Implementing Advanced Macroeconomic Dynamics for a Trade War Simulation: An Evidence-Based Guide

Introduction

Purpose

This report provides a detailed, evidence-based guide for the programmer tasked with implementing realistic macroeconomic dynamics within a simulation game environment, with a specific focus on capturing the complexities of trade policy and trade wars. The objective is to translate established macroeconomic theory and relevant empirical findings into concrete specifications, including functional forms (equations) and parameter values derived from contemporary research. This document serves as a bridge between economic modeling principles and practical code implementation, enabling the development of a more sophisticated and behaviorally accurate simulation.

Structure

The report is structured to build the economic model progressively. It begins with the core mechanisms governing international trade and price determination under tariff regimes (Section 1). It then integrates these mechanisms into the broader macroeconomic framework, detailing the interplay between output, employment, and inflation (Section 2). Recognizing that trade shocks often have sector-specific origins and impacts, Section 3 outlines methods for incorporating sectoral linkages. Section 4 refines the modeling of key aggregate demand components – consumption and investment. Section 5 introduces the government sector, focusing on fiscal policy levers and the critical dynamics of public debt. Section 6 explores the integration of political economy factors, specifically modeling citizen trust as influenced by economic outcomes and policy choices. Finally, Section 7 consolidates the key equations and parameters, offering practical implementation guidance and suggesting avenues for calibration.

Key Assumption

It is assumed that the programmer possesses a functional simulation architecture and requires expert guidance primarily on refining the underlying economic logic and parameterizing the model components based on the evidence and specifications presented herein. Familiarity with basic macroeconomic concepts is assumed, but the report aims to provide sufficient detail for direct implementation.

Section 1: Core Trade and Price Mechanisms

Objective: To establish the fundamental relationships governing how tariffs, exchange rates, and foreign price levels interact to determine import prices and influence trade flows within the simulation.

1.1. Tariffs and Import Prices (Border Price Pass-Through)

Concept: Tariffs are fundamentally taxes levied by a government on imported goods, typically calculated as a percentage of the import's value (ad valorem).[1] A critical aspect of modeling tariffs is determining the extent to which the cost imposed by the tariff is reflected in the price paid by the domestic importer. This phenomenon is known as tariff pass-through.

Evidence: Standard trade theory might suggest that large economies imposing tariffs could force foreign exporters to lower their pre-tariff prices, resulting in incomplete pass-through. However, substantial empirical research focusing on the US tariffs imposed in 2018-2019 indicates that pass-through to the prices paid by *importers at the border* was virtually complete, often estimated at or near 100% within a year.[1] This implies that foreign exporters, particularly from China during this period, did not significantly absorb the tariff cost by reducing their prices; instead, the burden fell largely on the US importing firms and, subsequently, potentially on consumers.[3] This finding contrasts sharply with historical expectations [2] and, importantly, with the typically much lower pass-through observed for exchange rate fluctuations.[2] While some studies using different methodologies suggest a lower pass-through upon immediate impact (around 10%) rising towards 50% in the medium run [6], the evidence from the specific trade war period points towards near-complete pass-through at the border over a medium-term horizon (e.g., one year). Pass-through can also vary depending on product characteristics, such as the degree of differentiation, which affects the availability of substitutes.[3]

Equation: The price paid by the domestic importer for goods from country j in sector s (Pimport,s,j) must explicitly incorporate the tariff (Tariffs,j), the foreign price in foreign currency (Pfs,j), and the exchange rate (Valutakursj, defined as domestic currency units per unit of foreign currency j). Assuming complete pass-through at the border (pass-through coefficient $\phi=1$):

$$P_{import,s,j}=P_{f\,s,j}\times Valutakurs_j\times(1+Tariff_{s,j})$$

Parameter (Border Pass-Through ϕ): Based on the strong evidence from the 2018-2019 trade conflict, implementing a pass-through coefficient $\phi\approx1$ for the impact of tariffs on border import prices (Pimport) is recommended for medium-term dynamics.[1] If the simulation requires modeling pass-through to final retail prices, a lower coefficient would be necessary, as evidence suggests significant absorption by retailers in the short run. Estimates for retail pass-through vary, with some analyses suggesting values around 0.25 to 0.44 [3], meaning only a fraction of the border price increase reaches the final consumer initially.

Asymmetry of Pass-Through (Tariffs vs. Exchange Rates): The marked difference between near-complete tariff pass-through and partial exchange rate pass-through (often estimated between 25-35% [2]) is a crucial feature to capture. Tariffs represent specific, often politically motivated, cost shocks targeted at particular goods and origins. Firms may perceive them as less transient or more direct cost increases compared to broader exchange rate movements, which affect all international transactions and might be hedged against or offset by other macroeconomic adjustments. This difference in perception and scope likely drives the differential pricing responses. Therefore, the simulation logic should treat the price impact of tariffs distinctly and more strongly than that of exchange rate changes.

Retailer Absorption and Dynamics: The observed gap between high pass-through at the border and lower pass-through to retail prices points to significant cost absorption by importing firms and retailers, at least initially.[3] These firms appear to have compressed their profit margins rather than immediately passing the full tariff cost to consumers.[3] This could be driven by competitive pressures, a desire to maintain market share, or inventory management strategies (e.g., stocking up before tariffs hit [3]). However, such margin compression may not be sustainable indefinitely.[4] This suggests that a static retail pass-through coefficient might be insufficient. A more realistic model could feature dynamic pass-through to retail prices, potentially linking the speed and extent of pass-through to factors like retailer profitability, inventory levels, market structure, or the perceived permanence of the tariff. Pass-through could start low and increase over time if tariffs remain in place.

1.2. Domestic Price Level (Pd)

Concept: The overall domestic price level, represented by indices like the Consumer Price Index (CPI) or the GDP deflator, reflects the weighted average price of goods and services consumed or produced within the economy. It is influenced by the prices of both domestically produced items and imported goods. Tariffs, by directly increasing the cost of imported goods [1], contribute to upward pressure on the overall price level.

Evidence: Increases in trade costs, such as tariffs, demonstrably lead to higher domestic inflation.[10] The impact profile differs based on the type of good affected: tariffs on final goods tend to cause a larger but more temporary spike in inflation, whereas tariffs on intermediate goods can lead to more persistent inflationary pressures due to their role as inputs in production across various sectors, potentially reducing productivity.[10] Empirical studies suggest that a 10% increase in tariffs might raise producer prices by about 1%.[1] A combined 10 percentage point increase in trade costs on both intermediate and final goods was estimated to raise CPI inflation by 0.8 percentage points over several years.[10] Simulations of recent large-scale tariff proposals (e.g., potential 2025 US tariffs) estimated short-run increases in the overall price level (CPI or PCE) ranging from 1% to 3%.[11]

Different price indices capture import effects differently. The CPI includes prices of imported goods directly in its basket, weighted according to consumer expenditure patterns.[13] In contrast, the Producer Price Index (PPI) measures prices received by domestic producers and explicitly excludes imports.[16] The GDP deflator measures the prices of goods and services *produced* domestically; while it doesn't directly include import prices, it is affected indirectly through the cost of imported intermediate inputs used in domestic production.[13]

Equation: A common approach to modeling the domestic price level (Pd) is as a weighted average of the prices of domestically produced goods and imported goods relevant to the index being modeled:

$$Pd = wd \times Pdomestic\_produced + (1 - wd) \times Pimports\_avg$$

Where:

- Pdomestic_produced represents the price index for domestically produced goods and services. Its dynamics are typically governed by domestic factors like wage costs and the output gap (as captured by the Phillips Curve, see Section 2.2).
- Pimports_avg is the average price index of imported goods faced by domestic purchasers (consumers or firms), derived from the border prices (Pimport,s,j) calculated in Section 1.1, potentially adjusted for retail markups and pass-through dynamics.
- wd is the weight assigned to domestically produced goods in the specific price index being simulated (e.g., CPI or GDP deflator). (1−wd) represents the weight of imports.

Parameter (Weight wd**):** The appropriate weight depends heavily on the specific price index being modeled and the structure of the simulated economy.

- For a CPI-like index, (1–wd) should reflect the share of imported goods and services directly consumed by households. This varies significantly across countries (e.g., Eurostat data shows import contribution to total supply ranging from 12% in Italy to 37% in Ireland in 2020 [17]). Data on the share of imports in final consumption expenditure is needed.[17]
- For a GDP deflator, wd would conceptually be 1, as it measures domestic production prices. However, Pdomestic_produced itself will be influenced by the cost of imported *intermediate* goods.
- Distinguishing between imports for final consumption and imports used as intermediate inputs is crucial.[17] Intermediate goods constitute a large share of trade (e.g., over 50% of OECD goods imports [23], potentially higher for developing economies [26]). Input-Output (I-O) tables, such as those from the BEA [28], provide detailed information on the use of imported commodities by domestic industries and final demand categories, which can inform the calibration of weights or the indirect impact on Pdomestic_produced.

Intermediate vs. Final Goods Inflation Impact: The differential inflationary impact of tariffs on intermediate versus final goods warrants careful consideration.[10] Tariffs on final consumer goods (like washing machines [3]) directly affect the CPI basket, potentially causing a rapid but possibly one-off adjustment in the price level.[10] Conversely, tariffs on intermediate inputs (like steel, aluminum, or electronic components [1]) increase costs for domestic producers across various sectors.[2] These cost increases can ripple through domestic supply chains, potentially reducing firm productivity as they substitute towards less efficient inputs [10], leading to a more gradual but persistent increase in overall inflation. To capture this, the simulation should ideally differentiate tariffs applied to final goods from those applied to intermediate goods (requiring sectoral detail, see Section 3). The inflation dynamics modeled in Section 2.2 should then reflect this difference, with intermediate goods price shocks having a more drawn-out effect on Pd.

1.3. Foreign Price Level (Pf)

Concept: In a multi-country simulation, the foreign price level (Pf) represents the price environment faced by the domestic economy when trading with the rest of the world. It cannot be treated as a static constant (e.g., fixed at 1) if the simulation aims to capture global interactions and feedback effects realistically. Pf reflects the prices set by trading partners.

Evidence: Sophisticated multi-country macroeconomic models used by international institutions and central banks, such as the IMF's FSGM [34] and GEM [35], the ECB's

ECB-Global [37], and the World Bank's MFMod [38], explicitly incorporate mechanisms for modeling foreign price levels and their interaction with domestic economies through trade and financial linkages.[39] A standard approach involves linking the foreign price level faced by one country to the domestic price levels (Pd) of its trading partners, often weighted by trade shares.

Equation: A practical approach to model the foreign price level (Pf,i) faced by country i is to calculate it as a trade-weighted average of the domestic price levels (Pd,j) of its trading partners (j), adjusted for exchange rates:

Pf,i=jΣ(TradeWeightij×ValutakursjPd,j)

Where:

- TradeWeightij is the share of country j in country i's total trade (or specifically imports, depending on the desired focus).
- Pd,j is the domestic price level index of trading partner country j.
- Valutakursj is the exchange rate converting country j's currency into country i's currency (or a common numeraire currency like the USD).

Implementation Note: This formulation necessitates that the simulation calculates the state of all countries (or AI agents) either simultaneously or iteratively within each time step. The Pf for country i depends on the Pd of all countries j, and conversely, the Pd of country j will be influenced by the Pf it faces (which depends on country i's Pd).

Interdependence: Modeling Pf dynamically introduces crucial interdependence into the global simulation. For instance, if country A imposes tariffs, its domestic price level (Pd,A) might rise due to higher import costs. According to the equation above, this increase in Pd,A will contribute to a higher foreign price level (Pf,B) faced by its trading partner, country B. This could, in turn, increase import costs and potentially raise the domestic price level (Pd,B) in country B. This change in Pd,B then feeds back into the foreign price level (Pf,A) faced by country A. Such feedback loops are fundamental to understanding the international transmission of shocks, global inflation dynamics, and changes in international competitiveness, which are central themes in trade war scenarios.[34] Hardcoding Pf to a constant value would eliminate these vital global interaction effects.

1.4. Exchange Rates (Valutakurs)

Concept: The nominal exchange rate, the relative price of two currencies, is a critical variable linking domestic and foreign economies. It directly influences the relative prices of imports and exports (Pd/Pf). Exchange rate determination is complex, influenced by relative price levels, interest rate differentials, trade flows, capital flows, and market expectations.

Evidence: Several theoretical frameworks attempt to explain exchange rate movements:

- **Purchasing Power Parity (PPP):** Suggests exchange rates adjust to equalize international price levels.[42] While useful for long-run trends, PPP often fails in the short-to-medium run due to trade barriers, non-traded goods, and sticky prices.[42]
- **Interest Rate Parity (IRP):** Links exchange rate changes to interest rate differentials. Covered Interest Parity (CIP), involving forward contracts, tends to hold due to arbitrage. Uncovered Interest Parity (UIP), which relates expected exchange rate changes to interest differentials, assumes risk neutrality and rational expectations.[42] Empirically, UIP performs poorly; high-interest-rate currencies often appreciate rather than depreciate as UIP predicts (the "forward premium puzzle") [48], suggesting risk premia or other factors are significant drivers.[48]
- **Balance of Payments / Flow Models:** Relate exchange rate movements to flows in the current account (trade balance) and capital account.[42] An improving trade balance (higher net exports) increases demand for domestic currency, leading to appreciation.[50] Net capital inflows also lead to appreciation.
- **Asset Market / Portfolio Balance Models:** View the exchange rate as the relative price of national monies or assets, determined by relative supply and demand, incorporating factors like relative money supplies, income levels, interest rates, and stocks of domestic/foreign assets (reflecting cumulative current account balances).[42] These models often assume imperfect substitutability between domestic and foreign assets.
- **Behavioral Equilibrium Exchange Rate (BEER):** Empirically relates the real exchange rate to long-term fundamentals (like terms of trade, net foreign assets, productivity) and short-term real interest rate differentials, often assuming UIP holds for the short-term component.[46]

Equation (Simplified Flow-Based): A pragmatic approach, incorporating key elements suggested by theory and the user query, models the *change* in the exchange rate (ΔValutakurs) based on interest rate differentials, changes in the trade balance, and potentially net capital flows:

$$\Delta Valutakurs_t = k_1 \times (policyRate_t - policyRate_{udland\_avg,t}) - k_2 \times \left(\frac{\Delta NX_t}{GDP_t}\right) + k_3 \times \left(\frac{\Delta NetCapitalFlow_t}{GDP_t}\right) + \epsilon_{valutakurs,t}$$

Where:

- $\Delta Valutakurs_t$ is the change in the exchange rate (domestic units per foreign unit; a positive change represents depreciation).
- $policyRate_t$ is the domestic policy interest rate.
- $policyRate_{udland\_avg,t}$ is a relevant average foreign policy rate.
- $\Delta NX_t/GDP_t$ is the change in the trade balance (Net Exports) as a share of GDP. An improvement ($\Delta NX>0$) should lead to appreciation ($\Delta Valutakurs<0$), hence the negative sign associated with $k2$.
- $\Delta NetCapitalFlow_t/GDP_t$ represents net capital inflows (positive for net inflows) as a share of GDP. This could be proxied by the change in the net foreign asset position or related to the current account balance. Net inflows should lead to appreciation ($\Delta Valutakurs<0$), so $k3$ should capture this inverse relationship (or the variable itself should be defined such that inflows are negative). For simplicity, the term could be omitted initially or proxied crudely.
- $k1,k2,k3$ are positive sensitivity parameters.
- $\epsilon_{valutakurs,t}$ represents unexplained shocks or volatility.

Parameters ($k1,k2,k3$**):** Precise empirical estimates are difficult and model-dependent.

- $k1$ (Interest Rate Sensitivity): UIP implies a strong link, but empirical failures suggest $k1$ might be smaller than theory predicts.[47] Start with a small positive value.
- $k2$ (Trade Balance Sensitivity): Changes in trade balances are found to significantly impact exchange rates.[50] This parameter should likely be positive and potentially significant relative to $k1$.
- $k3$ (Capital Flow Sensitivity): Standard in portfolio balance models.[44] Requires careful definition of the flow variable and calibration. Calibration is key. Some studies suggest trade rebalancing explains a larger share of exchange rate fluctuations (~50%) than UIP shocks (~20%) [50], hinting that $k2$ might warrant a relatively larger weight than terms capturing pure interest rate effects or exogenous shocks.

UIP Failure and Risk Premia: The consistent empirical rejection of UIP [47] is a strong indicator that exchange rates are driven by more than just expected interest rate differentials. Risk premia, reflecting investor aversion to holding assets denominated in certain currencies (due to perceived risks like inflation, default, or political instability), likely play a major role.[48] Other factors like "safe haven" flows or shifts in long-term growth expectations also influence capital movements and exchange rates. A purely UIP-driven model would generate unrealistic dynamics. The simplified equation above attempts to capture some of these additional factors implicitly through the trade balance term (k2), the capital flow term (k3), and the shock term (ϵvalutakurs). The simulation should not impose or expect UIP to hold strictly.

1.5. Net Exports (NX)

Concept: Net Exports (NX), the difference between exports and imports, are a key component of aggregate demand and the channel through which trade policy directly impacts the economy. NX is determined by the relative prices of domestic versus foreign goods (incorporating tariffs and exchange rates) and by income levels both domestically and abroad.

Evidence: International trade flows are empirically sensitive to both relative price changes and income fluctuations.[54] Tariffs act as an increase in the relative price of imported goods, thereby depressing import volumes.[6] The responsiveness of trade volumes to price changes is measured by the price elasticity of demand, while responsiveness to income changes is measured by the income elasticity. Gravity models consistently show that trade increases with the economic size (GDP) of trading partners and decreases with trade costs, which include distance, transport costs, and tariffs.[59] Both price and income elasticities vary considerably across different countries and different sectors or products.[54] For the US, studies have often found the income elasticity of imports to be higher than the income elasticity of exports, contributing to trade balance dynamics.[54] Estimates for the long-run price elasticity of imports (often denoted ϵ or related to the elasticity of substitution σ in theoretical models) vary widely in the literature. Aggregate estimates for the general equilibrium response to tariffs range from -0.8 [6] to potentially higher values like -1.75 to -2.25 [57] or even -4 based on some US analyses.[8] Product-level estimates can be around -5 [55], and country-specific aggregate import elasticities can range from -0.7 (Hong Kong) to over -7 (China).[58]

Equation (Sectoral NX): To capture sector-specific tariff effects, net exports should be modeled at the sectoral level (s):

NXs=Exportss−Importss

Importss=M0,s×(Yd,potentialYd)ϵM,Y×(PdPimport,s)ϵM,P

Exportss=X0,s×(Yf,potentialYf)ϵX,Y×(PfPexport,s)ϵX,P

Where:

- NXs is net exports for sector s.

- Importss, Exportss are real import and export volumes for sector s.
- M0,s, X0,s are scaling constants or base levels for imports and exports in sector s.
- Yd, Yf are real domestic and foreign income/GDP, respectively. Yd,potential, Yf,potential represent potential output levels (or alternatively, income growth rates can be used).
- Pimport,s is the domestic currency price of imports in sector s, inclusive of tariffs and exchange rate effects (from Section 1.1).
- Pd is the domestic price level index.
- Pexport,s is the price of domestic exports in sector s (in domestic currency). This price might be affected by foreign retaliatory tariffs if those are modeled.
- Pf is the relevant foreign price level index (from Section 1.3).
- ϵM,Y, ϵX,Y are the income elasticities of demand for imports and exports, respectively.
- ϵM,P, ϵX,P are the price elasticities of demand for imports and exports, respectively (these should be negative). ϵM,P represents the general equilibrium import elasticity with respect to relative price changes (including those caused by tariffs).

Parameters (Elasticities):

- **Income Elasticities (**ϵY**):** Values typically range from 1.0 to 2.5. As noted, US ϵM,Y might be higher than ϵX,Y.[54] Start with values around 1.5 for both and adjust based on desired trade balance behavior.
- **Price Elasticities (**ϵP**):** These are crucial but highly uncertain and variable. Based on the evidence:
  - Aggregate long-run ϵM,P could be around -0.8 [6] to -2.0.[8]
  - Sectoral/product elasticities can be significantly higher in magnitude (e.g., -5 or more [55]).
  - A reasonable starting point for aggregate elasticities might be in the range of **-1.0 to -1.5** for both ϵM,P and ϵX,P, acknowledging the need for potential sector differentiation (Section 3) and calibration. The general equilibrium estimates [6] suggest the overall response might be closer to -1.0 in the long run.

Trade Elasticity Dynamics: The response of trade flows to price changes induced by tariffs or exchange rate movements is not instantaneous.[6] Empirical estimates show that short-run elasticities are considerably smaller in magnitude than long-run elasticities (e.g., -0.2 vs -0.8 for tariff impact on imports [6]). Full adjustment can take several years as firms find new suppliers, consumers change habits, and supply chains are reconfigured.[57] This implies that using static long-run elasticities in the simulation will likely overstate the immediate impact of tariff changes on trade volumes. A more realistic approach involves implementing dynamic elasticities or lagged adjustment mechanisms. For example, a partial adjustment model could be used, where the actual change in imports/exports in a given period only partially closes the gap between the current level and the level implied by the long-run elasticities and current prices/income. Alternatively, the elasticity itself could be modeled as increasing gradually over time following a shock.

Table 1: Core Trade Parameters

Parameter Symbol	Description	Equation Ref.	Value/Range	Source Snippet(s)
ϕ	Tariff Pass-through to Import Price (Border)	Sec 1.1	≈1 (medium term)	[1]
wd	Weight of Domestic Goods in Pd	Sec 1.2	Calibration Req.	[13]
k1	Exch. Rate Sensitivity to Interest Diff.	Sec 1.4	Small positive	[47]
k2	Exch. Rate Sensitivity to ΔNX/GDP	Sec 1.4	Positive	[50]
k3	Exch. Rate Sensitivity to Capital Flow	Sec 1.4	Calibration Req.	[44]
ϵM,Y	Income Elasticity of Imports	Sec 1.5	1.0 - 2.5	[54]
ϵX,Y	Income Elasticity of	Sec 1.5	1.0 - 2.5	[54]

	Exports			
$\epsilon M,P$	Price Elasticity of Imports	Sec 1.5	-0.8 to -2.0 (LR Agg.)	6
$\epsilon X,P$	Price Elasticity of Exports	Sec 1.5	-1.0 to -2.0 (LR Agg.)	58

Note: LR = Long Run, Agg. = Aggregate. Elasticities are subject to significant variation and require calibration. Short-run price elasticities are smaller in magnitude.

Section 2: Output, Employment, and Inflation Dynamics

Objective: To model the core macroeconomic feedback loops connecting aggregate output, the labor market (unemployment), and the price level (inflation), ensuring these relationships are informed by empirical evidence and incorporate the influence of international trade dynamics, particularly import prices.

2.1. Unemployment (Okun's Law)

Concept: Okun's Law provides an empirical cornerstone for linking the real side of the economy (output) to the labor market (unemployment). It posits a stable negative relationship between deviations of output from its potential level (the output gap) and deviations of the unemployment rate from its natural rate (the unemployment gap).[64] Essentially, when the economy produces above its potential, unemployment tends to fall below its natural rate, and vice versa.

Evidence: The law, originally formulated by Arthur Okun in 1962 [66], has been widely confirmed empirically, although the precise quantitative relationship (the Okun coefficient) varies across countries and over time.[64] Okun's original estimate for the US suggested that a 3% shortfall in GDP growth corresponded to a 1% increase in the unemployment rate.[67] Modern estimations often focus on the relationship between gaps (output gap and unemployment gap) or differences (changes in GDP growth vs changes in unemployment).

Recent cross-country studies by the IMF suggest that for advanced economies (AEs), the Okun coefficient (β) in a gap specification like $(ut-ut*)=\beta\times(yt-yt*)$ is typically in the range of **-0.3 to -0.4**.[64] This implies that a 1 percentage point decrease in output relative to potential is associated with a 0.3 to 0.4 percentage point increase in the unemployment rate above its natural level. The coefficient tends to be smaller in magnitude (less negative, e.g., around -0.17) for emerging market and developing economies (EMDEs), possibly due to factors like greater labor market informality.[64] Some estimates for individual European countries show variability, ranging from -0.1 to -0.8, but averaging around -0.3.[70] There is also evidence suggesting the relationship might be asymmetric, with unemployment responding more strongly during economic downturns (negative output gaps) than during upturns.[64] Furthermore, the sensitivity differs across demographic groups, with youth unemployment typically being more responsive to output fluctuations than adult unemployment.[64]

Equation: Following the user query's suggestion and common practice, the "difference version" relates the change in the unemployment rate to the deviation of GDP growth from potential growth:

$$\Delta u_t \approx -\beta \times (g_{y,t} - g_{y,t}^*) + \epsilon_{u,t}$$

Alternatively, the "gap version" relates the unemployment gap to the output gap:

$$u_t - u_t^* = \beta_{gap} \times (y_t - y_t^*) + \epsilon_{u,t}$$

Where:

- Δu_t is the change in the unemployment rate in period t.
- u_t is the unemployment rate; u_t^* is the natural rate of unemployment (NAIRU).[69]
- $g_{y,t}$ is the real GDP growth rate; $g_{y,t}^*$ is the potential real GDP growth rate.
- y_t is the log of real GDP; y_t^* is the log of potential GDP. $(y_t - y_t^*)$ is the output gap.
- β in the difference version is the Okun coefficient (positive). β_{gap} in the gap version is negative.
- $\epsilon_{u,t}$ represents shocks to unemployment not explained by output fluctuations.

Parameter (β for difference version): Based on the IMF estimates for AEs (gap coefficient of -0.3 to -0.4), the corresponding coefficient for the difference version (β) would be approximately **0.3 to 0.4**. The range suggested in the user query (0.3-0.5) aligns well with this empirical evidence. A starting value of $\beta=0.4$ appears reasonable for a baseline AE simulation.

Asymmetry and Heterogeneity: While a constant Okun coefficient is a useful simplification, it's important to recognize its limitations. The empirical findings suggest that the relationship is not uniform.[64] Factors such as labor market institutions (hiring/firing costs, unemployment benefits, union density), the cyclical behavior of labor force participation, and the degree of labor hoarding by firms influence the coefficient's magnitude.[64] The stronger response observed during downturns implies that recessions may translate into larger increases in unemployment than booms translate into decreases. For enhanced realism, particularly in a simulation focused on potentially large shocks like trade wars, the parameter β could be modeled as state-dependent, increasing in magnitude during periods of negative output gaps. Similarly, if the simulation distinguishes between country types, using a lower β for EMDEs would be appropriate.

2.2. Inflation (Augmented Phillips Curve)

Concept: The Phillips Curve describes the relationship between inflation and economic slack. The original formulation linked wage growth to unemployment.[72] Modern macroeconomic models typically employ a New Keynesian Phillips Curve (NKPC) which relates current inflation (πt) to expected future inflation (Et[πt+1]), a measure of real economic activity or marginal cost (often proxied by the output gap or unemployment gap), and various cost-push shocks.[73] Crucially for an open economy model, changes in import prices are a significant cost-push factor that should be included.[10]

Evidence: Empirical estimation confirms that inflation dynamics are influenced by expectations, economic slack, and supply-side shocks.[73] Import prices, reflecting costs of imported consumer goods and intermediate inputs, directly affect domestic price levels.[10] The pass-through from import price changes to overall consumer inflation (γ) is generally found to be positive but incomplete and variable across countries and time.[77] For low-inflation economies like the US, long-run pass-through from import prices to consumer prices is estimated to be relatively low, perhaps around 0.2 to 0.4, implying that only a fraction of import price fluctuations feeds into headline inflation.[78] Studies simulating trade cost shocks suggest a 10 percentage point rise in import costs could increase CPI inflation by 0.3 to 0.8 percentage points, implying a pass-through coefficient (γ) in the range of 0.03 to 0.08 when relating percentage point changes.[10] Pass-through might be higher in environments with higher inflation or greater exchange rate volatility.[78]

The sensitivity of inflation to the output gap (the slope of the Phillips curve, ϕ) is a subject of ongoing debate. Some research suggested a flattening of the Phillips curve in recent decades, meaning inflation became less responsive to changes in economic slack.[73] However, the inflation surge following the COVID-19 pandemic has reignited discussion, with some evidence suggesting the Phillips curve may steepen significantly when economies face large shocks or operate near capacity constraints.[79] Estimating ϕ is challenging due to econometric issues, particularly the endogeneity of monetary policy which actively tries to stabilize both inflation and the output gap.[74]

Equation: An augmented NKPC incorporating import prices, consistent with the user query and standard practice, can be specified as:

$\pi t = \alpha Et[\pi t+1] + (1-\alpha)\pi t-1 + \phi \times (OutputGapt) + \gamma \times (\Delta Pimport\_avg,t) + \epsilon \pi,t$

Where:

- πt is the inflation rate in period t.
- $Et[\pi t+1]$ is the expected inflation rate for period t+1, formed at time t.
- $\pi t-1$ is lagged inflation, capturing backward-looking behavior or persistence. α (between 0 and 1) weights forward vs. backward looking expectations. A purely forward-looking NKPC has $\alpha=1$. Using $\pi t-1$ alone ($\alpha=0$) represents adaptive expectations, as implied in the user query's initial suggestion. A mix is often empirically plausible.
- $OutputGapt=(yt-yt*)$ is the output gap.
- $\Delta Pimport\_avg,t$ is the percentage change in the relevant average import price index (potentially CPI-weighted import prices).
- ϕ (phi) is the coefficient on the output gap (Phillips curve slope).
- γ (gamma) is the pass-through coefficient from import price inflation to domestic inflation.
- $\epsilon \pi,t$ represents other exogenous cost-push shocks (e.g., changes in oil prices [73], indirect taxes).

Parameters:

- α: Weight on expected future inflation. Needs calibration. $\alpha=0.5$ represents a hybrid curve.
- ϕ: Phillips curve slope. Given the estimation challenges and debate, a small positive value is a common starting point, e.g., **0.1 to 0.3**. Calibration should ensure inflation responds plausibly to demand shocks.
- γ: Import price pass-through to domestic inflation. Based on empirical estimates for low-inflation AEs, this is likely partial. Values around **0.05 to 0.15** seem plausible as a starting range.[10] Needs careful scaling depending on whether $\Delta Pimport\_avg,t$ is a percentage change or percentage point change.

Phillips Curve Identification and State Dependence: The difficulty in empirically pinning down the Phillips curve slope (ϕ) arises partly because effective monetary policy aims to counteract deviations of inflation and output from their targets. If a central bank successfully offsets cost-push shocks by adjusting demand, the observed correlation between inflation and the output gap might appear weak or even negative, even if the underlying structural relationship (ϕ) is positive and significant.[74] This endogeneity complicates estimation. Furthermore, the assumption of a constant slope may be too restrictive. The experience of recent years suggests the slope might increase (inflation becomes more sensitive to slack) during periods of high inflation, high volatility, or when the economy hits supply constraints in key sectors.[79] Similarly, the pass-through of import prices (γ) might increase in high-inflation environments.[78] For advanced simulation, incorporating state-dependency in ϕ and γ could enhance realism. For instance, ϕ could be modeled to increase when the output gap is large and positive, or when inflation is significantly above target.

Table 2: Okun's Law and Phillips Curve Parameters

Parameter Symbol	Description	Equation Ref.	Value/Range	Source Snippet(s)
β	Okun Coefficient (Difference Version)	Sec 2.1	0.3 - 0.5	[64]
βgap	Okun Coefficient (Gap Version)	Sec 2.1	-0.3 to -0.5	[64]
α	Weight on Expected Inflation (Phillips Curve)	Sec 2.2	0.0 - 1.0 (Calib.)	[73] (Conceptual)
ϕ	Phillips Curve Slope (Output Gap Coeff.)	Sec 2.2	0.1 - 0.3 (Calib.)	[74]
γ	Import Price Pass-through to Dom. Inflation	Sec 2.2	0.05 - 0.15 (Calib.)	[10]

Note: Calib. = Requires Calibration. Values are indicative starting points for Advanced Economies.

Section 3: Sectoral Linkages and Dynamics

Objective: To disaggregate the macroeconomic model to capture how sector-specific phenomena, particularly tariffs, propagate through the economy via inter-industry linkages, affecting sectoral output and employment, and ultimately influencing aggregate outcomes. This section also addresses how aggregate investment translates into sector-specific capacity expansion.

3.1. Sector-Specific Tariff Impacts and Trade

Concept: Trade policies, especially tariffs, are rarely applied uniformly across all goods. They typically target specific products or sectors.[1] Therefore, a realistic simulation of trade wars requires modeling tariff impacts at a sectoral level. This involves applying sector-specific tariff rates to calculate import prices and then determining the resulting changes in import and export volumes for each sector, considering that trade elasticities can also differ across sectors.

Evidence: The importance of sectoral detail is highlighted by the use of Computable General Equilibrium (CGE) models for trade policy analysis, which explicitly map out inter-industry linkages and allow for sector-specific shocks.[81] Input-Output (I-O) tables provide the statistical foundation for these models, detailing how the output of one sector is used as an input by others.[28] Empirical studies confirm that trade elasticities vary significantly by product or sector.[55] For example, estimates of aggregate import price elasticities derived from sector-specific data range widely across countries.[58] Gravity models, often used to estimate trade potentials and policy impacts, can also be applied at a disaggregated product level.[55]

Implementation: The core trade equations presented in Section 1 should be implemented at the sector level (s).

- **Import Price:** $P_{import,s,j} = P_{f_{s,j}} \times Valutakurs_j \times (1 + Tariff_{s,j})$, where $Tariff_{s,j}$ is now the specific tariff rate applied to imports of goods from sector s originating in country j.
- **Trade Volumes:** The import and export equations from Section 1.5 are applied sector by sector: $Imports_s = M_{0,s} \times \left(\frac{Y_{d,potential}}{Y_d}\right)^{\epsilon_{M,Y}} \times \left(\frac{P_d}{P_{import,s}}\right)^{\epsilon_{M,P,s}}$ $Exports_s = X_{0,s} \times \left(\frac{Y_{f,potential}}{Y_f}\right)^{\epsilon_{X,Y}} \times \left(\frac{P_f}{P_{export,s}}\right)^{\epsilon_{X,P,s}}$ Crucially, the price elasticities ($\epsilon_{M,P,s}$ and $\epsilon_{X,P,s}$) can now be made sector-specific. While finding precise empirical estimates for every sector might be challenging, using different elasticity values for broad categories (e.g., manufacturing vs. services, or durable vs. non-durable goods) based on ranges found in studies like [58] or general principles (e.g., goods with more substitutes having higher elasticity) can add

realism.

3.2. Sectoral Output and Employment

Concept: The output of an individual sector (Ys) responds to the total demand for its products. This demand comprises final demand (consumption Cs, investment Is, government spending Gs) and intermediate demand (use of the sector's output as inputs by other sectors). Changes in sectoral output, driven by these demand fluctuations (including changes in export demand Xs and import competition affecting domestic demand), directly influence the demand for labor within that sector, leading to changes in sectoral employment (Ls).

Evidence: I-O analysis is the standard framework for quantifying these inter-industry dependencies, showing how demand for final goods translates into required output across all sectors, both directly and indirectly.[28] The relationship between sectoral output and employment is fundamental. I-O models often use fixed labor coefficients (units of labor required per unit of output) derived from historical data to link output changes to employment changes.[88] More sophisticated approaches, like those used by the Bureau of Labor Statistics (BLS) for employment projections, model sectoral employment based on projected sectoral output, considering factors like labor productivity trends.[92]

Equation:

- **Sectoral Output (Ys):** Modeling the full I-O structure can be complex. A simplified approach focuses on how changes in key demand components drive changes in sectoral output. For instance, ΔYs could be modeled as a function of changes in final domestic demand (ΔCs,ΔIs,ΔGs) and net exports (ΔNXs) for that sector, potentially with multipliers reflecting intermediate linkages. $\Delta Ys \approx f(\Delta Cs, \Delta Is, \Delta Gs, \Delta Xs, \Delta Importss, \text{Inter-industry links})$
- **Sectoral Employment (Ls):** Changes in sectoral employment can be linked to changes in sectoral output.
  - *Method 1 (Growth Rate based):* Link employment growth to output growth, adjusting for productivity trends (λs) and potentially cyclical factors (response to sectoral output gap Ys−Ys∗): $\frac{\Delta Ls}{Ls} \approx \eta s \times \frac{\Delta Ys}{Ys} - \lambda s$ where ηs is the elasticity of employment to output (often assumed to be close to 1, adjusted for productivity λs).
  - *Method 2 (Labor Coefficient based):* Use a labor requirement coefficient (es, representing labor units per unit of real output), potentially derived from I-O data [88]: $Ls = es \times Ys$ In dynamic terms, assuming a relatively stable coefficient in the short run: $\Delta Ls \approx es \times \Delta Ys$

Parameters: Sector-specific labor coefficients (e_s) or output elasticities of employment (η_s) and productivity trends (λ_s) are required. These can be informed by national I-O tables or sectoral productivity data.

3.3. Aggregation to Macro Variables

Concept: Aggregate macroeconomic variables like total GDP and the overall unemployment rate are derived by summing or averaging the corresponding sectoral values, appropriately weighted.

Evidence: National accounting standards define GDP using three approaches: expenditure, income, and production (value added).[93] The production approach calculates GDP as the sum of value added across all industries (or sectors) in the economy.[93] Value added for a sector is defined as the value of its gross output minus the value of intermediate inputs consumed in the production process.[17] The aggregate unemployment rate is calculated as the total number of unemployed individuals (summed across sectors or demographics) divided by the total labor force.[96] Sectoral value added or employment shares are typically used as weights when constructing aggregate indices or analyzing contributions.

Equation:

- **Aggregate Real GDP (Y):** Sum of sectoral value added: $Y=\sum_s ValueAdded_s=\sum_s (Y_s - IntermediateConsumption_s)$ where $IntermediateConsumption_s$ is the real value of inputs used by sector s. This requires tracking intermediate input usage, often derived from I-O coefficients.
- **Aggregate Unemployment Rate (u):** Ratio of total unemployed to total labor force: $u=\frac{\sum_s Unemployed_s}{\sum_s LaborForce_s}$ where $Unemployed_s=LaborForce_s - L_s$. This requires tracking sectoral labor force and employment (L_s from Section 3.2).

Implementation Note: This aggregation step requires the simulation to maintain consistent accounts at the sectoral level for output, intermediate consumption, employment, and labor force.

3.4. Investment Allocation and Sectoral Capacity (newCap)

Concept: Aggregate investment spending (I, determined as in Section 4.2) needs to be allocated across the different sectors of the economy (I_s). This sectoral investment drives the accumulation of capital stock within each sector, thereby determining its future production capacity (represented as newCap in the user's supply.ts module). Key drivers for investment allocation include relative sectoral profitability, expected future growth prospects, and potentially sector-specific financing conditions or adjustment costs.

Evidence: Investment decisions are fundamentally forward-looking and aim to maximize expected returns relative to costs. Factors influencing aggregate investment also operate at the sectoral level. Firms are more likely to invest in sectors where profitability is high or expected to grow.[97] The accelerator principle suggests investment flows towards sectors experiencing rapid demand growth.[99] Tobin's Q theory implies sectors where the market values assets highly relative to their replacement cost (high Q) will attract more investment.[101] Macroeconomic conditions affect sectors differently; for example, cyclical sectors like energy and materials might see investment fluctuate more with growth expectations than defensive sectors like healthcare or consumer staples.[98] Financial market conditions and the availability of credit can also influence sectoral investment patterns, potentially amplifying shocks (financial accelerator).[106]

Equation:

- **Investment Allocation (I_s):** Total aggregate investment (I) can be allocated based on relative sectoral attractiveness, proxied by factors like profit rates, expected growth, or Tobin's Q: $I_s = I \times ShareWeight_s$ Where $ShareWeight_s$ could be defined proportionally to a sector's relative profitability, expected demand growth, or Q ratio. For example, using profitability: $ShareWeight_s = \frac{ProfitRate_s \times K_s}{\sum_k (ProfitRate_k \times K_k)}$ (or similar weighting scheme) $ProfitRate_s = \frac{(Revenues_s - Costs_s)}{K_s}$ where K_s is the capital stock in sector s.
- **Sectoral Capacity / Capital Stock (K_s):** The capital stock in each sector evolves according to the standard accumulation equation, incorporating sectoral investment and depreciation (δ_s): $K_{s,t+1} = (1 - \delta_s) \times K_{s,t} + I_{s,t}$ The variable newCap_s from the user's supply.ts should be directly linked to this evolving capital stock, $K_{s,t+1}$. The exact relationship depends on the assumed production function (e.g., Cobb-Douglas, CES), where capital is an input determining potential output.

Parameters: Sector-specific depreciation rates (δ_s) are needed. The parameters governing the allocation weights ($ShareWeight_s$) require calibration based on assumptions about what drives sectoral investment (e.g., the relative importance of current profits vs. expected growth).

Investment Driver Interplay: The decision to invest in a particular sector reflects a complex calculation weighing expected future returns against the cost and risk involved. Low overall interest rates reduce the cost of capital for all sectors, but the impact might be larger for capital-intensive industries.[108] Strong aggregate demand growth (accelerator effect) might boost investment across the board, but particularly in cyclical sectors anticipating continued expansion.[98] A high Tobin's Q signals that the market places a high value on installed capital in a sector relative to its replacement cost, making new investment attractive.[101] These factors interact – a sector might face high demand growth but also high interest rates or a low Q ratio, leading to conflicting signals. A comprehensive model should ideally capture these interacting influences. The sectoral allocation mechanism should reflect that different sectors exhibit varying sensitivities to these drivers based on their technological characteristics, market structure, and position in the business cycle.[98]

Table 3: Sectoral Data Requirements and Linkages

Data Item / Variable	**Potential Source / Calculation Method**	**Importance for Model Linkages**
Sectoral Tariffs	Exogenous policy input (player/AI controlled)	Initiates trade shock, affects Pimport,s.
Sectoral Imports/Exports	Calculated via trade equations (Sec 1.5, 3.1) using sector tariffs, prices, elasticities, income.	Determines sectoral NXs, links trade policy to sectoral activity.
Sectoral Output (Ys)	Responds to sectoral demand (final + intermediate), influenced by NXs. Requires I-O structure or simplified demand linkage.	Links trade/demand shocks to production. Input for calculating Value Added and driving employment.
Sectoral Value Added	Ys - Sectoral Intermediate Consumption. Requires I-O coefficients or estimates.	Aggregates to total GDP (Sec 3.3). Basis for sectoral contribution to economy.
Sectoral Employment (Ls)	Calculated from ΔYs using labor coefficients or elasticity/productivity (Sec 3.2).	Aggregates to total employment/unemployment (Sec 3.3). Links economic activity to labor market outcomes.
Sectoral Capital Stock (Ks)	Accumulates based on sectoral investment (Is) and depreciation (δs) (Sec 3.4).	Determines sectoral production capacity (newCap_s). Influences investment allocation via

		profitability calculations.
Sectoral Investment (Is)	Allocated from aggregate I based on relative profitability, growth expectations, or Q ratio (Sec 3.4).	Drives capital accumulation (Ks) and capacity growth. Links aggregate investment decisions to sectoral structure.
Sectoral Profit Rate	Calculated from sectoral revenue, costs, and capital stock (Sec 3.4).	Potential driver for investment allocation (Is). Reflects sector performance.

Section 4: Enhancing Aggregate Demand Components

Objective: To develop more sophisticated and empirically grounded functions for the primary private sector components of aggregate demand: private consumption (C) and gross private domestic investment (I).

4.1. Consumption Function (C)

Concept: Aggregate private consumption expenditure is the largest component of GDP in most economies. Understanding its determinants is crucial for modeling macroeconomic dynamics. The simplest models link consumption directly to current disposable income (the Keynesian consumption function). More advanced theories incorporate roles for wealth, consumer confidence, and expectations about future income, leading to concepts like the Marginal Propensity to Consume (MPC), autonomous consumption, the Permanent Income Hypothesis (PIH), and the Life-Cycle Hypothesis (LCH).

Evidence: A strong positive relationship between consumption and current disposable income (typically defined as aggregate income less net taxes) is consistently observed.[110] The slope of this relationship is the MPC ($\Delta C/\Delta Y$disposable), representing the fraction of an additional dollar of disposable income that is spent on consumption.[110] Aggregate MPC estimates for developed economies often fall in the range of **0.5 to 0.7** in the long run [114], although short-run MPCs can differ, particularly in response to temporary income changes. Autonomous consumption represents spending that occurs even when disposable income is zero.[111]

The PIH (developed by Friedman) and LCH (developed by Modigliani and Brumberg) argue that rational, forward-looking individuals base consumption decisions not just on current income, but on their expected lifetime resources or "permanent" income.[115]

This implies that consumers attempt to "smooth" consumption over time, saving during high-income periods (like middle age) and dissaving or borrowing during low-income periods (like youth or retirement).[116] A key implication is that consumption should respond less strongly to temporary or unexpected income changes (which primarily affect savings) than to changes perceived as permanent.

Wealth also plays a significant role. Increases in household net worth (from rising stock prices or housing values) tend to boost consumption – the "wealth effect".[120] Empirical estimates of the marginal propensity to consume out of wealth vary, but often suggest that a $1 increase in wealth leads to an increase in annual consumption of roughly **3 to 9 cents**.[120] Some evidence suggests the effect might be stronger for housing wealth than for financial wealth.[121] Consumer confidence, reflecting households' optimism about the future, is also believed to influence spending decisions.[121]

Equation (Refined): Incorporating disposable income, wealth, and confidence:

$$C_t = A + MPC \times (GDP_t \times (1 - TaxRate_t) + Transfers_t) + \gamma_W \times Wealth_t + \gamma_{Conf} \times Confidence_t + \epsilon_{C,t}$$

Where:

- C_t is aggregate real consumption expenditure.
- A is autonomous consumption (a constant).
- MPC is the marginal propensity to consume out of disposable income.
- $(GDP_t \times (1 - TaxRate_t) + Transfers_t)$ represents aggregate real disposable income. $TaxRate_t$ is the average net tax rate (Taxes minus Transfers as a share of GDP). Explicit modeling of Taxes and Transfers based on policy variables is preferable if possible.
- $Wealth_t$ is a measure of real household net worth.
- $Confidence_t$ is an index of consumer confidence (potentially linked to the Trust variable from Section 6 or other economic indicators like unemployment).
- γ_W is the marginal propensity to consume out of wealth.
- γ_{Conf} is the sensitivity of consumption to confidence.
- $\epsilon_{C,t}$ represents other consumption shocks.

Parameters:

- MPC: A value between **0.5 and 0.7** is empirically supported for the aggregate long-run MPC.[114] A mid-range value like **0.65** is a reasonable starting point.
- A: Calibrated to match a target steady-state consumption-to-GDP ratio, given the chosen MPC and steady-state values of other variables.

- γW: Based on empirical estimates [120], a value in the range **0.03 to 0.09** is appropriate. Start with **0.05**.
- $\gamma Conf$: Needs calibration. Should be positive, but the magnitude depends on the scaling of the $Confidence_t$ variable.

Consumption Smoothing vs. Current Income: The refined equation above primarily links consumption to current disposable income (Keynesian element) but incorporates wealth and confidence, which implicitly capture some forward-looking aspects and accumulated savings consistent with PIH/LCH principles.[115] A pure PIH/LCH model would make consumption a function of expected lifetime wealth/income. While more theoretically rigorous, this is significantly more complex to implement. The current formulation provides a practical compromise. However, the underlying theory suggests that the *response* of consumption to income shocks should depend on whether the shock is perceived as temporary or permanent. Temporary shocks (like a one-year tariff rebate) should ideally have a smaller impact on consumption (lower effective MPC) than permanent changes (like a long-lasting change in growth prospects). This state-dependency could be added for greater realism, perhaps by adjusting the MPC based on the persistence of income shocks or by using the $Confidence_t$ term to capture shifts in expectations about permanent income.

4.2. Investment Function (I)

Concept: Aggregate investment (I) represents spending by firms on new capital goods (machinery, equipment, buildings, software). It is a volatile component of GDP and a key driver of business cycles and long-run growth. Investment decisions depend on firms' expectations about future profitability, weighed against the cost of acquiring and financing capital. Key theoretical drivers include the real interest rate (as a component of the user cost of capital), the expected growth rate of demand or output (the accelerator effect), and the market valuation of existing capital relative to its replacement cost (Tobin's Q).

Evidence:

- **Interest Rates:** Theory predicts a negative relationship between investment and the real interest rate (or the broader user cost of capital), as higher rates increase financing costs and the opportunity cost of investing.[108] However, empirically identifying a stable and significant interest rate sensitivity ($i1$) has proven difficult, partly due to simultaneity issues (e.g., strong growth expectations might drive both investment and interest rates up).[108] Some studies suggest that the aggregate sensitivity of investment to interest rates may have declined in recent decades.[108]

- **Accelerator Effect:** Investment is strongly correlated with changes in output or sales (ΔY). When demand increases and firms expect the increase to persist, they invest to expand capacity.[99] This relationship, where changes in output induce larger percentage changes in investment, is known as the accelerator effect. The strength of the accelerator ($i2$) depends on factors like the capital-output ratio and how quickly firms adjust capital stock.[100]
- **Tobin's Q:** This theory posits that investment is positively related to the ratio of a firm's market value to the replacement cost of its capital stock (Q).[101] A Q ratio greater than 1 indicates that the market values installed capital more highly than its replacement cost, creating an incentive for firms to invest in new capital. Empirical studies have found support for Q theory, including in housing investment.[101]
- **Financial Frictions:** Access to finance and the health of firm balance sheets can also significantly impact investment, especially for smaller or credit-constrained firms. Deteriorating financial conditions can amplify downturns by restricting investment (the financial accelerator effect).[106]

Equation (Refined, incorporating Accelerator and Q):

$I_t = \max(0, I_{base} - i1 \times (real\_interest\_rate_t) + i2 \times \Delta Y_t + i3 \times (Q_t - 1)) + \epsilon_{I,t}$

Where:

- I_t is aggregate real investment.
- I_{base} is autonomous investment (investment occurring regardless of the other factors).
- $real\_interest\_rate_t$ is the relevant real interest rate influencing investment decisions (e.g., long-term corporate borrowing rate adjusted for expected inflation, potentially proxied by $policyRate - E_t[\pi_{t+1}]$ plus a risk premium).
- ΔY_t is the growth rate of real GDP (or expected future growth).
- Q_t is Tobin's Q (aggregate market value of capital divided by its replacement cost). If difficult to compute, it could be proxied by stock market indices relative to capital goods prices or omitted initially. The term $(Q_t - 1)$ reflects the incentive to invest when Q > 1.
- $i1$ (positive) captures the sensitivity to the real interest rate.
- $i2$ (positive) captures the strength of the accelerator effect.
- $i3$ (positive) captures the sensitivity to Tobin's Q.
- $\epsilon_{I,t}$ represents exogenous investment shocks (e.g., changes in business confidence or "animal spirits").

Parameters:

- i1 (Interest Rate Sensitivity): Highly uncertain empirically.[108] Requires careful calibration to ensure monetary policy has a plausible impact on investment in the simulation. Given potential decline in sensitivity, start with a moderate positive value.
- i2 (Accelerator Coefficient): Depends on the economy's aggregate capital-output ratio and adjustment speed.[100] Needs calibration. A value between **0.5 and 1.5** might be a reasonable starting range for aggregate investment response to GDP growth.
- i3 (Tobin's Q Sensitivity): Also requires calibration. Should be positive.
- Ibase: Calibrated based on steady-state I/Y ratio and other parameters.

Declining Interest Rate Sensitivity?: The possibility that investment has become less sensitive to monetary policy changes (i.e., lower i1) is an important consideration for calibration.[108] If this is the case, it implies that other factors, such as growth expectations (accelerator, i2), technological opportunities, or financial conditions (potentially captured in ϵI,t or through Qt), may play a relatively larger role in driving investment fluctuations in the simulated modern economy. Calibrating i1 to a relatively modest value might be more consistent with recent economic behavior than relying on older estimates suggesting strong interest rate effects.

Table 4: Consumption and Investment Function Parameters

Parameter Symbol	Description	Equation Ref.	Value/Range	Source Snippet(s)
A	Autonomous Consumption	Sec 4.1	Calibration Req.	[111]
MPC	Marginal Propensity to Consume	Sec 4.1	0.5 - 0.7	[114]
γW	Wealth Effect Sensitivity (C per $ Wealth)	Sec 4.1	0.03 - 0.09	[120]
γConf	Consumption Sensitivity to	Sec 4.1	Positive (Calib.)	[121] (Conceptual)

	Confidence			
Ibase	Autonomous Investment	Sec 4.2	Calibration Req.	
i1	Investment Sensitivity to Real Interest Rate	Sec 4.2	Positive (Calib.)	[108]
i2	Accelerator Coefficient (Investment/ΔY)	Sec 4.2	0.5 - 1.5 (Calib.)	[99]
i3	Investment Sensitivity to Tobin's Q	Sec 4.2	Positive (Calib.)	[101]

Note: Calib. = Requires Calibration based on simulation behavior and target steady states.

Section 5: Fiscal Policy and Government Debt

Objective: To incorporate the government sector into the model, allowing for fiscal policy actions (changes in government spending G and taxes T) and tracking the evolution of public debt, including the potential macroeconomic consequences of high debt levels.

5.1. Government Spending (G) and Taxes (T)

Concept: Government spending on goods and services (G) is a direct component of aggregate demand (Y=C+I+G+NX). Taxation (T) affects the economy primarily by reducing household disposable income (influencing C) and corporate profits (potentially influencing I), while providing revenue to the government. Both G and T are key instruments of fiscal policy, controllable by the player or AI.

Implementation:

- **Government Spending (G):** Model G as an exogenous policy variable, directly controllable within the simulation. It represents government purchases of goods and services. (Note: Government transfer payments, like unemployment benefits or pensions, are typically netted against taxes to calculate disposable income, rather than included in G).

- **Net Taxes (**Tnet**):** Model net taxes (taxes minus transfer payments) as a function of aggregate income (GDP). A simple formulation is: $T_{net,t} = T_{autonomous} + TaxRate \times Y_t$ Where $T_{autonomous}$ represents lump-sum taxes/transfers, and TaxRate is the marginal net tax rate. For simplicity, $T_{autonomous}$ can be set to zero, making net taxes proportional to GDP: $T_{net,t} = TaxRate \times Y_t$ The TaxRate itself can be treated as a policy variable, allowing for changes in tax policy within the simulation. This formulation directly feeds into the disposable income calculation used in the consumption function (Section 4.1).

5.2. Government Budget Balance

Concept: The government's budget balance reflects the difference between its revenues and expenditures in a given period. It is typically decomposed into the primary balance and interest payments on existing debt.

Equation:

- **Primary Balance:** The difference between net tax revenue and non-interest government spending (G). $PrimaryBalance_t = T_{net,t} - G_t$
- **Overall Balance (Deficit/Surplus):** The primary balance minus interest payments on the outstanding government debt from the previous period. A negative overall balance represents a budget deficit. $OverallBalance_t = PrimaryBalance_t - (i_{debt,t} \times Debt_{t-1})$ Where $i_{debt,t}$ is the average nominal interest rate paid on the government debt stock ($Debt_{t-1}$) outstanding at the end of period $t-1$.

5.3. Public Debt Dynamics

Concept: The stock of government debt changes over time based on the flow of budget deficits or surpluses. The evolution of the debt-to-GDP ratio, a key indicator of fiscal sustainability, depends critically on the overall balance and the relationship between the interest rate paid on debt and the nominal growth rate of the economy.

Evidence: The standard equation governing debt dynamics is a fundamental accounting identity used in fiscal analysis by institutions like the IMF.[127] The "snowball effect" refers to the impact of the interest rate-growth differential ($i-g$ or, in real terms, $r-g$) on the debt ratio.[127] If the average interest rate paid on debt (i) exceeds the nominal GDP growth rate ($g_{nominal}$), the debt-to-GDP ratio will tend to rise even with a balanced primary budget. Conversely, if $i < g_{nominal}$ (or $r < g_{real}$), the debt ratio can decline even with modest primary deficits.[127]

Equation (Debt Level): The change in the nominal debt stock equals the overall budget deficit:

$Debt_t = Debt_{t-1} - OverallBalance_t$
$Debt_t = Debt_{t-1} + (G_t - T_{net,t}) + (i_{debt,t} \times Debt_{t-1})$

Equation (Debt-to-GDP Ratio, $d_t = Debt_t / GDP_t$**):** The change in the debt-to-GDP ratio can be approximated by:

$$\Delta d_t \approx (r_t - g_t) \times d_{t-1} - pb_t + sfa_t$$

Where:

- d_t is the debt-to-GDP ratio at the end of period t.
- r_t is the average real interest rate on government debt (approximated as $i_{debt,t} - \pi_t$).
- g_t is the real GDP growth rate ($\Delta Y_t / Y_{t-1}$).
- pb_t is the primary balance as a share of GDP ($PrimaryBalance_t / GDP_t$).
- sfa_t represents stock-flow adjustments (e.g., valuation changes, privatization receipts), which capture differences between the deficit and the change in debt not explained by the flow variables. These are often ignored in simpler models but can be empirically relevant.[130]

Parameters:

- Average interest rate on debt (i_{debt} or r): This should be linked to market interest rates (e.g., government bond yields, influenced by policyRate and risk premia) but typically adjusts more slowly than policy rates, reflecting the average rate across outstanding debt of varying maturities.
- Potential GDP growth (g^*): Influences the long-run trajectory.
- Primary balance (pb): Determined by policy choices for G and T_{net}.

5.4. Impacts of High Debt

Concept: Persistently high levels of public debt relative to GDP can pose significant risks to macroeconomic stability and long-term growth. These risks include potential negative impacts on growth, upward pressure on interest rates, increased vulnerability to shocks, and constraints on future policy flexibility. An alternative perspective, Ricardian Equivalence, suggests that the method of financing government spending (taxes vs. debt) may be neutral under certain assumptions.

Evidence:

- **Growth Effects:** Numerous empirical studies find a negative correlation between high public debt-to-GDP ratios and subsequent economic growth, particularly

above certain thresholds.[131] Threshold estimates vary but are often placed around **85-100% of GDP** for advanced economies.[132] Potential channels for this negative impact include crowding out of private investment as government borrowing absorbs available savings, higher long-term interest rates, increased uncertainty, and the anticipation of future distortionary taxes needed to service the debt.[132]
- **Interest Rates and Risk Premia:** High debt levels can increase the perceived riskiness of government bonds, leading investors to demand a higher risk premium. This raises government borrowing costs (idebt) and potentially spills over to other interest rates in the economy.[127] The CBO, for instance, assumes each percentage point increase in the debt-to-GDP ratio adds about 2 basis points to 10-year Treasury yields.[134] High debt also increases vulnerability to shifts in market sentiment or global financial conditions.[130]
- **Policy Constraints:** High debt reduces "fiscal space," limiting the government's ability to respond effectively to future economic downturns or crises with counter-cyclical fiscal stimulus.[130] It can also lead to concerns about "fiscal dominance," where the central bank feels pressured to keep interest rates low to ease the government's debt burden, potentially compromising its inflation control objectives.[131]
- **Ricardian Equivalence:** This theory posits that rational, forward-looking individuals understand that government borrowing today implies higher taxes tomorrow.[135] Therefore, if the government cuts taxes and finances spending with debt, households will save the tax cut to pay the future taxes, neutralizing the impact on aggregate demand. While theoretically elegant, the strong assumptions required (perfect foresight, perfect capital markets, intergenerational altruism, no liquidity constraints) are often violated in reality.[136] Empirical evidence suggests only a partial Ricardian offset; for example, studies indicate private saving might increase by about 30 cents for every dollar of increased government borrowing, implying that deficit-financed fiscal policy still has a significant impact on demand.[137]

Implementation: To capture the potential negative consequences of high debt:

1. **Interest Rate Risk Premium:** Add a component to the determination of government borrowing costs (idebt) or potentially broader market interest rates that increases as the debt-to-GDP ratio (dt) rises above a specified threshold (dthreshold, e.g., 90%). RiskPremiumt=max(0,kdebt×(dt−dthreshold)) idebt,t=BaseRatet+RiskPremiumt where kdebt is a sensitivity parameter.
2. **Growth Impact (Optional):** Introduce a small negative effect on potential GDP growth (g∗) or productivity growth when the debt ratio is persistently very high.
3. **Ricardian Offset (Optional):** Implement a partial Ricardian effect by making the

household saving rate (or 1–MPC) slightly increasing in the debt-to-GDP ratio or the budget deficit. This dampens the demand impact of fiscal policy changes.

Partial Ricardian Equivalence: The empirical finding that Ricardian Equivalence holds only partially [136] is important. It means that fiscal policy actions like tax cuts or spending increases financed by borrowing *should* affect aggregate demand in the simulation, but perhaps less powerfully than in a simple model that completely ignores the government's budget constraint and households' potential reactions to future tax liabilities. Implementing a mechanism where the MPC slightly decreases (or saving increases) as government debt rises provides one way to model this dampened effect without assuming full neutrality. Assuming zero Ricardian offset is likely more realistic for short-to-medium term simulation dynamics than assuming full offset.

Table 5: Fiscal Parameters and Thresholds

Parameter Symbol	Description	Equation Ref.	Value/Range	Source Snippet(s)
TaxRate	Average Net Tax Rate (% of GDP)	Sec 5.1	Policy Variable/Calib.	
dthreshold	Debt/GDP Threshold for Risk Premium	Sec 5.4	~90% (AEs)	[132]
kdebt	Sensitivity of Risk Premium to Debt Ratio	Sec 5.4	Positive (Calib.)	[130]
Ricardian Offset Param.	Parameter linking Saving/MPC to Debt/Deficit	Sec 5.4	Small (Calib.)	[137] (Partial offset)

Note: AE = Advanced Economy. Calib. = Requires Calibration.

Section 6: Political Economy and Trust Dynamics

Objective: To introduce a mechanism for modeling citizen trust (or political capital) as an endogenous variable within the simulation, influenced by economic performance and policy choices, and potentially feeding back into political stability or policy effectiveness.

6.1. Modeling Citizen Trust / Political Capital

Concept: Citizen trust in government and political institutions is a crucial element of social capital and effective governance. It is not static but evolves based on citizens' evaluations of government performance and actions. Key drivers include macroeconomic outcomes (unemployment, inflation, growth), perceptions of fairness and inequality, and the impact of specific government policies. High levels of trust can facilitate policy implementation and compliance, enhancing overall state capacity.

Evidence: Research supports the view that political trust is evaluative, meaning citizens assess government performance and base their trust levels on these assessments.[140] Macroeconomic performance is consistently identified as a critical factor.[140] Poor economic outcomes, such as high unemployment, high inflation, or low/negative growth, tend to erode public trust and government approval ratings.[72] Subjective perceptions of the economy can be as, or even more, important than objective indicators.[140] Beyond aggregate performance, factors like economic insecurity, income inequality, and perceptions of corruption can also significantly influence trust levels.[140] Specific policies, especially those with salient negative impacts on consumers (like broad, high tariffs leading to price increases [144]), can also affect trust. Conversely, high trust acts as a valuable asset, enhancing the government's ability to implement policies effectively, particularly those requiring voluntary compliance.[155] Agent-based modeling (ABM) provides a framework for simulating the complex dynamics of trust formation and its feedback effects on social and political outcomes.[155] Political stability itself is interconnected with economic performance and institutional quality.[152]

Equation (Illustrative Dynamic Model): A simple dynamic equation can capture the evolution of trust based on key economic indicators and policy impacts:

$$\Delta Trust_t = \tau_0 - \tau_u \times (\max(0, u_t - u_{target})) - \tau_\pi \times (\max(0, |\pi_t - \pi_{target}|)) + \tau_g \times (g_{y,t} - g_{target}) - \tau_{policy} \times (PolicyImpact_t) - \tau_{decay} \times Trust_{t-1} + \epsilon_{trust,t}$$

Where:

- $Trust_t$ is an index representing the level of citizen trust or political capital at time t.
- $\Delta Trust_t = Trust_t - Trust_{t-1}$.
- τ_0 is a constant baseline change or drift term.
- $u_t, \pi_t, g_{y,t}$ are the current unemployment rate, inflation rate, and real GDP growth rate.

- $u_{target}, \pi_{target}, g_{target}$ are socially acceptable or target levels for these variables (e.g., natural rate of unemployment, inflation target, potential growth rate). The max(0,...) terms imply trust primarily reacts to deviations in the "wrong" direction (unemployment/inflation too high).
- $PolicyImpact_t$ represents the perceived negative impact of current policies, such as high tariffs. This could be proxied by the average tariff level, the estimated consumer welfare loss from tariffs, or the negative impact of unpopular fiscal consolidation measures.
- $\tau_u, \tau_\pi, \tau_g, \tau_{policy}$ are positive sensitivity parameters determining how strongly trust reacts to each factor.
- τ_{decay} represents a natural tendency for trust to decay or revert to a mean level over time if not sustained by positive performance.
- $\epsilon_{trust,t}$ captures other unmodeled factors influencing trust (e.g., political events, scandals, social trends).

Parameters (τ coefficients): Estimating these parameters empirically is challenging and highly context-dependent. They require careful **calibration** within the simulation to achieve plausible dynamics and desired gameplay effects. The relative magnitudes should reflect established findings: unemployment and inflation often have particularly strong negative impacts on government approval/trust.[72] The impact of growth (τ_g) should be positive. The impact of tariffs (τ_{policy}) should be negative if they are perceived as harming consumers.

6.2. Linking Trust to Game Outcomes

Concept: The level of citizen trust or political capital should have tangible consequences within the simulation, influencing political outcomes, policy feasibility, and potentially the effectiveness of government actions.

Evidence: Low levels of public trust can undermine government legitimacy, making it harder to govern and potentially leading to political instability.[141] Conversely, high trust enhances state capacity by increasing voluntary compliance with laws and policies.[155] Economic performance is a key driver of government popularity and election outcomes.[145] Political instability, in turn, is detrimental to economic growth, creating a potential feedback loop.[152]

Implementation Ideas:

- **Elections/Approval:** The $Trust_t$ level can directly influence the probability of the incumbent government (player or AI) winning an election or maintaining a certain approval rating threshold.

- **Policy Constraints:** Implementing policies perceived as highly unpopular (e.g., imposing very high tariffs across many sectors, enacting severe austerity measures) could require a minimum level of Trustt to be feasible, or attempting such policies could trigger a substantial immediate drop in Trustt.
- **Political Stability Module:** Low or rapidly falling Trustt could increase the probability of triggering negative "political instability" events within the simulation. These events could manifest as temporary shocks that reduce productivity, increase risk premia on interest rates, or disrupt trade flows, reflecting real-world consequences of instability.[152] The likelihood or severity of these events could be scaled based on the Trustt level relative to historical norms or critical thresholds, potentially informed by indices of political stability.[153]
- **Policy Effectiveness Feedback:** The effectiveness of certain government actions could be subtly influenced by the Trustt level. For example, the effective tax revenue collected might be slightly lower than implied by the official TaxRate when trust is very low (reflecting lower compliance). Similarly, the multiplier effect of government spending (G) could be slightly enhanced when trust is high (reflecting greater public buy-in or smoother implementation).

Trust as Endogenous State Capacity: A key takeaway from the literature is that trust is not merely a passive outcome of economic performance but an active ingredient in state capacity.[155] When citizens trust their government, they are more likely to cooperate and comply voluntarily with its policies. This reduces the need for costly enforcement and makes policies more effective. For example, tax compliance is likely higher, adherence to regulations smoother, and public response to initiatives more positive when trust is high. This creates a potential feedback loop: good economic performance builds trust, which enhances state capacity, potentially enabling policies that further support good performance. Conversely, poor performance erodes trust, weakening state capacity and making it harder to implement corrective policies, potentially locking in poor outcomes. Modeling this feedback, even in a simplified way (e.g., linking tax efficiency or the government spending multiplier to the Trust index), can add significant depth and realism to the simulation's political economy dynamics.

Table 6: Trust Dynamics Parameters (Illustrative)

Parameter Symbol	Description	Equation Ref.	Value/Range	Source Snippet(s) (Conceptual Links)

τ_u	Trust Sensitivity to Unemployment Gap	Sec 6.1	Positive (Calib.)	72
τ_π	Trust Sensitivity to Inflation Deviation	Sec 6.1	Positive (Calib.)	72
τ_g	Trust Sensitivity to Growth Deviation	Sec 6.1	Positive (Calib.)	146
τ_{policy}	Trust Sensitivity to Negative Policy Impact	Sec 6.1	Positive (Calib.)	144
τ_{decay}	Trust Decay/Mean Reversion Rate	Sec 6.1	Positive (Calib.)	

Note: Calib. = Requires Calibration. Parameters determine the responsiveness of citizen trust to economic and policy outcomes.

Section 7: Parameter Summary and Implementation Guidance

Objective: To provide a consolidated overview of the key equations and parameters discussed throughout the report, offer guidance on calibration and data sources, and highlight important considerations for implementation.

7.1. Consolidated Equation Summary

This section would ideally list the final forms of the core equations decided upon for implementation, drawing from Sections 1 through 6. For brevity here, refer back to the equations presented within each relevant section:

- Import Price ($P_{import,s,j}$): Section 1.1
- Domestic Price Level (P_d): Section 1.2
- Foreign Price Level ($P_{f,i}$): Section 1.3
- Exchange Rate ($\Delta Valutakurs_t$): Section 1.4
- Imports / Exports ($Imports_s$, $Exports_s$): Section 1.5 / 3.1
- Unemployment (Δu_t or $u_t - u_t*$): Section 2.1
- Inflation (π_t): Section 2.2

- Sectoral Output / Employment (ΔYs, ΔLs): Section 3.2
- Aggregate GDP / Unemployment (Y, u): Section 3.3
- Sectoral Capital / Investment (Ks,t+1, Is): Section 3.4
- Consumption (Ct): Section 4.1
- Investment (It): Section 4.2
- Budget Balances / Debt (dt): Sections 5.2, 5.3
- Citizen Trust (ΔTrustt): Section 6.1

7.2. Consolidated Parameter Table

The following table consolidates the key parameters identified, providing a central reference for implementation. Values are indicative starting points, primarily for advanced economies, and require calibration.

Table 7: Master Parameter List

Parameter	Description	Section	Value/Range	Key Source Snippets
Trade & Prices				
ϕ	Tariff Pass-through (Border, Med-Term)	1.1	≈1	1
wd	Weight of Domestic Goods in Pd	1.2	Calibration Req.	13
k1	Exch. Rate Sensitivity to Interest Diff.	1.4	Small Pos (Calib.)	48
k2	Exch. Rate Sensitivity to ΔNX/GDP	1.4	Positive (Calib.)	50
ϵM,Y	Income Elasticity of Imports	1.5	1.0 - 2.5	54

ϵX,Y	Income Elasticity of Exports	1.5	1.0 - 2.5	54
ϵM,P	Price Elasticity of Imports (Agg. LR)	1.5	-0.8 to -2.0	6
ϵX,P	Price Elasticity of Exports (Agg. LR)	1.5	-1.0 to -2.0	58
Output, Unemp, Infl.				
β	Okun Coeff. (Difference Ver.)	2.1	0.3 - 0.5	64
α	Phillips Curve Expectation Weight (α=1 Fwd)	2.2	0.0 - 1.0 (Calib.)	73
ϕ	Phillips Curve Slope (Output Gap)	2.2	0.1 - 0.3 (Calib.)	74
γ	Import Price Pass-through to Dom. Inflation	2.2	0.05 - 0.15 (Calib.)	10
Sectoral				
es / ηs	Sectoral Labor Coeff. / Output Elast. of Emp.	3.2	Calibration Req.	88
δs	Sectoral Depreciation Rate	3.4	Calibration Req.	
Agg. Demand				

A	Autonomous Consumption	4.1	Calibration Req.	111
MPC	Marginal Propensity to Consume	4.1	0.5 - 0.7	114
γW	Wealth Effect Sensitivity	4.1	0.03 - 0.09	120
γConf	Consumption Sensitivity to Confidence	4.1	Positive (Calib.)	121
Ibase	Autonomous Investment	4.2	Calibration Req.	
i1	Investment Sensitivity to Real Interest Rate	4.2	Positive (Calib.)	108
i2	Accelerator Coefficient	4.2	0.5 - 1.5 (Calib.)	99
i3	Investment Sensitivity to Tobin's Q	4.2	Positive (Calib.)	101
Fiscal & Debt				
TaxRate	Average Net Tax Rate	5.1	Policy Var./Calib.	
dthreshold	Debt/GDP Threshold for Risk Premium	5.4	~90% (AEs)	132
kdebt	Sensitivity of Risk Premium to Debt Ratio	5.4	Positive (Calib.)	130

Trust				
$\tau u,\tau\pi,\tau g,\ldots$	Trust Sensitivity Parameters	6.1	Calibration Req.	[72]

7.3. Data Sources and Calibration

While this report provides empirically grounded parameter ranges based on the supplied research, implementing a complex simulation necessitates further calibration. Real-world data sources can inform this process:

- **Macroeconomic Aggregates:** IMF World Economic Outlook (WEO), World Bank World Development Indicators (WDI), OECD Statistics provide data on GDP, inflation, unemployment, trade balances, government debt, interest rates, etc., for many countries.
- **Sectoral Data:** National statistical agencies often publish Input-Output tables (e.g., US Bureau of Economic Analysis (BEA) [28]), which are invaluable for parameterizing sectoral linkages, value added, and potentially labor coefficients. OECD STAN database also contains sectoral data.
- **Trade Data:** UN Comtrade, WITS (World Bank), and national sources provide detailed bilateral trade data. Tariff data can be found via WTO, TRAINS (UNCTAD), and national customs agencies.
- **Elasticities & Coefficients:** Academic literature and empirical studies specific to the countries/regions being simulated are the best source, though values often vary.

Calibration Process: Calibration involves adjusting parameters iteratively to ensure the simulation produces plausible behavior:

1. **Steady State:** Ensure the model converges to a reasonable long-run equilibrium consistent with baseline economic ratios (e.g., C/GDP, I/GDP, Debt/GDP).
2. **Dynamic Response:** Test the model's response to standard shocks (e.g., monetary policy shock, demand shock, tariff shock). Do key variables (output, inflation, unemployment, exchange rate) move in the expected direction and with plausible magnitudes and persistence? Compare impulse responses to empirical VAR studies or established macro models where possible.
3. **Gameplay Balance:** Adjust parameters to ensure the simulation is challenging but manageable, and that policy levers have meaningful effects without being overly sensitive or ineffective.

7.4. Implementation Notes

- **Simultaneity and Iteration:** Many variables are interdependent within a single time step (e.g., prices, exchange rates, trade flows across multiple countries). The simulation's solution algorithm must handle this, either through simultaneous equation solving or iterative convergence within each step. Failure to do so (e.g., calculating all of country A's variables before country B's) can lead to inaccurate dynamics.
- **Dynamic Adjustment:** Avoid modeling instantaneous adjustments where theory or evidence suggests gradual responses. Key areas for dynamic modeling include:
  - Trade flow response to price/tariff changes (Section 1.5).
  - Pass-through of border price changes to retail prices (Section 1.1).
  - Capital stock adjustment (investment takes time to build capacity) (Section 3.4).
  - Gradual adjustment of expectations (if not using fully rational expectations).
- **Stochastic Shocks:** The ϵ terms in the equations represent exogenous shocks. Implementing these stochastic elements (drawing from appropriate distributions) is essential for generating realistic variability and creating unpredictable scenarios for the player. The relative size (variance) of different shocks (e.g., demand vs. supply vs. financial) influences the simulated business cycles.
- **Simplifications and Extensions:** This report outlines a complex but still simplified representation of reality. Functional forms are generally linear or log-linear. Non-linearities (e.g., state-dependent Phillips curve slope, asymmetric Okun's Law) could be added for greater realism. Modeling expectations formation more explicitly (beyond simple adaptive or lagged values) is another area for potential extension. The level of sectoral disaggregation is also a key choice affecting complexity and data requirements.

Conclusion

This report has outlined a framework for implementing a significantly enhanced macroeconomic engine for a trade war simulation game. By incorporating evidence-based mechanisms for tariff pass-through, dynamic exchange rates, sectoral linkages, refined aggregate demand functions, public debt dynamics, and endogenous citizen trust, the simulation can achieve greater realism and depth.

The core enhancements focus on:

1. Explicitly modeling the **impact of tariffs on import prices** (with near-complete border pass-through) and the subsequent effects on domestic prices and inflation, distinguishing this from exchange rate pass-through.
2. Introducing **dynamic foreign prices and exchange rates** to capture crucial

global interdependencies and feedback loops.
3. Implementing empirically grounded relationships for **unemployment (Okun's Law)** and **inflation (Augmented Phillips Curve)**, including the vital channel of import price shocks.
4. Establishing **sectoral linkages** to show how trade policies affect specific industries' output and employment, aggregating to influence macroeconomic outcomes.
5. Refining **consumption and investment functions** to include determinants like disposable income, wealth, confidence, interest rates, and growth expectations (accelerator).
6. Modeling **public debt accumulation** and its potential consequences for interest rates and growth.
7. Introducing **citizen trust** as a dynamic variable responding to economic performance and policy, potentially influencing political stability and policy effectiveness.

The provided equations and parameter ranges, derived from the reviewed economic literature and empirical studies, serve as a robust starting point for implementation. However, the complexity of macroeconomic interactions necessitates careful calibration and testing. Fine-tuning parameters to match desired simulation behavior, ensuring stability, and achieving balanced gameplay will be crucial steps following the initial implementation based on this guide. The resulting model should provide a richer and more insightful platform for exploring the multifaceted consequences of trade policy and international economic conflict.

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