction: welfare and real GDP decline in China, welfare rises while real GDP declines in the United States, and the terms of trade deteriorate for China but improve for the United States. These findings indicate that the principal macroeconomic results are directionally robust. The welfare pattern identified here differs from studies reporting losses in both China and the United States [4]. Differences in the period examined, benchmark construction, tariff scenarios, and welfare-accounting methods may account for this divergence.

Given that the positive US welfare effect is driven primarily by the terms-of-trade gain, this result should also be distinguished from the short-run tariff pass-through evidence in [5–7]. The pass-through evidence concerns whether foreign exporters reduce their tariff-exclusive border prices, whereas the terms of trade depend on aggregate US export prices relative to tariff-exclusive import prices. Thus, near-complete pass-through to prices paid by US importers can coexist with a terms-of-trade gain if aggregate US export prices rise sufficiently, as illustrated by the general-equilibrium results in [5]. Moreover, whereas [6,7] mainly examine tariff-affected products and specific trade destinations, GTAP captures economy-wide price adjustments across products, origins, and destinations. The simulated USD 68.94 billion gain should therefore be interpreted as a model-dependent economy-wide relative-price effect, rather than as a direct measure of the share of the 2025 tariffs borne by foreign exporters.

The sequential experiment complements the common-baseline analysis by examining changes between successive equilibria. The common-baseline experiment measures the cumulative effect of each tariff scenario relative to the common 2023 benchmark, whereas the sequential experiment measures the incremental effect of each tariff adjustment relative to the equilibrium established in the preceding stage. Despite these different reference points, both experiments under the baseline elasticity setting show welfare losses in China and welfare gains in the United States during S1–S4. Sequential S5 is evaluated relative to the S4 equilibrium and represents a reduction in the tariff shock from 145% to 30%. Real GDP increases in both countries at this stage, while the welfare pattern reverses: China gains and the United States loses. Tariff de-escalation therefore alleviates the adverse output effects of the peak-tariff setting but does not produce simultaneous welfare gains for both countries. Because the peak tariff rate remained in effect only briefly in practice, the sequential results should be interpreted as comparative-static equilibrium outcomes under alternative tariff settings rather than as a representation of the actual dynamic adjustment paths of the two economies. Sequential S5 captures an improvement relative to the S4 equilibrium and does not imply a return to the common 2023 benchmark.

Energy-market adjustments vary considerably across products and countries. Tariffs alter the relative prices of goods from different sources, prompting firms and consumers to substitute among domestic products, imports from the bilateral partner, and alternative foreign suppliers. Coal, crude oil, natural gas, and electricity consequently follow different adjustment paths in output, exports, and imports. Under S4, energy imports increase in both countries across all five Armington-elasticity settings. Although the magnitude of these responses varies with the elasticity assumptions, their direction remains stable. By contrast, a small number of energy-output and export responses change sign under alternative elasticity settings, indicating greater parameter sensitivity. Energy-trade effects should therefore be interpreted in conjunction with product characteristics, initial trade values, and the reported sensitivity ranges. Large percentage changes under a single parameter setting should not be treated as precise forecasts.

Bilateral tariff shocks also spill over to third-party economies through substitution among supply sources. Under S4, increases in third-party energy trade occur more frequently than decreases, although this pattern does not extend to every energy product or economy. The US–China tariff conflict may therefore create market opportunities for some alternative suppliers while imposing adjustment costs on other products or economies. The simulated reallocation of energy trade toward third-party economies is broadly consistent with previous findings that the US–China trade conflict generated trade-diversion effects and broader global trade reallocations [3,9,13]. Overall, the effects extend beyond bilateral trade and influence the wider pattern of energy trade through relative-price changes and source substitution. Their direction and magnitude depend on the energy product, the economy concerned, and the assumed substitution elasticities.

6. Conclusions and Policy Implications

This study uses a GTAP model recursively updated to a common 2023 benchmark to examine the effects of the 2025 US–China tariff conflict on economic welfare, real GDP, and energy trade. Five independent scenarios assess the cumulative effects of tariff shocks relative to the common benchmark, while a sequential experiment measures the incremental effect of each tariff adjustment relative to the equilibrium established in the preceding stage. Welfare decomposition and alternative Armington-elasticity settings are used to identify the sources of the welfare effects and assess the parameter sensitivity of the principal results.

The analysis yields four main conclusions. First, the simulations indicate that tariff escalation reduces real GDP in both China and the United States but produces asymmet-

ric welfare effects. Under the baseline elasticity setting, both the common-baseline and sequential experiments show welfare losses in China and welfare gains in the United States during S1–S4. The welfare decomposition shows that China experiences both allocative-efficiency and terms-of-trade losses, whereas the US terms-of-trade gain exceeds its allocative-efficiency loss. Across the five Armington-elasticity settings, the principal S4 results remain unchanged in direction: China experiences lower welfare and real GDP, the United States records higher welfare but lower real GDP, and the two countries experience opposing terms-of-trade effects. The central macroeconomic conclusions are therefore directionally robust.

Second, the sequential results show that reducing the tariff shock from its peak level in S4 to the lower S5 setting increases real GDP in both countries relative to the S4 equilibrium. The welfare effects nevertheless move in opposite directions: China gains, whereas the United States loses. Tariff de-escalation thus improves output in both economies but retains a marked asymmetry in welfare and reverses the welfare pattern observed during the escalation stages. These results describe the stage-to-stage change from S4 to S5 and do not imply that either economy has returned to the common 2023 benchmark.

Third, the bilateral tariff conflict creates trade-diversion opportunities for some third-party economies. Under S4, increases in third-party energy trade are more frequent than decreases, suggesting that some alternative suppliers can absorb demand diverted from bilateral US–China trade. These effects are uneven across economies and energy products, however, and higher trade volumes do not necessarily translate into welfare gains. Because the results are conditional on the assumption that third-country tariff structures remain unchanged, they should be interpreted as selective trade opportunities rather than as general gains shared by all economies. Trade responses could differ if third-party economies changed their own trade policies.

Fourth, the effects on energy production and trade vary across products and countries. Coal, crude oil, natural gas, and electricity exhibit different responses in output, exports, and imports. Under S4, energy imports increase in both China and the United States across all five Armington-elasticity settings. Some output and export responses, however, change direction when the elasticity assumptions are varied. The direction of the import responses is therefore more robust than that of several product-specific output and export responses. Large percentage changes in electricity and coal trade should also be interpreted in relation to their initial trade values.

These findings have three policy implications. First, China and the United States should maintain mechanisms for tariff de-escalation and economic and trade consultation and avoid a return to the extreme tariff rates represented by S4. The sequential results show that moving away from the peak-tariff setting improves real GDP in both economies, although the welfare effects remain asymmetric. Tariff de-escalation should therefore not be characterized as generating welfare gains for both countries. Subsequent negotiations should recognize the distributional effects of tariff adjustment in order to improve the stability and durability of the resulting arrangements.

Second, third-party economies should evaluate the market opportunities created by the tariff conflict at the product level rather than treating trade diversion as a general benefit. Under S4, coal exports increase in all reported third-party economies, whereas electricity exports decline in most of them, with the largest reductions occurring in Australia and the combined Japan–South Korea region. On the import side, coal imports rise in most third-party economies, natural-gas imports decline across all groups, and electricity imports increase throughout. Coal-exporting economies may therefore monitor diverted demand and related transport capacity, while natural-gas and electricity authorities should pay attention to changes in import sources and cross-regional trade. Because these results

are conditional on a specific US–China bilateral tariff scenario and the assumption that third-country tariff structures remain unchanged, simulated trade-diversion opportunities should not alone justify long-term capacity expansion; such decisions should also account for product-specific responses and initial trade values.

Third, China and the United States should incorporate the trade uncertainty generated by the tariff conflict into energy-security policy. The import and export responses of coal, crude oil, natural gas, and electricity differ in both direction and magnitude, and some output and export effects change sign under alternative elasticity settings. Energy authorities and firms should assess import dependence and supplier concentration on a product-specific basis [20] and consider diversifying import sources where feasible, while recognizing that the effectiveness and practical constraints of diversification vary across products and economies [19]. They should also assess export-market exposure on the basis of the product-level simulation results reported in this study. Risk assessments should consider both the sensitivity ranges and initial trade values rather than relying on a single estimate or a large percentage change in isolation. Such an approach would strengthen the capacity of the energy-trade system to absorb future tariff shocks.

Several limitations should be acknowledged. The results depend on the structure and assumptions of the GTAP model, the aggregation of countries and sectors, the specification of uniform bilateral tariff shocks, and historically estimated Armington elasticities. Actual tariff measures are more complex in their product coverage and rates, while historical substitution patterns may not fully capture trade adjustment under exceptionally high tariffs. Future research could incorporate more detailed tariff and product data and extend the framework to include emissions, technology-specific electricity generation, adjustment costs, and investment responses. These extensions would permit a more comprehensive assessment of the longer-term implications of tariff policy for energy transition and sustainable development.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/en19204812/s1, Supplementary Material S1: Common-Baseline Tariff-Shock Simulations; Supplementary Material S2: Sequential-Equilibrium Tariff-Shock Simulations.

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