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Optimal Tariffs in Static and Dynamic Settings: Under Observed Trade Imbalances

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We develop a multi-region, multi-sector growth model with forward-looking dynamics. We consider three different balance-of-payments closures to evaluate trade deficits in a welfare analysis of US tariff policy. Extending the classical inverse-elasticity formula to an intertemporal setting with uniform time-invarient tariffs, we consider capital market access, as financial valuation effects and endogenous current-account. Under the within-horizon closure, anticipation and retaliation emerge as distinct forces: the former governs pre-implementation investment surges and current-account dynamics, while symmetric retaliation eliminates the terms-of-trade gains, imposing persistent macroeconomic losses over the horizon.

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1. Introduction

The question of whether a large country should tax its imports is among the oldest in trade theory, yet it has acquired renewed practical urgency. Since early 2018, and again with greater scope after 2025, the United States has deployed sweeping tariff increases with the explicit dual objective of improving the terms of trade and reducing the bilateral trade deficit with China and other major partners. These two objectives are not the same, and standard trade theory provides little guidance on how they interact when the importing country already runs a large and persistent current-account deficit financed by the rest of the world.

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The classic result—that a country with market power in world markets can improve welfare by taxing imports at a rate equal to the inverse of the foreign export-supply elasticity—was derived under balanced trade (Johnson, 1953). Whether and how that result survives in the presence of observed trade imbalances, endogenous capital flows, and forward-looking investment is the central question this paper addresses.

The tension is both conceptual and quantitative. On the one hand, a tariff that improves the terms of trade by compressing import prices raises tariff revenue and permits a welfare gain for the imposing country. On the other hand, a country that runs a trade deficit is, by definition, an international net borrower: the rest of the world is making real transfers to it in every period. A tariff that raises the cost of imports may reduce the volume of those transfers, and—crucially—may alter the valuation of the accumulated stock of net foreign liabilities in ways that offset or even reverse the conventional terms-of-trade gain. Moreover, in a dynamic setting, capital in the deficit country becomes less attractive to foreign investors when trade costs rise, creating a second channel through which the tariff-induced gain is attenuated. Neither channel is captured by the static, balanced-trade optimal tariff formula.

This paper revisits the optimal tariff problem by embedding trade policy analysis in a multi-region, Armington-based dynamic general equilibrium framework calibrated to observed trade flows and macroeconomic accounts from the Global Trade Analysis Project (GTAP). Our model, implemented within the GTAPinGAMS infrastructure of Lanz and Rutherford (2016), explicitly tracks trade balances, capital accumulation, and intertemporal consumption and investment decisions in the presence of tariff distortions. Rather than treating trade deficits as exogenous or imposing static trade-balance conditions, the framework allows tariff policy to interact with balance-of-payments adjustment through forward-looking behavior and international financial flows. The theoretical backbone of the model is a multi-region Ramsey growth model (Ramsey, 1928; Cass, 1965; Koopmans, 1963) implemented in the complementarity format proposed by Lau, Pahlke, and Rutherford (2002), which permits a more precise approximation of infinite-horizon equilibria than optimization-based methods and accommodates endogenous changes in net indebtedness over a finite model horizon.

We analyze three balance-of-payments regimes that correspond to alternative dynamic CGE closures and capture different degrees of access to international capital markets. Under a *period-by-period* balance-of-payments constraint, the trade imbalance is fixed in every period, limiting the economy's ability to leverage international capital markets. Under a *within-horizon* closure, international borrowing and lending are permitted, but net foreign asset positions must return to their initial shares of global capital by the terminal period. Finally, a *perfect capital markets* benchmark allows accumulated external debt to be serviced without retirement of the accumulated principal, highlighting the role of consumption smoothing and asset-valuation effects in shaping the dynamic consequences of tariffs.

Our analysis under the within-horizon balance-of-payments closure produces three principal findings, with cross-closure comparisons reserved for subsequent work. First, tariff anticipation and retaliation operate as distinct forces: anticipation governs the magnitude of pre-implementation investment surges and current-account dynamics, while retaliation determines the long-run equilibrium level. Symmetric retaliation eliminates the terms-of-trade gain entirely, imposing persistent declines of approximately 1.2 percent in consumption and 2.2 percent in the capital stock by 2060. Second, the intertemporal welfare Laffer curve is single-peaked at a 25 percent optimal tariff, yielding a peak gain of 0.85 percent relative to the free-trade benchmark; the observed 60 percent tariff on China recovers only roughly half this maximum, implying a substantial welfare cost of over-tariffing. Third, the dynamic optimum under this closure corresponds precisely to the static inverse-elasticity formula—with $\varepsilon = 5$, the classical rule yields $\tau^* = 1/(\varepsilon - 1) = 25$ percent—suggesting that intertemporal capital-accumulation and borrowing channels do not substantially modify the *level* of the optimal tariff at the unilateral optimum, though they do alter the curvature of the welfare function away from it. Whether this correspondence survives under the period-by-period and perfect capital markets closures is the subject of ongoing analysis.

This paper makes three contributions to the literature. Methodologically, we develop a forward-looking multi-region Ramsey growth model with endogenous capital accumulation, bilateral time-varying tariffs, and explicit treatment of balance-of-payments closures in a complementarity format. This framework bridges the CGE literature on optimal tariffs (Balistreri and Markusen, 2009; Mc Daniel and Balistreri, 2003) with the neoclassical growth literature on balance-of-payments dynamics (Lau, Pahlke, and Rutherford, 2002). Theoretically, we generalize the static optimal tariff formula to a dynamic setting with observed trade imbalances, showing that the implicit transfer associated with a deficit position modifies tariff incentives in ways that depend on the denomination of that transfer—a mechanism related to but distinct from the valuation effects emphasized by Itskhoki and Mukhin (2025). Empirically, we quantify the welfare implications of alternative U.S. tariff schedules under each closure, providing a structured comparison of how the timing and persistence of optimal tariffs depend on the assumed degree of capital market access.

The remainder of the paper is organized as follows. Section 2 reviews the relevant literature. Section 3 develops the multi-region dynamic general equilibrium model and defines the three balance-of-payments closures. Section 4 describes the calibration strategy and data. Section 5 presents welfare and macroeconomic results across regimes. Section 6 concludes.

2. Literature Review

The terms-of-trade argument for import protection originates with Torrens (1844) and was formalized by Johnson (1953), who showed that a country with market power can raise welfare by setting its tariff equal to the inverse of the foreign export-supply elasticity, and who extended the analysis to show that bilateral tariff retaliation leaves both sides worse off. Lerner (1936) established that import tariffs and export taxes are equivalent, a symmetry we exploit by consolidating both instruments into a single output tax. Syropoulos (2002) showed that each country's Nash tariff rises with its own relative size and falls with its partner's, with Prisoner's Dilemma outcomes arising only at intermediate size configurations. These results share a common limitation: they assume balanced trade, perfect competition, and a static environment. Our paper relaxes all three.

Within the Armington trade structure that underpins our model, Mc Daniel and Balistreri (2003) show that even small countries hold market power and that optimal tariffs are sensitive to the assumed substitution elasticity—lower elasticities imply higher market power and larger tariffs. Balistreri and Markusen (2009) find that firm-level product differentiation substantially reduces optimal tariffs relative to the Armington benchmark, since firms preempt terms-of-trade manipulation through variety pricing. We adopt the Armington structure standard in GTAP-based analysis (Armington, 1969; Lanz and Rutherford, 2016) and calibrate substitution elasticities to the estimates of Hertel et al. (2007), keeping these market-power implications in view when interpreting our results.

The standard literature abstracts from balance-of-payments dynamics entirely. Beshkar and Shourideh (2020) break from this convention in a dynamic Ricardian setting, showing that optimal tariffs are counter-cyclical and that the optimal pattern varies over time as the government responds to period-specific productivity conditions—a result with no counterpart in static models. They also show that capital controls are a poor substitute for trade policy, delivering negligible welfare gains relative to optimal trade taxes. Our work extends this inquiry to a multi-region Armington setting with three explicit balance-of-payments closures, asking whether the classic inverse-elasticity formula survives when the tariff-imposing country is an observed net international borrower.

Two recent papers are closest to our theoretical contribution. Itskhoki and Mukhin (2025) show that for a country with domestic-currency-denominated liabilities, a tariff-induced exchange rate appreciation raises the real value of foreign claims on the home economy, creating a financial offset that lowers the optimal tariff below the balanced-trade benchmark. Costinot and Werning (2025) establish that tariffs can close trade deficits when the Engel curve for aggregate imports is strictly convex, as the resulting rise in the domestic real interest rate generates saving incentives that reduce the imbalance. Building on both, Dávila et al. (2025) derive a fully intertemporal tariff formula for dynamic heterogeneous-agent economies, showing that the sequence-space Jacobian of foreign export supply—together with relative tariff revenue weights—constitutes sufficient statistics for the optimal tariff.

Our quantitative framework disciplines these intertemporal elasticities through a forward-looking general equilibrium structure rather than imposing them exogenously.

On the methodological side, Lau, Pahlke, and Rutherford (2002) demonstrate that a complementarity formulation of infinite-horizon growth models outperforms optimization-based approaches by using state-variable targeting for terminal capital stocks, avoiding the need to pre-specify a steady-state growth rate. We implement their approach and extend it to the multi-sector, multi-region setting of Lanz and Rutherford (2016). Prior applied work on this platform includes Li, Balistreri, and Zhang (2020), who find that the 2018–2019 U.S.–China tariffs reduced Chinese welfare by 1.7 percent and U.S. welfare by 0.2 percent in a static framework, and Balistreri, Hillberry, and Rutherford (2011), who show that firm-level heterogeneity amplifies the gains from liberalization roughly fourfold relative to the Armington benchmark. Our contribution is to add forward-looking capital accumulation and endogenous balance-of-payments adjustment to this platform, enabling welfare analysis along the full transition path. Obstfeld and Rogoff (2001) motivate this design by showing that trade costs generate nonlinear wedges between domestic and world interest rates that constrain current-account imbalances—an interaction our three closures are designed to capture.

The immediate policy context is the wave of U.S. tariff increases that began in 2018 and broadened sharply after 2025. Standard theory holds that tariffs cannot persistently reduce the current account without altering the saving-investment balance, a neutrality that breaks down through valuation effects (Itskhoki and Mukhin, 2025) or Engel-curve convexity (Costinot and Werning, 2025) under realistic conditions. Consistent with this prediction, Li, Balistreri, and Zhang (2020) find that the 2018–2019 tariffs produced trade diversion without meaningfully improving the U.S. external balance. Our framework quantifies these dynamics in a setting where capital accumulation, intertemporal optimization, and balance-of-payments adjustment are jointly determined, offering a richer foundation for evaluating observed U.S. tariff policy than static models alone can provide.

3. Theoretical Model

3.1 Overview

We develop a multi-region, multi-sector structure dynamic general equilibrium model in the spirit of Lau, Pahlke, and Rutherford (2002), extended to incorporate an Armington trade structure, endogenous tariff instruments, and explicit balance-of-payments accounting.[1] The economy consists of R regions indexed by r (or s), N tradeable and non-tradeable sectors indexed by i (or j), primary factors indexed by f. The model is computed over the horizon from $t = 0$ to T, but we use a strategy for approximating the infinite horizon representative-agent problem (see Lau, Pahlke, and Rutherford, 2002). All quantities grow along a balanced steady-state path at the exogenous rate g, and present-value prices decay at the household rate of time preference ρ. This calibration strategy follows Lau, Pahlke, and Rutherford (2002) and ensures that the benchmark equilibrium is consistent with balanced growth; the multi-sector, multi-region data structure is drawn from the GTAPinGAMS platform of Lanz and Rutherford (2016).

3.2 Households and Intertemporal Preferences

Each region r is populated by a representative infinitely-lived household that maximizes a discounted sum of instantaneous utility. In the complementarity implementation, the household's intertemporal utility index is represented by a constant-elasticity-of-substitution (CES) aggregator over time:

$$U_r = \sum_{t=0}^{T} \frac{1}{(1+\rho)^t} \frac{C_{rt}^{1-\gamma}}{1-\gamma} \quad , \tag{1}$$

where C_{rt} is an index of final consumption in region r at time t, and $\sigma = 1/\gamma$ is the intertemporal elasticity of substitution. When we set the intertemporal elasticity of substitution to unity, the implied primal utility function is simply the discounted sum of log consumption in each time period ($U_r = \sum (1+\rho)^{-t} \ln C_{rt}$).

[1] The model is aggregated to a single sector for the current analysis, but the structure accommodates multiple sectors.

In the MPSGE implementation, the intertemporal utility sector $U(r)$ produces a single unit of utility price PU_r from period-t consumption goods $PC_{r,t}$, with the reference quantity in period t given by $vom_c^r \cdot qref_t$ and the reference price by $pref_t$. The household's demand for consumption in each period is derived from cost minimization over the CES expenditure function, yielding demands consistent with the Euler equation for consumption growth:

$$\frac{C_{r,t+1}}{C_{r,t}} = \left(\frac{1+r_t}{1+\rho}\right)^{\sigma}, \tag{2}$$

where r_t is the net return to capital in period t. Along a balanced steady-state path with $r_t = \rho$ for all t, consumption grows at the exogenous rate g.

3.3 Production Technology

Production in each sector j of region r at time t combines primary factors and intermediate inputs. The zero-profit condition for sector j in region r at time t requires that the value of output equal the cost of all inputs:

$$PY_{j,r,t} \cdot vom_{j,r} = c^{Y}_{j,r,t}(PA_{i,r,t}, PF_{f,r,t}), \tag{3}$$

where $PY_{j,r,t}$ is the domestic output price, $PA_{i,r,t}$ is the Armington composite price for good i, and $PF_{f,r,t}$ is the primary factor rental. The production function nests a value-added aggregate (combining capital and labor) with intermediate inputs at the top level with unit elasticity of substitution:

$$Y_{j,r,t} = \min\left\{\frac{VA_{j,r,t}}{\alpha_{j,r}}, \frac{A_{i,j,r,t}}{\beta_{ij,r}}\right\}, \tag{4}$$

where $VA_{j,r,t}$ is the value-added composite and $A_{i,j,r,t}$ is the quantity of Armington composite good i used in sector j. Within the value-added nest, capital and labor are combined with unit elasticity of substitution (Cobb–Douglas):

$$VA_{j,r,t} = \left(\frac{K_{j,r,t}}{\kappa_{j,r}}\right)^{\kappa_{j,r}} \left(\frac{L_{j,r,t}}{\lambda_{j,r}}\right)^{\lambda_{j,r}}, \tag{5}$$

where $K_{j,r,t}$ and $L_{j,r,t}$ are capital and labor inputs, and $\kappa_{j,r}$ and $\lambda_{j,r} = 1 - \kappa_{j,r}$ are calibrated factor value shares.

Output taxes and export taxes are consolidated into a unified instrument following the approach of Lanz and Rutherford (2016); specifically, export tax revenues are moved upstream into the output tax instrument so that a single ad-valorem rate $\tau^o_{j,r}$ is defined net of the consolidated revenue. Specifically, export tax revenues $\tau^x_{j,r,s} \cdot vxmd_{j,r,s}$ are moved upstream into the output tax instrument, so that a single ad-valorem output tax rate $\tau^o_{j,r}$ is defined net of the consolidated revenue:

$$vom^{\text{new}}_{j,r} = vom_{j,r}(1 - \tau^o_{j,r}) + \sum_s \tau^x_{j,r,s}\, vxmd_{j,r,s}, \tag{6}$$

and the export tax is set to zero in the consolidated benchmark. This consolidation is exact and does not alter equilibrium allocations; it simplifies the policy representation by reducing the number of instruments.

Capital tax treatment. The gross return to capital in the GTAP accounts includes an implicit marginal tax on capital income, which we calibrate as follows. Let $rk^0_r = \rho + \delta$ be the initial gross rate of return to capital, and let $K^r_0 = I^r_0/(g + \delta)$ be the initial capital stock consistent with steady-state investment at rate g with depreciation rate δ. The calibrated marginal tax rate on capital returns is:

$$\tau^K_r = \frac{\sum_j vfm_{\text{cap},j,r}(1 + rtf_{\text{cap},j,r})}{K^r_0 \cdot rk^0_r} - 1, \tag{7}$$

where $vfm_{\text{cap},j,r}$ is the value of capital employed in sector j of region r, and $rtf_{\text{cap},j,r}$ is the sectoral factor tax on capital. This tax rate is held constant in counterfactual experiments; the representative agent receives the associated revenue.

3.4 Armington Trade Structure

Domestic and imported varieties of each good are imperfect substitutes, following Armington (1969). The Armington composite in region r for good i is produced by an aggregator sector $A(i, r, t)$ that combines domestically produced output and aggregate imports:

$$A_{i,r,t} = \left[\phi_{i,r}\ (D_{i,r,t})^{(\varepsilon_i - 1)/\varepsilon_i} + (1 - \phi_{i,r})\ (M_{i,r,t})^{(\varepsilon_i - 1)/\varepsilon_i}\right]^{\varepsilon_i/(\varepsilon_i - 1)}, \tag{8}$$

where $D_{i,r,t}$ is domestic production used domestically, $M_{i,r,t}$ is the aggregate import bundle, ε_i is the Armington elasticity of substitution for sector i (set to 5 in the baseline following the econometric estimates in Hertel et al. 2007; see also Lanz and Rutherford 2016 for the GTAPinGAMS implementation of sector-specific elasticities), and $\phi_{i,r}$ is calibrated to benchmark value shares.

Aggregate imports $M_{i,r,t}$ are themselves a CES composite over bilateral imports from each source country s:

$$M_{i,r,t} = \left[\sum_s \mu_{i,s,r} \, (m_{i,s,r,t})^{(\varepsilon_i - 1)/\varepsilon_i} \right]^{\varepsilon_i/(\varepsilon_i - 1)}, \tag{9}$$

where $m_{i,s,r,t}$ is the volume of good i imported from source s and $\mu_{i,s,r}$ is calibrated to bilateral trade shares. The zero-profit condition for the import aggregator $M(i, r, t)$ implies a bilateral import price:

$$PM_{i,r,t} = \left[\sum_s \mu_{i,s,r} \left(\frac{PY_{i,s,t} \, pvxmd_{i,s,r}}{1 + \tau_{i,s,r,t}} \right)^{1-\varepsilon_i} \right]^{1/(1-\varepsilon_i)}, \tag{10}$$

where $PY_{i,s,t}$ is the exporter's output price, $pvxmd_{i,s,r}$ is the benchmark price ratio (incorporating transport margins), and $\tau_{i,s,r,t}$ is the bilateral ad-valorem tariff. Tariff revenues are rebated to the representative agent of the importing region r.

3.5 International Transport Services

Transport services are modeled as a global CES composite $YT(t)$ produced from national outputs using bilateral trade-margin coefficients $vst_{i,r}$ (the value of good i from region r used as transport services). The zero-profit condition for the transport sector requires:

$$PT_t \cdot vtw = \sum_{i,r} PY_{i,r,t} \cdot vst_{i,r} \cdot YT_t, \tag{11}$$

where PT_t is the price of transport services and $vtw = \sum_{i,j,r,s} vtwr_{i,j,r,s}$ is total benchmark transport value. Transport margins are incorporated into the production cost of sector j via the input $vtus_{j,r}$, which is the value of transport services required per unit of output.

3.6 Capital Accumulation

Capital accumulation follows the standard law of motion for each region r. The capital stock sector $K(r,t)$ transforms the current period's capital stock into rental services, depreciated capital carried forward, and a terminal-period scrap value:

$$K_{r,t+1} = (1-\delta)\, K_{r,t} + I_{r,t}, \qquad K_{r,0} = \bar{K}_r, \tag{12}$$

where δ is the depreciation rate and $\bar{K}_r$ is the initial capital stock. In the complementarity formulation, the capital accumulation zero-profit condition is:

$$PK_{r,t} = PF_{\text{cap},r,t} + (1-\delta)\, PK_{r,t+1}, \tag{13}$$

where $PK_{r,t}$ is the scrap price of a unit of capital at the beginning of period t and $PF_{\text{cap},r,t}$ is the rental price of capital services. The investment sector $INV(r,t)$ converts the macro good $P_{r,t}$ into new capital:

$$PK_{r,t+1} \leq P_{r,t}, \tag{14}$$

with equality whenever positive investment occurs, $I_{r,t} > 0$.

Following Lau, Pahlke, and Rutherford (2002), the terminal capital stock is determined endogenously via a state-variable-targeting constraint. Rather than imposing a fixed terminal capital stock or assuming the economy is in steady state at period T, we require that the growth rate of investment in the terminal period equal the growth rate of consumption—a variant of the state-variable-targeting approach of Lau, Pahlke, and Rutherford (2002), who demonstrate that any stable quantity aggregate may serve as the reference variable in the terminal condition:

$$\frac{INV_{r,T}}{INV_{r,T-1}} = \frac{C_{r,T}}{C_{r,T-1}}, \tag{15}$$

where $INV_{r,t}$ and $C_{r,t}$ are the activity levels of the investment and consumption sectors, respectively. This condition, which enters as an auxiliary constraint paired with an auxiliary variable TKD_r representing the terminal capital demand, does not require an ex ante specification of the steady-state growth rate and is therefore appropriate for settings in which tariff policy may shift the long-run growth trajectory or in which the model horizon is short relative to the transitional dynamics (Lau, Pahlke, and Rutherford, 2002).

3.7 Tariff Instruments

Tariffs are modeled as bilateral, time-varying ad-valorem instruments. The tariff parameter $\tau_{i,r,s,t}$ is defined as the ad-valorem tax on imports of good i into region r from source s in period t. In the benchmark equilibrium, $\tau_{i,r,s,t_0} = \overline{\tau}_{i,r,s}$ for all t, where $\overline{\tau}_{i,r,s}$ is calibrated to GTAP-reported applied protection rates. Policy scenarios involve imposing counterfactual tariff schedules $\tau_{i,r,s,t}$ for t in the policy window $\mathcal{T}^w \subset \mathcal{T}$.

Tariff revenues are rebated lump-sum to the representative household of the importing region:

$$TR_{r,t} = \sum_{i,s} \tau_{i,s,r,t} \cdot PY_{i,s,t} \cdot pvxmd_{i,s,r} \cdot vxmd_{i,s,r} \cdot M_{i,r,t} \left(\frac{pvxmd_{i,s,r}\, PM_{i,r,t}}{(1+\tau_{i,s,r,t})\, PY_{i,s,t}} \right)^{\varepsilon_i} . \tag{16}$$

The revenue expression reflects the fact that import demands are homogeneous of degree zero in prices, and the Armington demand share of source s in region r's imports of good i depends on the relative price ratio raised to the power of the substitution elasticity ε_i.

3.8 Balance-of-Payments Accounting

The current account of region r in period t is defined as the value of exports minus the value of imports, inclusive of transport margins:

$$CA_{r,t} = X_{r,t} - Z_{r,t}, \tag{17}$$

where exports $X_{r,t}$ and imports $Z_{r,t}$ are constructed from equilibrium trade flows:

$$X_{r,t} = \sum_{i,s} PY_{i,r,t}\, vxmd_{i,r,s}\, M_{i,s,t} \left(\frac{pvxmd_{i,r,s}\, PM_{i,s,t}}{(1+\tau_{i,r,s,t})\, PY_{i,r,t}} \right)^{\varepsilon_i} + \sum_i vst_{i,r}\, PT_t\, YT_t, \tag{18}$$

$$Z_{r,t} = \sum_{i,s} PY_{i,s,t}\, vxmd_{i,s,r}\, M_{i,r,t} \left(\frac{pvxmd_{i,s,r}\, PM_{i,r,t}}{(1+\tau_{i,s,r,t})\, PY_{i,s,t}} \right)^{\varepsilon_i} + \sum_j PT_t\, vtus_{j,r}\, Y_{j,r,t}. \tag{19}$$

The auxiliary variable $CA_{r,t}$ is linked to the representative agent's endowment of utility in foreign regions, which determines international capital flows. The specific form of this linkage defines the balance-of-payments closure.

3.9 Balance-of-Payments Closures

A central contribution of this paper is the systematic comparison of three balance-of-payments closures. Each closure corresponds to a different assumption about the degree of access to international capital markets, and each produces a different interaction between tariff policy and the intertemporal distribution of welfare.

3.9.1 Closure I: Period-by-Period Balance-of-Payments Constraint

Under the most restrictive closure, the trade imbalance is held constant at the observed benchmark value $\bar{b}_r$ in every period:

$$CA_{r,t} = -\bar{b}_r \cdot qref_t \cdot pref_t, \qquad \forall\, t \in \mathcal{T}, \tag{20}$$

where $\bar{b}_r$ is the observed trade balance in the GTAP accounts and $qref_t = (1+g)^{t-t_0}$ is the reference quantity path. This closure eliminates intertemporal borrowing and lending, so that in each period the current account adjusts passively to maintain the benchmark imbalance as a share of growing output. In this setting, tariff policy produces welfare effects driven primarily by contemporaneous terms-of-trade changes and tariff revenue, closely approximating the static optimal tariff logic.

3.9.2 Closure II: Within-Horizon Closure

Under the within-horizon closure, international borrowing and lending are permitted within the model horizon, but net foreign asset positions must return to their initial shares of global capital by the terminal period. Formally, the representative agent of region r receives endowments of utility in other regions' markets according to the benchmark trade-balance share:

$$\theta_r = \frac{\left(I_0^r + K_0^r(1-\delta)\right) qref_T}{\sum_{r'} \left(I_0^{r'} + K_0^{r'}(1-\delta)\right) qref_T}, \tag{21}$$

where θ_r is the share of global terminal capital allocated to region r. The current-account auxiliary variable $CA_{r,t}$ satisfies a scaling constraint that links it to the equilibrium utility price index, normalizing the trade imbalance relative to a price numeraire:

$$CA_{r,t} \cdot \sum_{r'} PU_{r'} \, \theta_{r'} = X_{r,t} - Z_{r,t}. \tag{22}$$

The terminal capital constraint (15) ensures consistency between intertemporal saving decisions and the terminal asset positions implied by θ_r. Under this closure, tariff policy generates temporary adjustments to trade imbalances and intertemporal reallocation, while welfare incentives reflect the long-run requirement to reverse external deficits. This closure corresponds to the within-horizon MCP formulation of Lau, Pahlke, and Rutherford (2002) (their equation (50)) and is the primary scenario analyzed in the current paper.

3.9.3 Closure III: Perfect Capital Markets Benchmark

Under the perfect capital markets closure, accumulated external debt may be serviced without retirement of the accumulated principal. This approximates the infinite-horizon neoclassical growth equilibrium in which the intertemporal budget constraint is satisfied in present-value terms. In this setting, the representative agent's endowment of utility in foreign regions is determined by the permanent present-value balance of the current account, so that the transversality condition for net foreign assets holds:

$$\lim_{T \to \infty} pref_T \cdot NFA_{r,T} = 0, \tag{23}$$

where $NFA_{r,T}$ is the net foreign asset position. In the finite-horizon approximation, this is implemented by allowing terminal capital allocations to deviate from their benchmark shares θ_r, so that regions may maintain permanent surplus or deficit positions. This closure highlights the role of consumption smoothing and asset-valuation effects in shaping the dynamic consequences of tariffs and provides an upper bound on the intertemporal flexibility available to deficit countries.

3.10 Representative Agent Income and Walras's Law

The income of the representative agent RA_r is derived from four sources: labor income, the initial capital stock endowment, tariff revenue, and net transfers from or to the rest of the world through the balance-of-payments mechanism:

$$RA_r = \underbrace{\sum_t PF_{\mathrm{lab},r,t}\, evom_{\mathrm{lab},r}\, qref_t}_{\text{labor income}} + \underbrace{PK_{r,t_0}\, K_0^r}_{\text{initial capital}} + \underbrace{\sum_t TR_{r,t}}_{\text{tariff revenue}} - \underbrace{PKT_r\, TKD_r}_{\text{terminal capital}}, \tag{24}$$

where PKT_r is the terminal capital price and TKD_r is the terminal capital demand auxiliary variable. Government expenditure is treated as an exogenous endowment that reduces the agent's disposable income:

$$\text{(net income)} = RA_r - \sum_t P_{r,t}\, vom_g^r\, qref_t, \tag{25}$$

where vom_g^r is the benchmark value of government expenditure. Walras's law is satisfied by construction: the zero-profit and market-clearing conditions for all activities and goods, together with the income-balance equation, imply that the goods and factor markets clear simultaneously.

3.11 Market Clearing

Market clearing requires that supply equals demand in every market at every date. For the macro good in region r at time t:

$$CIG_{r,t} + \sum_j Y_{j,r,t} = PA_{i,r,t}\text{-market demand}, \tag{26}$$

where $CIG_{r,t}$ is the final-demand aggregator (combining consumption, investment, and government demand) and $Y_{j,r,t}$ is sectoral output. For the primary factors, labor and capital are inelastically supplied within each region at each date:

$$\sum_j L_{j,r,t} = evom_{\mathrm{lab},r}\, qref_t, \tag{27}$$

$$\sum_j K_{j,r,t} = K_{r,t}, \tag{28}$$

where $K_{r,t}$ is the aggregate capital stock determined by the accumulation equation (12). Labor supply grows at the exogenous rate g, consistent with the balanced growth path.

3.12 Equilibrium Definition

A competitive equilibrium in this economy is a sequence of activity levels $\{Y_{j,r,t}, M_{i,r,t}, A_{i,r,t}, YT_t, C_{r,t}, INV_{r,t}, K_{r,t}, U_r\}$, price indices $\{PY_{i,r,t},\ PM_{i,r,t}, PA_{i,r,t},\ PT_t, PF_{f,r,t},\ PC_{r,t}, P_{r,t},\ PK_{r,t}, PKT_r,\ PU_r\}$, and income levels $\{RA_r\}$ such that:

(i) All production activities satisfy zero-profit conditions (complementary slackness with activity levels);

(ii) All markets satisfy clearing conditions (complementary slackness with prices);

(iii) Each representative agent satisfies an income-balance condition (complementary slackness with income);

(iv) The terminal capital stock satisfies the state-variable-targeting constraint (15);

(v) The balance-of-payments auxiliary variable $CA_{r,t}$ satisfies the closure- specific constraint defined in equations (20), (22), or (23).

This formulation constitutes a Mixed Complementarity Problem (MCP) of the form $F(z) \perp z \geq 0$, where z collects all activity levels, prices, and auxiliary variables, and $F(z)$ collects the associated excess-profit, excess-supply, and excess-income functions. The benchmark equilibrium—in which all policy instruments are at their calibrated levels and all quantity variables equal their reference paths— satisfies this system with $Y_{j,r,t} = M_{i,r,t} = \ldots = qref_t$ and all prices equal to $pref_t$ times the appropriate benchmark price ratio. A standard replication check (setting the iteration limit to zero) confirms that the benchmark is balanced before proceeding to counterfactual experiments.

3.13 Steady-State Growth and Calibration Consistency

For the model to be well-defined along a balanced growth path, several consistency conditions must hold. First, the initial capital stock must equal the steady-state investment-to-capital ratio:

$$K_0^r = \frac{I_0^r}{g + \delta}. \tag{29}$$

Second, the gross return to capital must equal the sum of the rate of time preference and the depreciation rate:

$$rk^0 = \rho + \delta. \tag{30}$$

Third, all benchmark quantity variables must grow at the rate g, and all present-value prices must decay at the rate ρ, so that the ratio of any price to $pref_t$ is constant across periods at the benchmark. These conditions are used to calibrate initial capital stocks, factor tax rates, and the terminal-period balance-of-payments shares θ_r from the GTAP benchmark accounts.

Table 1 summarizes the key structural parameters of the model.

Table 1. Key Structural Parameters

Parameter	Description	Symbol	Value
Growth rate	Annual steady-state growth	g	0.02
Time preference	Household discount rate	ρ	0.05
Depreciation	Capital depreciation rate	δ	0.08
Armington elasticity	Top-level substitution	ε_i	5.0
Model horizon	Terminal year	T	2060
Base year	Calibration year	t_0	2020

The Armington elasticity of 5 is applied uniformly across sectors in the baseline, drawing on the econometric estimates reported in Hertel et al. (2007); sensitivity analysis varies this parameter across a plausible range around the baseline. The model horizon of 2060 (40 periods) is sufficient to approximate the infinite-horizon saddle path with high precision under the MCP terminal condition (15), as demonstrated by Lau, Pahlke, and Rutherford (2002) for analogous parameterizations.

4. Data & Calibration

The model is calibrated to the GTAP 11 database documented in Aguiar et al. (2023), which provides a consistent set of national accounts, bilateral trade flows, and input-output linkages for the global economy in the 2017 benchmark year. We adopt the nine-region aggregation employed by Balistreri, Ali, and McDaniel (2025) and Balistreri, Böhringer, and Rutherford (2025): the United States, EU-27 plus, China, Canada, Mexico, South Korea, Mercosur, the Rest of OECD, and the Rest of World. This aggregation is motivated by the principal bilateral relationships implicated in recent U.S. tariff policy and preserves the regional heterogeneity most relevant for current-account analysis. Production technologies and preference structures follow the multi-sector Armington formulation of Lanz and Rutherford (2016), with 57 sectors spanning agriculture, manufacturing, and services. Intermediate input linkages, benchmark tax distortions, and imbalanced bilateral trade flows are incorporated as measured in the GTAP 11 accounts.

The dynamic extension requires calibration of additional parameters governing intertemporal behavior. The initial capital stock in each region is inferred from the GTAP value-added accounts under the assumption of a steady-state capital-output ratio consistent with observed investment shares. The depreciation rate and the subjective discount factor are set to standard values in the applied growth literature, with terminal capital stocks determined endogenously through the state-variable targeting procedure of Lau, Pahlke, and Rutherford (2002) rather than imposed exogenously. The three balance-of-payments closures are implemented by imposing alternative restrictions on the current-account path: a balanced-trade closure that prohibits net borrowing, a fixed-transfers closure that holds the real value of net foreign assets constant, and an endogenous-adjustment closure that allows the current account to clear through intertemporal optimization subject to a no-Ponzi condition.

5. Simulation Results

We present results from four core tariff scenarios and an optimal tariff experiment, all evaluated within the dynamic multi-region Ramsey growth model developed in Section 3. The tariff scenarios impose a 60 percent ad-valorem tariff on all U.S. imports from China and a 10 percent uniform tariff on imports from all other trading partners, broadly calibrated to the tariff schedule that emerged from U.S. trade policy actions in 2025. We consider the four combinations arising from two binary dimensions: (i) whether the tariff is *unanticipated*—implemented immediately in the base year with no prior signal—or *anticipated* several years (three years in these cases) in advance, generating pre-implementation investment and trade responses; and (ii) whether trading partners *retaliate* symmetrically or accept the tariff without policy adjustment. The optimal tariff experiment identifies the unilateral tariff rate that maximizes U.S. intertemporal welfare absent retaliation.

Macroeconomic dynamics are reported in two complementary formats. Proportional deviation figures display the percentage deviation of consumption (C), investment (I), and the capital stock (K) from their respective balanced-growth baseline paths. Level deviation figures display the deviation of the current account balance ($X - M$) from its baseline level in billions of dollars at 2020 prices. All deviations are reported for the United States.

5.1 Within-Horizon Closure

The results reported in this section are generated under the *within-horizon* balance-of-payments closure (Closure II, equation 22), in which international borrowing and lending are permitted within the model horizon subject to the requirement that each region's share of global terminal capital returns to its benchmark value by period T. This closure occupies the intermediate position in the spectrum of capital market access: it is less restrictive than the period-by-period constraint, which eliminates all intertemporal trade in assets, and more restrictive than the perfect capital markets benchmark, which allows accumulated external debt to be serviced in perpetuity. The within-horizon closure is therefore the empirically relevant regime for a country like the United States, which has persistent access to international capital markets but faces a long-run intertemporal budget constraint that requires the present value of the trade balance to be non-negative over any sufficiently long horizon.

The critical economic implication of this closure is that tariff-induced changes in domestic absorption are not required to clear in each period through contemporaneous trade-balance adjustment. Instead, the model allows the U.S. economy to borrow from the rest of the world—or reduce net lending—in response to tariff-induced changes in investment opportunities and consumption paths, with the net foreign asset position returning to its benchmark share of global capital only at the terminal date. This intertemporal smoothing capacity fundamentally alters the transmission of tariff shocks relative to a no-indebtedness regime: the welfare consequences of a given tariff depend not only on contemporaneous terms-of-trade effects but on the full intertemporal profile of consumption, investment, and capital accumulation across the model horizon.

5.1.1 Unanticipated Tariff, No Retaliation

Figures 1 and 2 display the macroeconomic and trade-balance responses to an unanticipated tariff in the absence of foreign retaliation. Because the tariff is implemented without prior notice, households and firms have no opportunity to adjust investment or saving decisions ahead of the policy change; all equilibrium responses originate in the period of implementation.

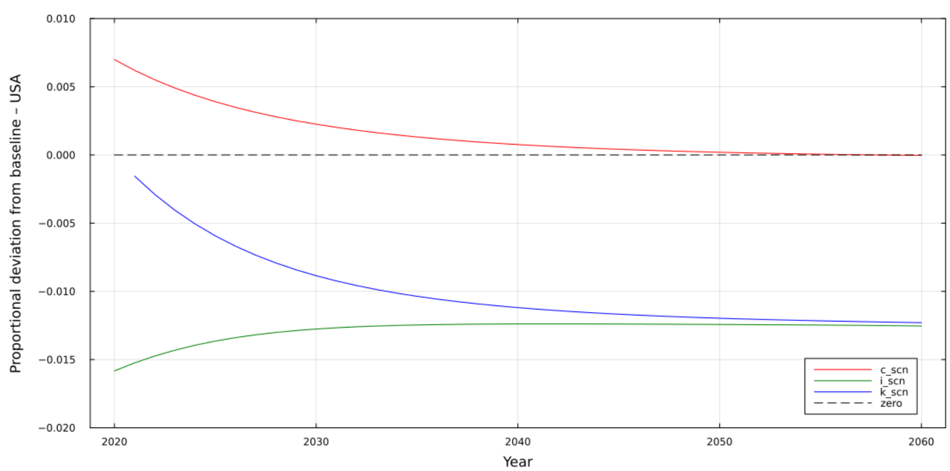

Figure 1. Unanticipated tariff, no retaliation: Proportional deviations of consumption (C), investment (I), and capital (K) from the baseline growth path, United States, 2020–2060. All deviations expressed as fractions of the corresponding baseline value.

The unanticipated tariff produces a short-run consumption gain of approximately 0.7 percentage points, driven by the classical terms-of-trade mechanism: with $\varepsilon = 5$, U.S. import demand commands sufficient market power to extract price concessions from foreign suppliers, and lump-sum rebate of tariff revenue raises real household purchasing power.

Investment tells the opposing story. It falls immediately by roughly 1.5 percentage points and converges to -1.3 percentage points by 2060, as the tariff raises intermediate input costs economy-wide and depresses the marginal product of capital. The capital stock declines monotonically in tandem. Critically, this is not a borrowing-constraint artifact—the within-horizon closure explicitly permits external financing—but rather the equilibrium response of forward-looking firms to a permanently lower expected return. The consumption gain consequently erodes over time, approaching zero by 2040–2050 and turning marginally negative in terminal periods as the intertemporal budget constraint binds.

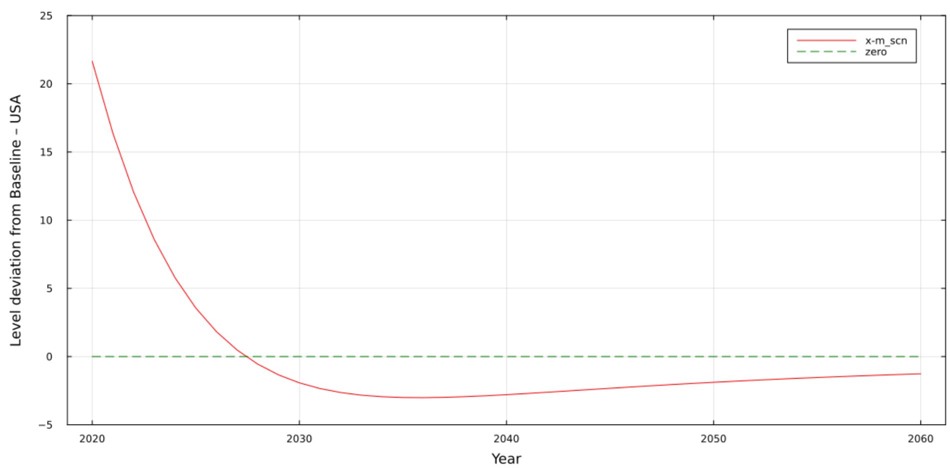

Figure 2. Unanticipated tariff, no retaliation: Level deviation of the U.S. current account balance ($X - M$) from baseline, billions of 2020 U.S. dollars, 2020–2060.

The current account improves by approximately $21–22 billion on impact, reflecting tariff-induced import compression. This surplus dissipates by 2027–2028 and gives way to a moderate deficit of $2–3 billion—the economy optimally borrowing against its contemporaneous terms-of-trade gain to smooth consumption through capital adjustment—before converging back to zero as the terminal constraint closes.

5.1.2 Anticipated Tariff, No Retaliation

Figures 3 and 4 display the corresponding responses when the tariff is fully anticipated. Anticipation fundamentally alters the transmission mechanism: forward-looking households and firms adjust portfolios prior to implementation, generating pre-tariff investment and current account dynamics that have no counterpart in the unanticipated scenario. Under the within-horizon closure, this anticipation channel is amplified relative to a no-indebtedness regime, because external borrowing is available to finance the pre-implementation investment surge without requiring a commensurate contemporaneous sacrifice of consumption.

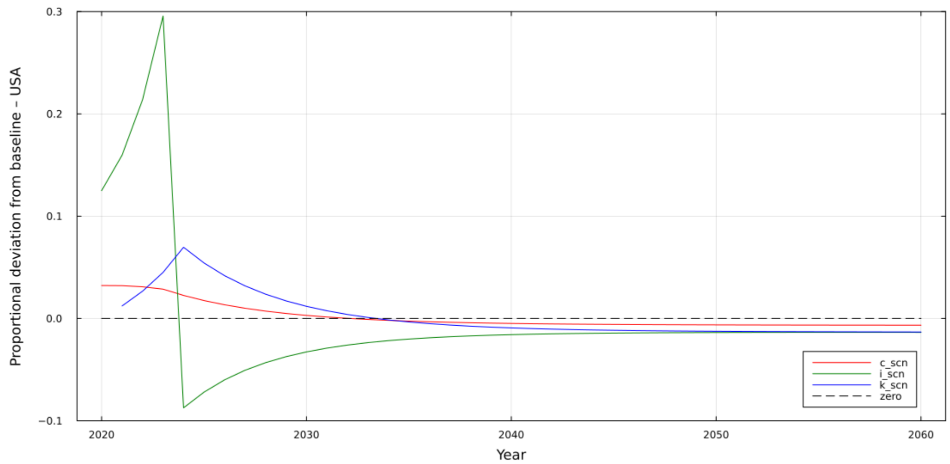

Figure 3. Anticipated tariff (from 2024), no retaliation: Proportional deviations of consumption, investment, and capital from baseline, United States, 2020–2060.

Anticipation amplifies the transmission mechanism dramatically. Forward-looking firms front-load capital accumulation before intermediate costs rise, producing a pre-implementation investment surge of approximately 29–30 percentage points above baseline by 2022–2023. External borrowing under the within-horizon closure finances this boom without requiring contemporaneous consumption sacrifice—a channel unavailable under period-by-period balance, where the surge would necessarily crowd out current absorption. The subsequent dynamics are correspondingly sharp: investment collapses to approximately -10 percentage points following implementation, recovering only partially to -3 to -4 percentage points by 2060. The capital stock peaks roughly 7 percentage points above baseline around 2024–2026 before declining persistently. Consumption, buoyed initially by capital income and external borrowing, eventually turns marginally negative as the terminal net-foreign-asset constraint forces a modest repayment adjustment.

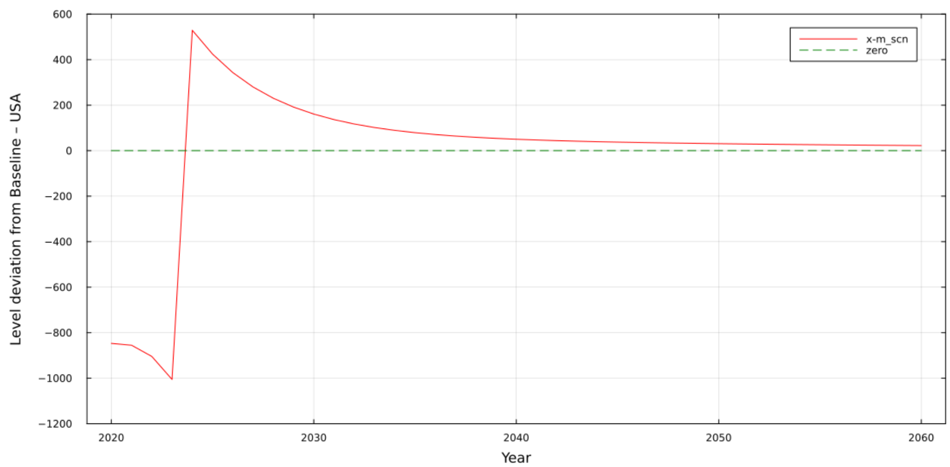

Figure 4. Anticipated tariff (from 2024), no retaliation: Level deviation of the U.S. current account balance from baseline, billions of 2020 U.S. dollars, 2020–2060.

The current account path is the most striking feature. The pre-implementation investment boom is financed by a deterioration of approximately $900–1,000 billion, followed by a $530 billion post-implementation surplus—an amplitude roughly 40 times larger than in the unanticipated scenario. The discounting embedded in the closure ensures that the present value of post-implementation surpluses equals that of pre-implementation deficits, as reflected in the approximately 2:1 undiscounted ratio between the deficit and surplus phases.

5.1.3 Unanticipated Tariff with Retaliation

Figures 5 and 6 introduce symmetric foreign retaliation: China responds to the 60 percent U.S. tariff with an equivalent tariff on U.S. exports, and rest-of-world partners retaliate against the 10 percent U.S. tariff. Retaliation eliminates the primary welfare-improving mechanism of the unilateral case—the terms-of-trade gain—replacing it with a symmetric terms-of-trade deterioration and generating a Nash tariff equilibrium in which both sides bear the efficiency costs of elevated protection without the asymmetric income transfer that characterizes the unilateral outcome.

Symmetric retaliation eliminates the asymmetric income transfer underlying the unilateral gain, replacing it with mutual efficiency losses. All three aggregates deteriorate immediately and remain persistently below baseline. Consumption falls approximately 1.2 percentage points on impact and is essentially flat at that level through 2060; investment declines 2.6 percentage points initially and recovers to -2.2 percentage points by the terminal period; the capital stock erodes monotonically, reaching -2.2 percentage points by 2060.

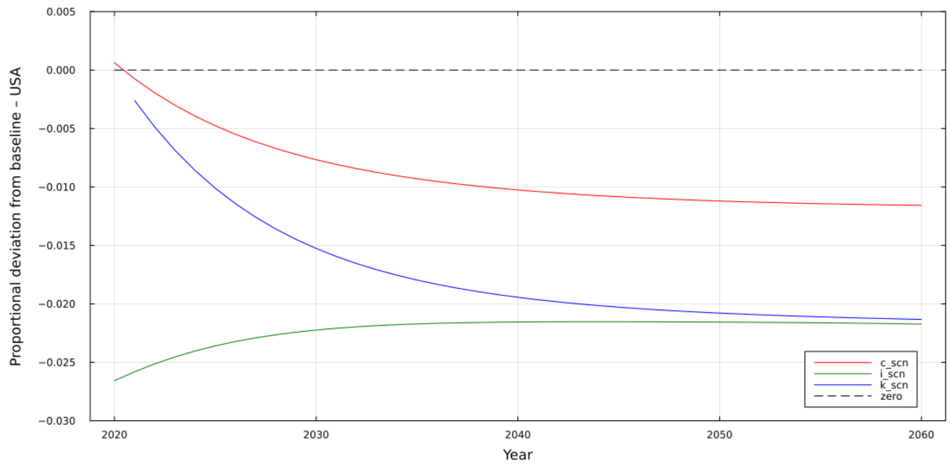

Figure 5. Unanticipated tariff with retaliation: Proportional deviations of consumption, investment, and capital from baseline, United States, 2020–2060.

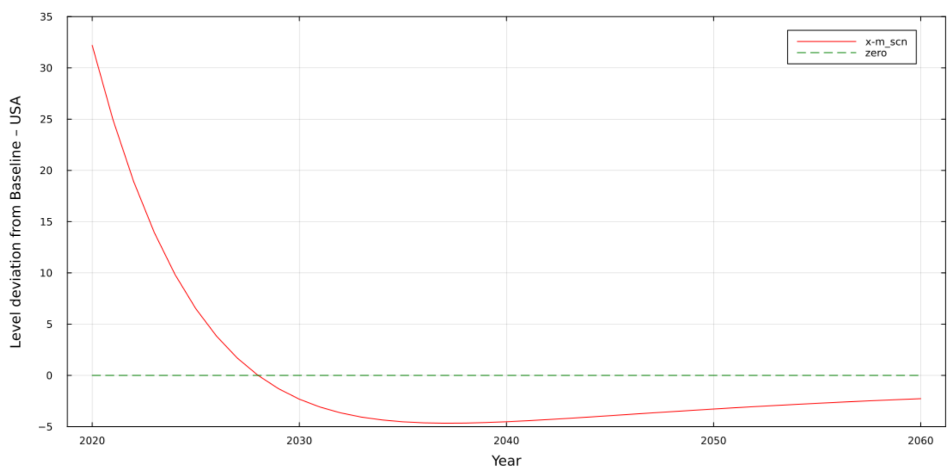

Figure 6. Unanticipated tariff with retaliation: Level deviation of the U.S. current account balance from baseline, billions of 2020 U.S. dollars, 2020–2060.

The structural mechanism differs importantly from the no-retaliation case. Foreign retaliatory tariffs compress U.S. export revenues, lowering economy-wide capital returns permanently. Under the within-horizon closure, borrowing capacity is endogenous to expected future income: a permanent reduction in export profitability contracts the income stream against which external debt can be serviced, so the full shock passes through to contemporaneous macroeconomic aggregates with limited smoothing. The initial current-account improvement of $32 billion—slightly larger than the no-retaliation case due to symmetric import compression—deteriorates to a deficit of $4–5 billion by 2030–2040 before recovering, reflecting the income-driven reduction in national saving that accompanies the export revenue loss.

5.1.4 Anticipated Tariff with Retaliation

Figures 7 and 8 present the most complex scenario: a fully anticipated tariff with symmetric foreign retaliation. This scenario combines the pre-implementation investment and borrowing surge documented in Section 5.1.2 with the permanent terms-of-trade deterioration imposed by retaliation. The interaction between these two forces—one operating through the anticipation channel, the other through the export-competitiveness channel—produces dynamics that are qualitatively richer than either scenario in isolation.

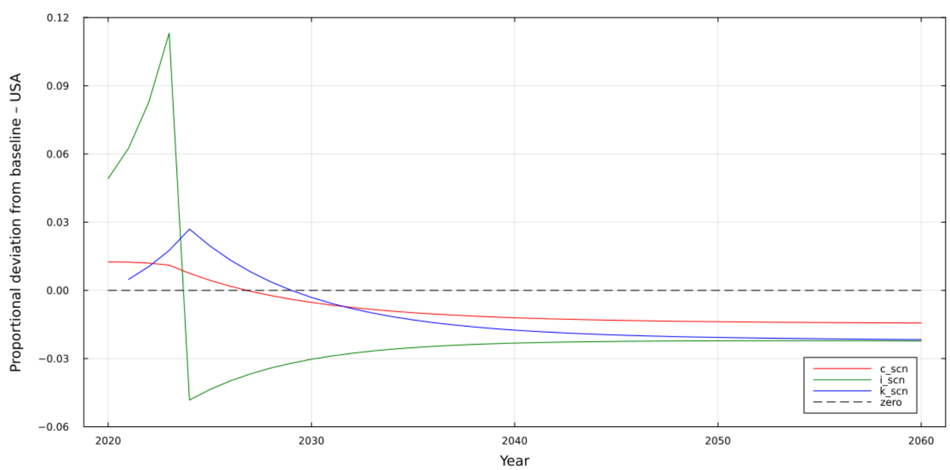

Figure 7. Anticipated tariff with retaliation: Proportional deviations of consumption, investment, and capital from baseline, United States, 2020–2060.

This scenario superimposes the anticipation and retaliation channels, yielding dynamics that are qualitatively recognizable from each isolated case but quantitatively distinct. The pre-implementation investment surge is substantially attenuated—peaking at +11 percentage points rather than +29—because anticipated retaliation reduces the expected post-tariff marginal product of capital through export-competitiveness deterioration, compressing the net incentive to pre-invest. More importantly, the long-run outcomes are governed by retaliation, not anticipation. Whereas anticipation alone produces near-zero terminal deviations, anticipation with retaliation yields persistent long-run losses of approximately -1.5 percent in consumption and -2.5 percent in the capital stock, comparable in magnitude to the unanticipated retaliation scenario. This confirms the central structural finding: *anticipation shapes the transition path and the scale of the pre-implementation surge; retaliation determines the long-run equilibrium level.* The within-horizon closure moderates the transition dynamics but cannot offset the permanent reduction in steady-state capital returns that retaliation imposes.

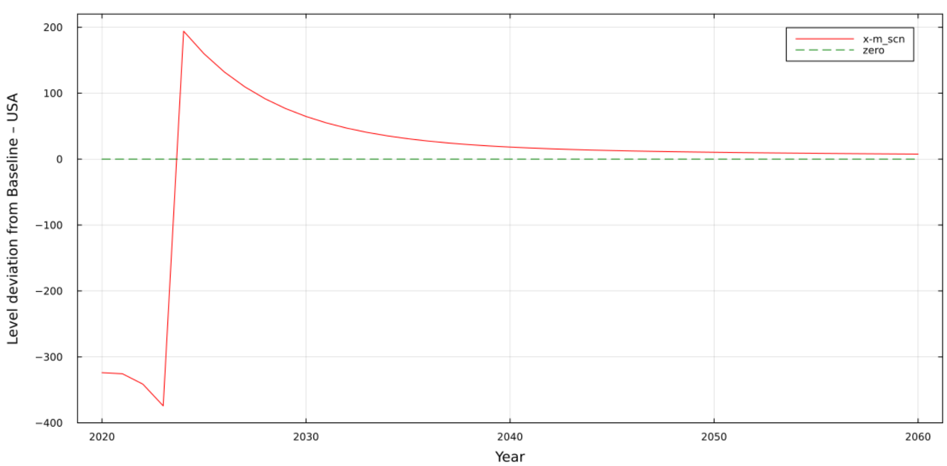

Figure 8. Anticipated tariff with retaliation: Level deviation of the U.S. current account balance from baseline, billions of 2020 U.S. dollars, 2020–2060.

Current account dynamics are biphasic but muted: the pre-implementation deficit reaches approximately $-\$350$ to $-\$380$ billion and the post-implementation surplus approximately $+\$195$ billion—both roughly one-third of their counterparts in the non-retaliation anticipated case. The discounting ratio between deficit and surplus phases is preserved by construction through the terminal capital constraint (15).

5.1.5 Optimal time-invariant uniform tariff: Unilateral Welfare Maximization

Figure 9 presents the intertemporal welfare Laffer curve for the United States under the within-horizon closure, computed by sweeping the uniform bilateral tariff rate from 0 to approximately 85 percent with foreign policy held fixed. Welfare is measured as the proportional change in the representative agent's intertemporal utility index U_r (equation 1) relative to the free-trade benchmark.

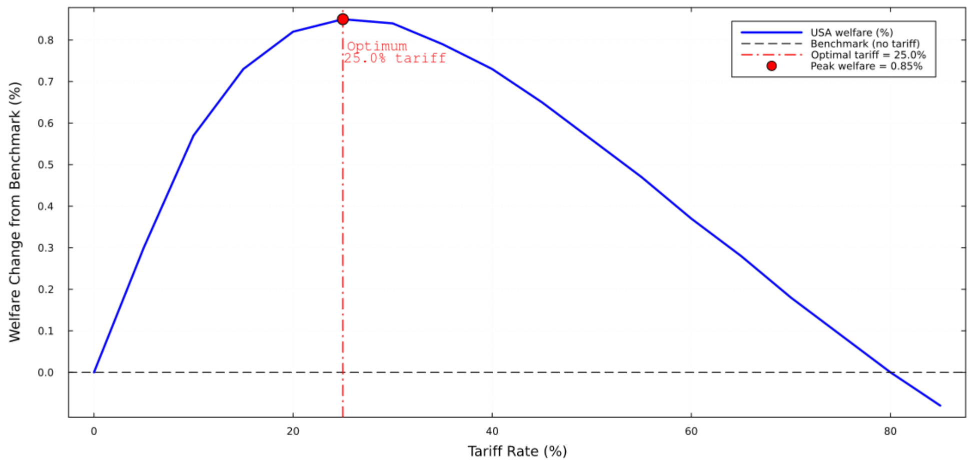

Figure 9. U.S. intertemporal welfare as a function of the unilateral tariff rate under the within-horizon closure. The optimal tariff maximizes the present-value utility of the U.S. representative household in the absence of foreign retaliation. The welfare curve is computed by solving the full dynamic equilibrium at each tariff rate.

The welfare Laffer curve is single-peaked with an interior optimum at 25 percent, yielding a peak intertemporal welfare gain of 0.85 percent relative to the free-trade benchmark. Beyond the optimum, each additional tariff increment generates a larger Armington substitution distortion than terms-of-trade gain, and the welfare function is strictly concave in the neighborhood of the peak. Three implications follow.

First, the 25 percent dynamic optimum coincides precisely with the static inverse-elasticity formula: with $\varepsilon = 5$,

$$\tau^* = \frac{1}{\varepsilon - 1} = 0.25, \tag{31}$$

a correspondence that holds under the fully forward-looking within-horizon closure and suggests that intertemporal capital-accumulation and borrowing channels do not materially shift the *level* of the optimal tariff at the unilateral optimum, though they do alter the curvature of the welfare function away from it.

Second, the 0.85 percent gain represents an upper bound for this closure. The period-by-period constraint would yield a lower gain by precluding intertemporal smoothing, while the perfect capital markets benchmark would permit a higher gain by allowing the United States to borrow indefinitely against a permanent terms-of-trade rent stream. Whether this ordering is preserved under alternative parameterizations is the subject of ongoing analysis.

Third, the observed 60 percent China tariff recovers only approximately 0.40–0.45 percentage points of welfare—roughly half the attainable maximum—implying a deadweight cost of over-tariffing on the order of 0.4 percentage points of intertemporal welfare, compounded by the capital decumulation and current-account overshooting documented in Sections 5.1.2 and 5.1.4.

6. Conclusion

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