Contents

The Gravity Model of International Trade

> **Big Idea**: Bilateral trade between countries is proportional to their economic sizes (GDP) and inversely proportional to the distance between them - just like Newton's gravity law. This is one of the most robust empirical regularities in economics, explaining 60+ years of trade data.

Core Principles

Foundation

- **Empirical Workhorse**: Most successful empirical model in international economics (Leamer & Levinsohn, 1995)
- **Robust Prediction**: Explains 60-80% of variation in bilateral trade flows
- **Theoretical Grounding**: Multiple theoretical foundations (Anderson, Eaton-Kortum, Chaney, Melitz)
- **Policy Applications**: Used by WTO, World Bank, central banks for trade policy analysis
- **Universal Applicability**: Works across time periods, country pairs, and product categories

Historical Development

- **Tinbergen (1962)**: First application of gravity to trade
- **Pöyhönen (1963)**: Independent development of gravity framework
- **Anderson (1979)**: First theoretical microfoundation
- **Bergstrand (1985-1989)**: Monopolistic competition foundation
- **Eaton & Kortum (2002)**: Ricardian foundations with technology differences
- **Anderson & van Wincoop (2003)**: Structural gravity with multilateral resistance
- **Chaney (2008)**: Extensive margin and firm heterogeneity
- **Helfrich & Gonchar (2025)**: Time-varying distance with nightlights and population

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The Basic Gravity Equation

Intuitive Form

The simplest gravity equation:

X_{ij} = G · (Y_i · Y_j) / D_{ij}^

Where: - X_{ij} = exports from country i to country j - Y_i = GDP of exporting country i - Y_j = GDP of importing country j - D_{ij} = distance between i and j - = distance elasticity (typically 0.9 to 1.5) - G = gravitational constant (captures world trade openness)

Analogy to Physics: Newton's gravity: F = G(M M)/D² Trade gravity: X = G(Y Y)/D

Log-Linear Estimation Form

Taking logs yields the standard estimating equation:

ln(X_{ij}) = + ln(Y_i) + ln(Y_j) + ln(D_{ij}) + _{ij}

Expected signs: - > 0 (larger exporter → more exports) - > 0 (larger importer → more imports) - < 0 (greater distance → less trade)

Augmented Gravity

Extended version includes additional variables:

ln(X_{ij}) = + ln(Y_i) + ln(Y_j) + ln(D_{ij}) + (Common Border) + (Common Language) + (Colonial Ties) + (FTA) + _{ij}

Trade facilitators (positive effects): - Common border - Common language - Colonial history - Free trade agreements (FTAs) - Common currency - Legal system similarity

Trade barriers (negative effects): - Distance - Tariffs - Non-tariff barriers - Regulatory differences - Cultural distance

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Theoretical Foundations

1. Anderson (1979): CES Preferences

First rigorous microfoundation using: - **Constant Elasticity of Substitution** (CES) preferences - **Armington assumption**: Products differentiated by country of origin - **Trade costs**: Iceberg costs (fraction of goods "melts" in transit)

Key result: Bilateral trade proportional to: - Exporter's GDP (supply) - Importer's GDP (demand) - Inverse of bilateral trade costs

2. Eaton & Kortum (2002): Ricardian Model

Technology-based foundation: - **Technology differences** across countries (Ricardian) - **Fréchet distribution** of productivities - **Comparative advantage** emerges endogenously

Trade equation: X_{ij} / X_j = (T_i(c_i d_{ij})^{- }) / (Σ_k T_k(c_k d_{kj})^{- })

Where: - T_i = technology level of country i - c_i = input costs in country i - d_{ij} = bilateral trade costs -   = trade elasticity parameter

3. Anderson & van Wincoop (2003): Multilateral Resistance

Major innovation: Bilateral trade depends not just on bilateral costs, but on: - **Outward multilateral resistance (OMR)**: Average trade barrier exporter faces - **Inward multilateral resistance (IMR)**: Average trade barrier importer faces

Structural gravity equation: X_{ij} = (Y_i Y_j / Y^W) · (t_{ij} / (Π_i P_j))^{1- }

Where: - Y^W = world GDP - t_{ij} = bilateral trade cost - Π_i = outward multilateral resistance of i - P_j = inward multilateral resistance of j -   = elasticity of substitution

Key insight: "Border puzzle" resolved - trade within countries is much larger than between countries because of multilateral resistance, not just bilateral barriers.

Multilateral resistance terms: Π_i^{1- } = Σ_j (_j / P_j^{1- }) t_{ij}^{1- } P_j^{1- } = Σ_i (_i / Π_i^{1- }) t_{ij}^{1- }

Where _i, _j are GDP shares.

4. Chaney (2008): Extensive Margin

Adds firm heterogeneity (à la Melitz 2003): - **Intensive margin**: How much each firm exports - **Extensive margin**: How many firms export - **Selection**: Only most productive firms export to distant markets

Result: Distance elasticity depends on: - Firm productivity distribution - Fixed costs of exporting - Variable trade costs

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Measuring Distance: From Simple to Sophisticated

Traditional Distance Measures

1. **Great Circle Distance**
   - Shortest path on Earth's surface between capitals or centroids
   - Formula: d = r · arccos(sin   sin   + cos   cos   cos(-))
   - Simple but assumes all economic activity at single point
2. **Capital-to-Capital Distance**
   - Distance between national capitals
   - Easy to compute, widely used
   - **Problem**: Capitals may not represent economic centers (e.g., Australia: Canberra vs Sydney/Melbourne)
3. **Population-Weighted Distance**
   - Weights distances by population in multiple cities
   - d_{ij} = Σ_k Σ_l (pop_k/pop_i)(pop_l/pop_j) d_{kl}
   - Better captures spatial distribution of economic activity

Helfrich & Gonchar (2025): Nightlights Innovation

Novel Contribution: Time-varying distance measures using satellite data

Key Innovation: Traditional measures are **time-invariant** - assume economic geography is fixed. But economic activity shifts over time!

Their Approach: 1. **Nighttime lights data**: Satellite images showing light intensity - Proxy for economic activity (factories, cities, commercial areas) - Annual data from 1992-present - High spatial resolution (0.5-1 km grid)

2. **Population rasters**: Gridded population data
    - Annual updates of population distribution
    - Captures urbanization, migration, regional development
3. **Dynamic centroids**: Calculate weighted centers each year
    - Nightlights-weighted centroid: Center of economic production
    - Population-weighted centroid: Center of consumption/demand
    - Directional measures: Different centroids for exports vs imports

Formula: Centroid_i^t = (Σ_pixels weights_pixel^t · coordinates_pixel) / (Σ_pixels weights_pixel^t)

Where weights are nightlights intensity or population

Advantages: - **Captures structural transformation**: As countries develop, economic centers shift - **China example**: Coastal development → centroid moved east over time - **Time-varying**: Reflects actual changes in economic geography - **Directional**: Different origins for exports (production) vs imports (consumption) - **Improved predictions**: Better fit to actual trade data than static measures

Empirical Results (Helfrich & Gonchar 2025): - Nightlights-based distance improves gravity model R^2 by 3-5% - Particularly important for: - Large countries with dispersed economic activity - Developing countries with rapid urbanization - Long time series (captures structural change)

Estimation Methods

1. OLS with Logs

Traditional approach: ln(X_{ij}) = + ln(Y_i) + ln(Y_j) + ln(D_{ij}) + controls + _{ij}

Problems: - **Zero trade flows**: ln(0) undefined - drops many observations - **Heteroskedasticity**: Error variance related to trade volume - **Selection bias**: Zeros are not random - **Jensen's inequality**: E[ln X] ln E[X]

2. Poisson Pseudo-Maximum Likelihood (PPML)

Modern standard (Santos Silva & Tenreyro 2006):

Specification: X_{ij} = exp(ln(Y_i) + ln(Y_j) + ln(D_{ij}) + controls) · _{ij}

Advantages: - Handles zeros naturally - Consistent under heteroskedasticity - Preserves adding-up constraints - Unbiased estimates even with log-normal errors

Estimation: Maximize Poisson likelihood L = Σ_{ij} [X_{ij} · ln(_{ij}) - _{ij} - ln(X_{ij}!)]

Where _{ij} = E[X_{ij}] = exp('Z_{ij})

3. Structural Gravity with Fixed Effects

Anderson & van Wincoop implementation:

Specification: X_{ij} = exp(_i + _j + 'Z_{ij}) · _{ij}

Where: - _i = exporter fixed effect (captures Y_i/Π_i) - _j = importer fixed effect (captures Y_j/P_j) - Z_{ij} = bilateral variables (distance, FTA, etc.)

Key advantage: Fixed effects automatically control for multilateral resistance!

No need to compute Π_i and P_j explicitly - absorbed by FEs.

Empirical Regularities

Typical Parameter Estimates

From meta-analysis of 1000+ studies:

Variable	Typical Estimate	Range
ln(GDP_exporter)	+1.0	[0.8, 1.2]
ln(GDP_importer)	+1.0	[0.8, 1.2]
ln(Distance)	-1.0	[-0.7, -1.5]
Common border	+0.5	[0.2, 0.8]
Common language	+0.4	[0.2, 0.7]
Colonial ties	+0.9	[0.5, 1.5]
FTA	+0.4	[0.2, 1.0]
Common currency	+0.6	[0.3, 1.2]

Interpretation of log coefficients: - Distance -1.0: Doubling distance reduces trade by 50% - FTA +0.4: FTA increases trade by 49% (e^0.4 - 1 0.49)

The Distance Puzzle

Puzzle: Distance coefficient has not decreased over time despite: - Falling transport costs - Communication revolution - Trade liberalization

Explanations (Disdier & Head 2008): 1. **Composition shift**: More differentiated goods traded (higher distance sensitivity) 2. **Increased trade in intermediates**: Multiple border crossings multiply distance effects 3. **Quality upgrading**: Distant partners trade higher-quality goods (less price-sensitive) 4. **Time costs**: Time in transit increasingly important (perishable, JIT production)

Applications

1. Trade Policy Analysis

Question: What is the effect of a Free Trade Agreement (FTA)?

Method: Compare actual trade with counterfactual (no FTA)

Steps: 1. Estimate gravity equation with FTA dummy 2. Predicted trade with FTA: X_{ij}^FTA = exp('Z_{ij} + · FTA) 3. Predicted trade without FTA: X_{ij}^{No FTA} = exp('Z_{ij}) 4. **Trade creation**: X_{ij}^FTA - X_{ij}^{No FTA}

Example: NAFTA increased US-Mexico trade by ~50% (controlling for other factors)

2. Brexit Impact Assessment

Scenario: UK leaves EU single market

Gravity prediction: - EU-UK trade faces new barriers (tariffs, customs, regulations) - Barrier equivalent to distance increase or losing FTA benefit - Gravity coefficient on FTA 0.5 → trade falls by ~40%

Actual outcome (post-2021): UK-EU trade fell 20-25%, consistent with gravity predictions

3. Gains from Trade Liberalization

General Equilibrium (Arkolakis, Costinot, Rodríguez-Clare 2012):

Welfare gains from trade: ΔW/W = (_domestic)^{1/ }

Where: - _domestic = share of domestic spending on domestic goods - = trade elasticity (typically 4-8)

Gravity role: Estimate from distance coefficient!

Result: Countries with high trade share (low _domestic) gain most from openness

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Numerical Example: US-Mexico Trade

Data (2023): - Y_US = $27 trillion - Y_Mexico = $1.8 trillion - Distance (DC to Mexico City) = 1,887 km - Common border: Yes - FTA (USMCA): Yes - Common language: No

Gravity prediction:

ln(X_{US→MX}) = 10 + 1.0 · ln(27000) + 1.0 · ln(1800) - 1.0 · ln(1887) + 0.5 · (Border) + 0.4 · (FTA)

= 10 + 10.20 + 7.50 - 7.54 + 0.5 + 0.4 = 21.06

Predicted exports: X_{US→MX} = exp(21.06) = $1.44 billion (scaled)

Actual US exports to Mexico (2023): ~$320 billion

With proper scaling constant: Gravity explains observed magnitude

Counterfactual - No USMCA: ln(X) = 21.06 - 0.4 = 20.66 X = exp(20.66) = $1.06 billion (scaled)

Trade creation from USMCA: (1.44 - 1.06)/1.06 = 36% increase

Extensions and Modern Developments

1. Sectoral Gravity

Different sectors have different distance sensitivities: - **Agricultural products**: High distance elasticity (perishable) - **Manufactured goods**: Medium distance elasticity - **Services**: Mixed (tourism: high; digital: low)

2. Firm-Level Gravity

Incorporating Melitz (2003) heterogeneous firms: - **Extensive margin**: Number of exporting firms - **Intensive margin**: Exports per firm - **Selection**: Only productive firms export to distant markets

3. Global Value Chains

Trade in tasks, not just goods: - **Value-added trade**: Tracking domestic content in exports - **Forward/backward linkages**: Position in supply chains - **Distance effects amplified**: Multiple border crossings

4. Digital Trade and Services

New challenges: - **Zero distance for some services**: Software, consulting - **Regulatory distance**: Data localization, privacy laws - **Platform effects**: Amazon, Alibaba reduce trade costs

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Limitations and Criticisms

Theoretical Critiques

1. **Black box**: Multiple theories generate same gravity equation
2. **Structural parameters**: Hard to identify deep parameters (preferences, technology)
3. **General equilibrium**: Partial equilibrium nature misses feedback effects

Empirical Challenges

1. **Omitted variables**: Unobserved bilateral factors
2. **Reverse causality**: Trade affects GDP (simultaneity bias)
3. **Measurement error**: GDP, distance, trade data quality
4. **Missing data**: Informal trade, transfer pricing

Policy Limitations

1. **Extrapolation**: Predictions for large policy changes uncertain
2. **Dynamic effects**: Gravity is static; ignores investment, growth effects

3. **Heterogeneity**: Average effects may not apply to specific country pairs

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Gravity vs Other Trade Models

Feature	Gravity	Ricardian	HO	New Trade
Focus	Bilateral volumes	Comparative advantage	Factor endowments	Firm heterogeneity
Empirical success	Excellent	Moderate	Mixed	Good
Policy applications	Extensive	Limited	Moderate	Growing
Data requirements	Moderate	Low	High	Very high
Microfoundations	Multiple	Clear	Clear	Clear
Predictive power	High	Medium	Medium	High

Complementarity: Gravity predicts *volumes*; other models predict *composition*

Key Takeaways

1. **Empirical Workhorse**: Gravity explains 60-80% of bilateral trade variation
2. **Simple but Powerful**: GDP and distance are primary determinants
3. **Theoretical Grounding**: Multiple theories converge to gravity equation
4. **Policy Tool**: Essential for trade agreement analysis, Brexit assessments
5. **Evolving Measures**: Helfrich-Gonchar nightlights innovation improves accuracy
6. **Estimation Matters**: PPML with fixed effects is modern best practice
7. **Multilateral Resistance**: Bilateral trade depends on all trading partners
8. **Robust Over Time**: Distance effects persist despite falling transport costs

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Recent Innovation

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Surveys

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Problem-Solving Framework

Predicting Bilateral Trade

1. Collect data: Y_i, Y_j, D_{ij}, other bilateral variables
2. Choose specification: Basic or augmented gravity
3. Estimate using PPML with fixed effects
4. Interpret coefficients (elasticities)
5. Predict trade: X_{ij} = exp(’Z_{ij})

Evaluating Trade Policies

1. Estimate baseline gravity with policy dummy
2. Compute counterfactual (set policy = 0)
3. Calculate trade creation/diversion
4. Welfare analysis (if general equilibrium model)

Improving Predictions

1. Use time-varying distance (Helfrich-Gonchar approach)
2. Include sector-specific effects
3. Control for multilateral resistance (fixed effects)

4. Handle zeros properly (PPML)
5. Check for heterogeneity across country pairs

Last Updated: January 2026 **Status**: Comprehensive reference including latest research (Helfrich & Gonchar 2025)