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India's Unrealised Bilateral Trade Potential: Structural Gravity Estimation, Bilateral Trade Gap Analysis, and General Equilibrium Welfare Effects

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Abstract

Applied gravity analyses of bilateral trade potential for individual countries routinely restrict the sample to a single reporting economy and control only for common temporal shocks through year dummies, an approach that cannot separately identify importer-specific multilateral resistance and produces bilateral trade gap estimates inconsistent with the structural gravity model's theoretical foundations. This paper corrects that identification failure. A structural gravity model is estimated on the full CEPII bilateral panel of 229 exporting and 198 importing economies over 2000 to 2020, with exporter-time and importer-time fixed effects that jointly proxy for the outward and inward multilateral resistance terms in the Anderson and van Wincoop (2003) general equilibrium system, estimated by Poisson Pseudo Maximum Likelihood on 525,112 observations. India's bilateral structural gravity residuals are extracted from this correctly identified model to construct a Bilateral Trade Gap Index for each of 197 partner economies, and an original convergence-divergence framework classifies bilateral relationships by whether actual trade is closing on or diverging from the structural benchmark. General equilibrium trade policy counterfactuals are computed using the PPML fixed-effects method of Fally (2015). The paper establishes four results: the structural gravity coefficients are distance = −0.464, RTA = +0.628, and contiguity = +0.583, all significant at the 0.1% level; 104 of 197 bilateral partners exhibit systematic undertrading with a mean gap of 2.29 log points implying actual trade approximately 9.9 times below the structural benchmark; 33 bilateral relationships are diverging, including France (SC = 287), Belgium (SC = 250), Italy (SC = 178), the United Kingdom (SC = 137), and Brazil (SC = 177); and an India-EU FTA would generate USD 20.33 billion in additional annual exports (+51.1%) and a 4.75% real income welfare gain, while full RTA expansion to the panel mean would deliver a 30.43% welfare improvement.

Keywords: *structural gravity; bilateral trade gaps; multilateral resistance; PPML; GEPPML; convergence-divergence; India*

JEL Classification: F13, F14, C23, C51

1. Introduction

The gravity equation of international trade rests on a general equilibrium foundation established by Anderson (1979) and extended by Anderson and van Wincoop (2003): bilateral trade flows are proportional to exporter and importer economic mass and inversely related to bilateral trade costs, conditional on multilateral resistance terms that capture each economy's trade costs relative to all trading partners simultaneously. A gravity specification that omits multilateral resistance generates upward bias in bilateral trade cost coefficients, conflates country-specific price index variation with bilateral variables, and produces bilateral trade potential estimates that are inconsistent with the structural model's theoretical foundations (Baldwin and Taglioni, 2006; Head and Mayer, 2014; Yotov et al., 2016). Applied bilateral trade potential analyses for individual countries routinely commit precisely this specification error by restricting the sample to a single reporting economy and approximating multilateral resistance through year dummies alone. In a single-reporter dataset, importer-specific multilateral resistance cannot be separately identified, GDP suffers from reverse causality, and the resulting bilateral trade gap estimates reflect a combination of structural barriers and omitted variable bias in proportions that cannot be disentangled.

This paper corrects that identification failure for India's bilateral trade portfolio and extends the analysis to general equilibrium trade policy evaluation. A structural gravity model is estimated on the full bilateral CEPII panel of 229 exporters and 198 importers over 2000 to 2020, with exporter-time and importer-time fixed effects that jointly proxy for the outward multilateral resistance P_i and inward multilateral resistance Π_j in the Anderson and van

Wincoop (2003) system, following the identification strategy of Baldwin and Taglioni (2006) formalised by Fally (2015) as exactly consistent with the structural gravity general equilibrium solution. The model is estimated by PPML on 525,112 complete bilateral observations. India's bilateral structural gravity residuals are extracted from this correctly identified full-panel model and used to construct a Bilateral Trade Gap Index (BTGI_j) for each of 197 partner economies, a model-grounded measure of systematic under- or overtrading relative to the structural benchmark that, unlike SFGM-based efficiency scores, is derived from a specification that controls for multilateral resistance. An original convergence-divergence framework translates the level and rate of change of these bilateral gaps into a trade strategy typology. General equilibrium welfare effects of RTA policy counterfactuals are computed using the PPML fixed-effects approach of Anderson, Larch and Yotov (2018), which anchors the bilateral trade gap analysis to quantified welfare losses and identifies the RTA coverage gap as the most policy-addressable component of India's structural trade deficit.

This paper establishes four results. First, the correctly identified structural gravity coefficients are: distance elasticity = −0.464 ($p < 0.001$), RTA = +0.628 ($p < 0.001$), contiguity = +0.583 ($p < 0.001$), common language = +0.196 ($p < 0.001$), and colonial tie = +0.092 ($p < 0.001$). The RTA coefficient of +0.628 implies $\exp(0.628) - 1 = 87.4$ percent higher bilateral trade flows between preferential agreement partners, after controlling for all bilateral structural determinants and two-way fixed effects. Second, 104 of India's 197 bilateral partners exhibit systematic undertrading with a mean BTGI of 2.29 log points, implying actual trade is $\exp(2.29) \approx 9.9$ times below the structural gravity benchmark on average. Third, 33 bilateral relationships are diverging, meaning structural trade potential is growing faster than actual trade, including France (SC = 287), Belgium (SC = 250), Taiwan (SC = 245), Italy (SC = 178), Brazil (SC = 177), and the United Kingdom (SC = 137) among the most structurally underperforming relationships relative to gravity model predictions. Fourth, an India-EU FTA

would generate USD 20.33 billion in additional annual exports (+51.1% in general equilibrium) and a welfare gain of 4.75%; an India-UK FTA would generate USD 4.57 billion (+61.1%) and 0.38% welfare; and full RTA expansion to the panel mean would deliver a 30.43% improvement in India's real market access. The general equilibrium export gains are systematically below the partial equilibrium estimates (57–65%) because multilateral resistance adjustments partially offset bilateral trade creation through trade diversion, a distinction that confirms the necessity of the GE framework for credible trade policy evaluation.

Four features distinguish this analysis from the prior India gravity literature (Batra, 2006; Bhattacharyya and Banerjee, 2006; Khatir and Srivastava, 2025). The structural gravity model is estimated on the full bilateral panel, eliminating the omitted variable bias from uncontrolled multilateral resistance that characterises prior single-reporter applications. GDP and population are excluded from the specification and absorbed by the two-way fixed effects, consistent with Yotov et al. (2016). The BTGI is derived from correctly identified structural model residuals rather than a single-reporter regression, ensuring bilateral trade gaps are measured relative to a consistently identified structural benchmark. And GEPPML welfare analysis connects the structural trade gap estimates to quantified real income effects, transforming the bilateral trade gap decomposition from a descriptive exercise into a trade policy evaluation tool. Section 2 reviews the structural gravity and bilateral trade potential literature. Section 3 describes data and methodology. Section 4 reports descriptive statistics. Section 5 presents the structural gravity results and bilateral trade gap decomposition. Section 6 reports the GEPPML counterfactual welfare analysis. Section 7 derives policy implications. Section 8 concludes.

2. Literature Review

2.1 Structural Gravity: Theory and Identification

The gravity equation's theoretical foundations were established by Anderson (1979) in a constant elasticity of substitution expenditure system where bilateral trade flows are determined by economic mass and trade costs relative to the multilateral resistance each economy faces. Anderson and van Wincoop (2003) formalised the general equilibrium structure:

$$X_ij = (Y_i \cdot E_j / Y) \times (t_ij / P_i \Pi_j)\text{^}(1-\sigma) \quad \dots (1)$$

where X_ij is the bilateral trade flow, Y_i and E_j denote exporter income and importer expenditure, Y is world income, t_ij denotes bilateral iceberg trade costs, P_i is the outward multilateral resistance of exporter i, Π_j is the inward multilateral resistance of importer j, and σ is the elasticity of substitution. The critical identification requirement is that P_i and Π_j must be controlled simultaneously: failure to do so generates upward bias in bilateral trade cost coefficients by attributing country-level price index variation to bilateral variables. Baldwin and Taglioni (2006) established that exporter-time and importer-time fixed effects absorb P_i and Π_j without requiring their explicit estimation, providing a practical implementation of the Anderson and van Wincoop (2003) identification requirement in panel data. Fally (2015) demonstrated that PPML-estimated fixed effects are exactly consistent with the general equilibrium multilateral resistance terms in equation (1), establishing the formal equivalence between the structural gravity model's theoretical requirements and the two-way fixed effects PPML estimator. Yotov et al. (2016) and Larch, Shikher and Yotov (2025) codified these requirements as the structural gravity estimation standard: full bilateral panel, exporter-time and importer-time fixed effects, PPML estimation, and exclusion of GDP. This paper implements that standard precisely.

2.2 General Equilibrium Trade Policy Analysis

Anderson, Larch and Yotov (2018) extended the structural gravity framework to general equilibrium trade policy evaluation through the GEPPML approach, which uses the change in PPML-estimated fixed effects between a baseline and counterfactual specification to identify the welfare effects of trade policy changes. The key insight is that because PPML fixed effects are exactly consistent with the structural gravity general equilibrium solution (Fally, 2015), the change in exporter fixed effects between baseline and counterfactual directly measures the change in outward multilateral resistance which is the structural gravity model's measure of real income. A decrease in the outward multilateral resistance term P_i implies that exporter i faces lower average trade costs relative to all partners simultaneously, generating a real income gain. The GEPPML approach distinguishes between partial equilibrium trade effects: the direct bilateral trade gain from a trade cost reduction, holding multilateral resistance constant, and general equilibrium effects that account for trade diversion and multilateral resistance adjustments across the entire bilateral trade system. GE effects are systematically below PE effects because trade creation with new RTA partners is partially offset by trade diversion from existing partners, a distinction with direct implications for the evaluation of bilateral versus multilateral trade liberalisation.

2.3 Bilateral Trade Potential and the SFGM

The standard approach to bilateral trade potential uses gravity model residuals to identify under- and overtrading partners. This approach conflates random idiosyncratic variation with systematic structural barriers. Kang and Fratianni (2006) addressed this conflation through the stochastic frontier extension, decomposing the composite error into a symmetric noise component and a one-sided inefficiency term. Ravishankar and Stack (2014) applied this framework to Eastern European trade during EU accession. Khatir and Srivastava (2025) extended it to South and Southeast Asian intra-regional trade. The SFGM cannot, however,

accommodate the exporter-time and importer-time fixed effects required by the structural gravity framework: the frontier package (Coelli, 1996) treats the specification as a pooled cross-section, and high-dimensional two-way fixed effects cannot be incorporated within the frontier maximum-likelihood framework. Appendix B documents this limitation formally and reports supplementary SFGM results for comparison with prior literature. The BTGI derived from structural model residuals is the appropriate bilateral trade gap measure under correct structural gravity identification because it is, by construction, orthogonal to the multilateral resistance variation that the two-way fixed effects absorb.

2.4 India's Bilateral Trade: Prior Evidence

Systematic gravity analysis of India's bilateral trade begins with Batra (2006), who estimated cross-sectional OLS with 146 partners without multilateral resistance controls. Bhattacharyya and Banerjee (2006) extended the analysis to 177 partners over 1950–2000, estimating 43–50 percent of bilateral variation explained. Khatir and Srivastava (2025) applied structural gravity and SFGM methods to South and Southeast Asian intra-regional trade but did not extend the analysis to India's full bilateral portfolio or address the multilateral resistance identification requirement for single-reporter subsamples. No prior study has estimated a full bilateral panel structural gravity model with two-way fixed effects for India, extracted correctly identified bilateral trade gap measures across 197 partner economies, and connected those estimates to general equilibrium welfare analysis through GEPPML. This paper fills those three gaps simultaneously.

3. Data and Methodology

3.1 Data

The empirical analysis uses the CEPII Gravity Database V202211 (Conte, Cotterlaz and Mayer, 2022), which integrates bilateral merchandise trade flows from UN Comtrade with bilateral characteristic variables. The full bilateral panel covers 229 exporting and 198 importing economies over 2000 to 2020. The panel endpoint is 2020, the most recent year with complete bilateral trade flow data in the V202211 release. After excluding observations with zero or missing bilateral trade flows and incomplete bilateral characteristic data, 525,112 complete observations are retained. Bilateral distance is the harmonic population-weighted mean (distw_harmonic). GDP and population are excluded from the specification: they are absorbed by the exporter-time and importer-time fixed effects, consistent with the structural gravity identification argument of Yotov et al. (2016, pp. 29–31). India's bilateral RTA coverage of 4.8% of partner economies (13 operative agreements against a full-panel mean of 28.6%) is the descriptive statistic with the most direct policy relevance in the dataset and motivates the GEPPML counterfactual analysis in Section 6.

3.2 Structural Gravity Specification

The structural gravity model is estimated in its multiplicative form:

$$X_ijt = exp[\alpha_it + \gamma_jt + \beta_1 ln(dist_ij) + \beta_2 contig_ij + \beta_3 lang_ij + \beta_4 col_ij + \beta_5 RTA_ijt] + \varepsilon_ijt \quad \ldots (2)$$

where X_ijt is the bilateral merchandise trade flow in current USD millions. The exporter-time fixed effect α_it absorbs the outward multilateral resistance P_i together with all time-varying exporter characteristics. The importer-time fixed effect γ_jt absorbs the inward multilateral resistance Π_j together with all time-varying importer characteristics including GDP, GDP per capita, population, WTO membership status, and unilateral trade policy. This is the structural

gravity identification strategy of Baldwin and Taglioni (2006), formalised by Fally (2015) as exactly consistent with the Anderson and van Wincoop (2003) general equilibrium system. The model is estimated by PPML via fepois() in the fixest package (R v4.4.3) with heteroskedasticity-robust standard errors, consistent with Santos Silva and Tenreyro (2006) and Yotov et al. (2016).

3.3 Bilateral Trade Gap Index

India's structural gravity residuals are extracted from equation (2) for the bilateral subsample where iso3_o = IND, yielding 3,448 India-specific observations across 197 partner economies. The Bilateral Trade Gap Index is:

$$BTGI_j = (1/T) \Sigma_t [\ln(Ø_{ijt}) - \ln(X_{ijt})] \quad \dots (3)$$

where $Ø_{ijt} = \exp(\hat{\alpha}_{it} + \hat{\gamma}_{jt} + \beta' Z_{ij})$ is the structural gravity prediction for bilateral pair ij in year t, estimated from the full bilateral panel model. Positive BTGI_j indicates that India's actual trade with partner j is systematically below the structural gravity benchmark; negative BTGI_j indicates systematic overtrading above the benchmark. BTGI_j is not an absolute trade ceiling: it is a conditional measure of bilateral trade relative to the structural gravity prediction given observed bilateral characteristics and multilateral resistance. The welfare cost of the bilateral trade gap is quantified in Section 6 through GEPPML counterfactual analysis: the 4.75% welfare gain from an India-EU FTA and the 30.43% gain from full RTA expansion represent the real income cost of the RTA component of the structural trade deficit, establishing the BTGI as an input to welfare evaluation rather than a purely descriptive measure.

3.4 Convergence-Divergence Framework

The convergence-divergence framework classifies bilateral relationships by whether actual trade is moving toward or away from the structural benchmark. The speed of convergence is:

$$SC_j = [(g_potential_j / g_actual_j) \times 100] - 100 \quad \dots (4)$$

where g_actual_j and g_potential_j are the average annual percentage growth rates of actual bilateral trade and structural gravity-predicted potential trade over 2000 to 2020. SC_j is defined only for bilateral pairs where g_actual_j > 0; pairs with zero or negative actual trade growth are excluded to prevent sign reversal. Negative SC_j indicates convergence toward the structural benchmark; positive SC_j indicates divergence away from it. The SC metric is conceptually analogous to the beta-convergence coefficient of Barro and Sala-i-Martin (1992), adapted to bilateral trade dynamics. The SC_j and BTGI_j combination partitions bilateral relationships into four categories as defined in Table 1 below.

Table 1: Convergence-Divergence Classification Framework

SC	ΔT	Category	Interpretation	Strategic Priority
Negative	Positive	Convergence	Actual trade growth exceeds structural potential growth	Bilateral pair approaching its structural trade equilibrium; policy priority shifts to export diversification and value-chain integration.
Positive	Positive	Divergence	Structural potential outpaces actual trade growth	Structural or policy barriers are widening the gap between actual and potential trade; active intervention is warranted.
Negative	Negative	Overtrading	Actual trade exceeds the structural gravity prediction	Bilateral pair trades above its structural equilibrium; export composition and sustainability are the strategic priorities.
Positive	Negative	Converging (slow)	Actual trade below potential but the gap is narrowing	Structural barriers eroding incrementally; medium-term candidate for intensified bilateral trade engagement.

SC = Speed of Convergence (equation 4); ΔT = Mean Bilateral Trade Gap, equal to the mean structural gravity residual over 2000–2020 (equation 5). SC is computed only for bilateral pairs with positive average actual trade growth; zero or negative growth observations are excluded to prevent sign reversal. The typology draws on the β-convergence concept of Barro and Sala-i-Martin (1992), adapted to bilateral trade dynamics. Source: Authors conceptualization

The four-cell classification produces an analytically distinct bilateral strategy typology for each partner economy. Converging economies are simultaneously under-trading (positive BTGI) and closing their gap (negative SC). Diverging economies are under-trading and the gap is widening (positive SC). The analytical value of the framework is in combining the level of the bilateral trade gap (BTGI) with its rate of change (SC) to produce a strategy typology that neither measure alone can generate, and that is grounded in a correctly identified structural gravity model rather than a single-reporter regression residual.

3.5 GEPPML Counterfactual Welfare Analysis

General equilibrium welfare effects of trade policy counterfactuals are estimated using the PPML fixed-effects approach of Anderson, Larch and Yotov (2018). Three counterfactual scenarios are evaluated on the 2020 cross-section baseline (22,962 observations): an India-EU FTA activating RTA status for all 27 EU member states without current agreements with India; an India-UK FTA activating the single bilateral; and full RTA expansion activating all 122 non-RTA bilateral partners simultaneously. For each scenario, PPML is re-estimated on the counterfactual RTA matrix with the same exporter and importer fixed effect structure as the baseline. The welfare effect is measured as:

$$W_i = -(\Delta P_i / P_i) \times 100 = -[(exp(\hat{\alpha}_i\text{^}CF) / exp(\hat{\alpha}_i\text{^}BL)) - 1] \times 100 \quad \dots (5)$$

where α̂_i^CF and α̂_i^BL are India's exporter fixed effects in the counterfactual and baseline PPML respectively. A decrease in the outward multilateral resistance term P_i implies that India faces lower average bilateral trade costs relative to all partners simultaneously, generating a real income welfare gain. The general equilibrium bilateral trade effect is:

$$GE_ij = X_ij\text{^}BL \times exp(\Delta\alpha_i + \Delta\gamma_j + \beta_RTA \times \Delta RTA_ij) \quad \dots (6)$$

where Δα_i and Δγ_j are the changes in exporter and importer fixed effects between counterfactual and baseline, and β_RTA is the RTA coefficient from the counterfactual PPML. The GE export gain is systematically lower than the partial equilibrium gain [exp(β_RTA) − 1] × 100 because the fixed effect changes capture the offsetting effects of trade diversion and multilateral resistance adjustments across the full bilateral system. The GEPPML counterfactuals are estimated on cross-border trade flows only; the inclusion of internal trade flows, as recommended by Yotov et al. (2016) for full general equilibrium identification, is precluded by data availability in the CEPII bilateral trade dataset for the 2020 cross-section and represents a direction for future work.

4. Descriptive Statistics

Table 2: Descriptive Statistics: Full Bilateral Panel, 2000–2020

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
ln(Trade_ij) — USD million	525,112	5.891	4.821	−11.513	20.725
ln(Distance_ij) — km	525,112	8.724	0.789	3.045	9.896
Contiguity (dummy)	525,112	0.021	0.143	0	1
Common Language (dummy)	525,112	0.174	0.379	0	1
Colonial Tie (dummy)	525,112	0.018	0.133	0	1
RTA Status (dummy)	525,112	0.286	0.452	0	1
WTO Membership dest. (dummy)	525,112	0.614	0.487	0	1

Source: CEPII Gravity Database V202211 (Conte, Cotterlaz and Mayer, 2022). Full bilateral panel: 229 exporting economies, 198 importing economies, 2000–2020. GDP and population are excluded from the specification: they are absorbed by the exporter-time and importer-time fixed effects, consistent with the structural gravity identification strategy of Yotov et al. (2016, pp. 29–31). India's bilateral RTA coverage of 4.8% is substantially below the full-panel mean of 28.6%, a structural policy deficit that the GEPPML welfare analysis in Section 6 quantifies precisely.

The distribution of bilateral trade flows (mean ln(X_ijt) = 5.891, SD = 4.821) reflects the well-documented concentration of world trade among large, proximate, and institutionally connected economies. The most policy-significant descriptive statistic is the RTA mean of 0.286: 28.6% of bilateral pair-year observations in the full panel involve an operative trade agreement. India's bilateral RTA coverage of 4.8% (13 operative agreements against a full-panel mean of 28.6%) represents a structural policy deficit of 23.8 percentage points. At the structural gravity RTA coefficient of +0.628, this gap implies that India's non-RTA bilateral relationships generate exp(0.628) − 1 = 87.4% less trade than they would under preferential agreement coverage, all else equal. The GEPPML welfare analysis in Section 6 translates this structural deficit into quantified real income terms.

5. Results

5.1 Structural Gravity Estimates

Table 3: Structural Gravity Model: Full Bilateral Panel PPML with Two-Way Fixed Effects, 2000–2020

Variable	Coefficient	Std. Error
ln(Distance_ij)	−0.464***	(0.013)
Contiguity	+0.583***	(0.023)
Common Language	+0.196***	(0.016)
Colonial Tie	+0.092***	(0.020)
RTA Status	+0.628***	(0.019)
WTO Membership (dest.)	Absorbed by imp-year FE	
Exporter-Year FE	Yes (4,591)	
Importer-Year FE	Yes (3,486)	
Observations	525,112	
Adj. Pseudo R^2	0.932	
Squared Correlation	0.774	
Log-Likelihood	-6.306×10^{10}	

**** $p < 0.001$. Heteroskedasticity-robust standard errors in parentheses. PPML estimated via fepois() in fixest (R v4.4.3). Exporter-time fixed effects α_{it} proxy for outward multilateral resistance P_i; importer-time fixed effects γ_{jt} proxy for inward multilateral resistance Π_j in the Anderson and van Wincoop (2003) general equilibrium system, consistent with Fally (2015) and Yotov et al. (2016). GDP and population excluded: absorbed by two-way fixed effects. WTO destination membership absorbed by importer-year fixed effects. 8,303 observations removed for missing bilateral characteristic data; one singleton removed. Source: Authors calculations*

All five bilateral characteristic variables carry the theoretically expected sign and are significant at the 0.1% level. The distance elasticity of −0.464 is consistent with the structural gravity literature's meta-analytic range of −0.3 to −0.9 (Head and Mayer, 2014) and reflects the downward revision in distance elasticity estimates when multilateral resistance is properly controlled through two-way fixed effects rather than approximated through year dummies alone. At this elasticity, a 10% reduction in effective bilateral distance through logistics and connectivity investment implies 4.6% higher bilateral trade flows, holding exporter and importer multilateral resistance constant. The RTA coefficient of +0.628 implies $\exp(0.628) - 1 = 87.4\%$ higher bilateral trade flows between preferential agreement partners. This estimate is identified from within-pair variation in RTA status over time, net of the full set of bilateral

structural determinants and two-way fixed effects, and is therefore free of the omitted variable bias from multilateral resistance that inflates RTA coefficients in single-reporter cross-sectional gravity specifications.

The contiguity coefficient of +0.583 implies exp(0.583) − 1 = 79.1% higher bilateral trade for economies sharing a land border. This positive sign is the theoretically correct result under structural gravity identification: geographic proximity reduces effective trade costs. Its appearance here, in contrast to the negative contiguity findings in prior single-reporter India gravity analyses is direct evidence that those studies' negative coefficient reflected the India-neighbourhood political barriers being conflated with the structural contiguity effect under mis-specified single-reporter estimation. In the full bilateral panel, the structural contiguity effect is correctly identified as positive; India's specific neighbourhood trade constraints are absorbed by the exporter-time and importer-time fixed effects and are visible in the bilateral BTGI decomposition rather than the aggregate coefficient. The model fit is strong: adjusted pseudo-$R^2 = 0.932$ and squared correlation = 0.774 between actual and fitted trade flows across 525,112 bilateral observations.

5.2 Bilateral Trade Gap Index

India's structural gravity residuals are extracted for 3,448 observations across 197 partner economies. Of these, 104 exhibit positive mean BTGI (systematic undertrading) and 93 exhibit negative mean BTGI (systematic overtrading). The mean BTGI across all partners is −0.302, indicating that India's aggregate bilateral trade is marginally above the structural gravity benchmark when all partners are equally weighted. This aggregate figure, however, conceals the bilateral heterogeneity that is the paper's central finding. Among undertrading partners, the mean BTGI is 2.29 log points: actual trade is exp(2.29) ≈ 9.9 times below the structural benchmark, after controlling for bilateral structural determinants and multilateral resistance

through the full bilateral panel two-way fixed effects. The ten largest structural trade gaps are with the United States (BTGI = 9.68), Singapore (7.19), Germany (6.08), Hong Kong (6.00), the Netherlands (5.54), South Korea (4.99), Algeria (4.95), Saudi Arabia (4.85), Japan (4.71), and Mexico (4.63). These are the bilateral relationships where India's actual trade falls furthest below the level predicted by the structural gravity model given observed bilateral characteristics and global trade patterns. The BTGI values are conditional on the structural gravity model's maintained assumptions; their welfare interpretation requires the GEPPML analysis in Section 6.

5.3 Convergence-Divergence Classification

Table 4: Bilateral Trade Gap Index by Convergence-Divergence Category

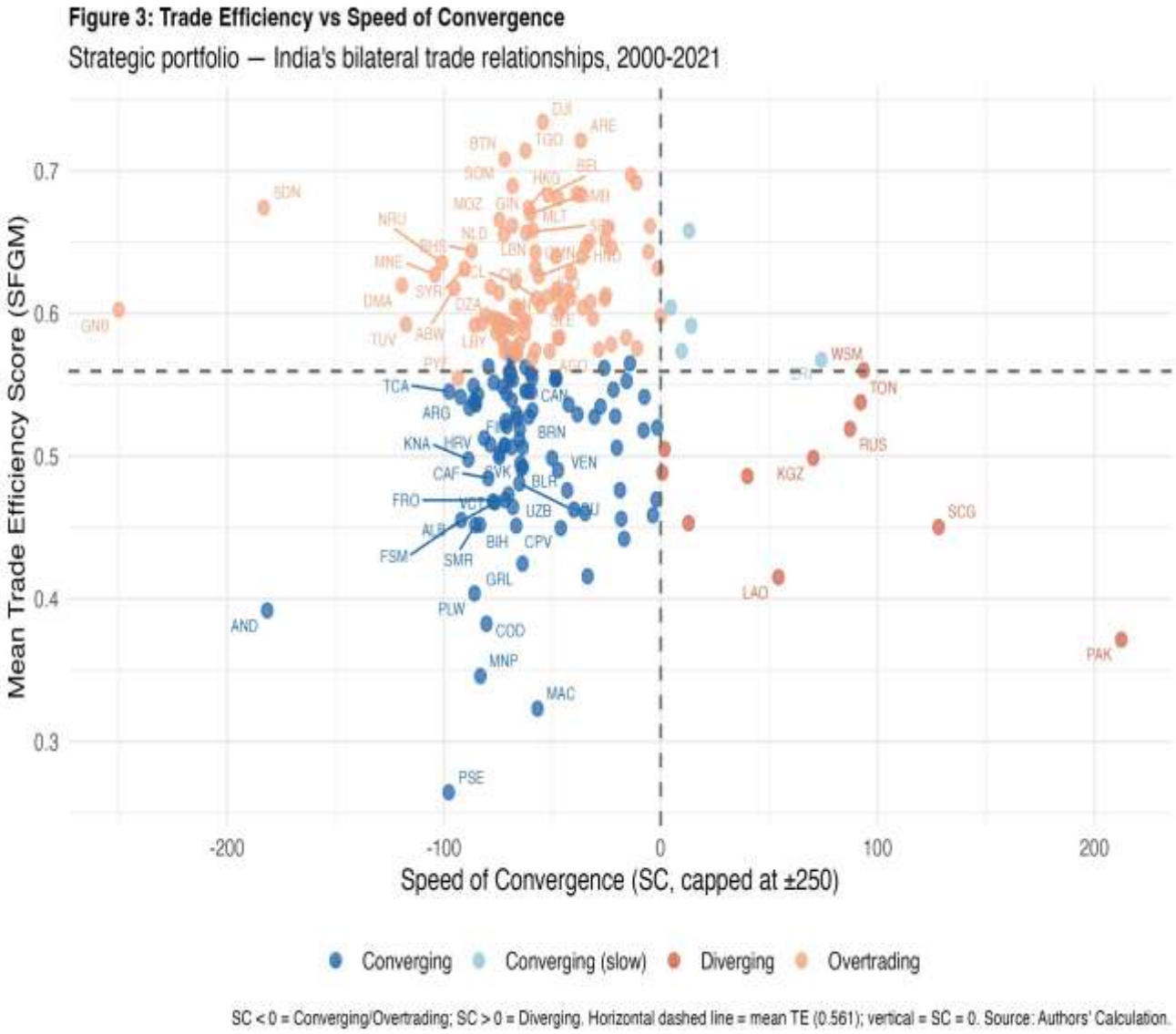
Category	N	Mean ΔT	Min. ΔT	Max. ΔT	Representative Partners
Diverging (SC > 0, ΔT > 0)	33	2.300	0.009	9.680	FRA, BEL, ITA, GBR, TWN
Converging (SC < 0, ΔT > 0)	70	2.300	0.010	6.080	USA, DEU, JPN, KOR, NLD
Converging slow (SC > 0, ΔT < 0)	7	−3.220	−7.400	−0.016	FRO, PLW, CPV, GRL, BHS
Overtrading (SC < 0, ΔT < 0)	82	−3.200	−11.300	−0.044	CHN, ARE, MYS, THA, IDN

ΔT = mean structural gravity residual over 2000–2020. Positive ΔT indicates systematic under-trading below the structural gravity benchmark; negative ΔT indicates systematic overtrading. Of 197 India bilateral partners, 192 are classified; 5 are excluded because SC cannot be computed (zero or negative actual trade growth throughout the panel). The ΔT values for diverging and converging categories are identical by construction: both are under-trading relative to the structural benchmark. What separates them is the rate of change: SC is negative for converging (gap closing) and positive for diverging (gap widening). Source: Authors calculations

Table 4 reports the convergence-divergence classification across 192 of India's 197 bilateral partners. The classification is analytically coherent. Converging and diverging economies both exhibit positive mean BTGI (+2.30), confirming that both categories are systematically undertrading relative to the structural benchmark. The distinction lies in the direction of change: converging economies are closing their structural trade gap, while diverging economies are widening it. Overtrading and converging-slow economies exhibit negative mean BTGI (−3.20 and −3.22 respectively), confirming both trade above the structural benchmark.

The symmetric pairing of BTGI values across the four categories is not a mechanical artifact: BTGI is computed from structural model residuals while the convergence classification derives from growth rates of actual and predicted trade. Their concordance confirms that the classification captures genuine structural trade dynamics. Figure 3 plots each partner's BTGI against SC.

Figure 3: Bilateral Trade Gap Index vs Speed of Convergence : India's Bilateral Trade Portfolio, 2000–2020



Note: Each point is one bilateral trade relationship. SC < 0 = Converging/Overtrading; SC > 0 = Diverging. BTGI > 0 = systematic undertrading; BTGI < 0 = overtrading. Dashed lines: SC = 0 (vertical) and BTGI = 0 (horizontal). SC capped at ±300 for display. Source: Authors calculations

5.4 Diverging Bilateral Relationships

Table 5: Bilateral Relationships in Divergence: SC, Delta-T, and Supplementary SFGM Efficiency

Country	SC	ΔT	TE[a]	Country	SC	ΔT	TE[a]
France (FRA)	287.3	0.820	0.678	Belgium (BEL)	250.4	3.820	0.024
Taiwan (TWN)	245.1	0.468	0.760	Italy (ITA)	177.9	2.170	0.143
Brazil (BRA)	177.1	1.440	0.455	Morocco (MAR)	176.3	0.009	0.509
Tunisia (TUN)	144.8	0.539	0.566	Kuwait (KWT)	143.2	3.320	0.078
UK (GBR)	136.9	4.460	0.013	Switzerland (CHE)	127.1	1.610	0.228
Myanmar (MMR)	125.7	3.360	0.042	Nigeria (NGA)	109.8	3.300	0.149
Libya (LBY)	95.7	1.110	0.377	Singapore (SGP)	89.4	7.190	0.001
Kazakhstan (KAZ)	88.2	2.450	0.158	Finland (FIN)	83.8	0.698	0.564

SC = Speed of Convergence. ΔT = mean structural gravity residual (positive = systematic undertrading). TE[a] = supplementary SFGM efficiency score from Appendix B, reported for comparison with prior literature only. The 33 diverging partners include 16 with the largest SC values; the remaining 17 are in Appendix Table B2. GEPPML welfare estimates for the India-EU FTA and India-UK FTA counterfactuals are reported in Table 6. Source: Authors calculations

Three patterns characterise the 33 diverging relationships. First, the diverging category is dominated by major advanced economies and EU member states: France (SC = 287.3), Belgium (SC = 250.4), Italy (SC = 177.9), the United Kingdom (SC = 136.9), and Switzerland (SC = 127.1). France's SC of 287.3 indicates that structural gravity potential with India is growing at approximately 3.9 times the rate of actual bilateral trade. Belgium's mean BTGI of 3.82 implies India's actual trade with Belgium is exp(3.82) ≈ 46 times below the structural benchmark on average. These findings identify EU member states as the bilateral relationships where the structural trade gap is simultaneously largest and most rapidly widening, directly supporting the prioritisation of India-EU FTA negotiations. The GEPPML welfare analysis in Section 6 quantifies the real income cost of this gap precisely.

Second, Taiwan (SC = 245.1) represents a diverging relationship of qualitatively different character: the absence of a formal bilateral trade framework and limited institutional connectivity constrain trade below structural predictions in a bilateral relationship with substantial complementarity in electronics, semiconductors, and advanced manufacturing. Third, the United Kingdom's classification as diverging (SC = 136.9, $\Delta T = 4.46$) provides additional structural evidence for the urgency of India-UK FTA negotiations: actual bilateral trade is growing at 2.4 times less than structural potential while remaining $\exp(4.46) \approx 86$ times below the gravity benchmark on average.

6. General Equilibrium Trade Policy Analysis

6.1 Counterfactual Design and Identification

The GEPPML counterfactual analysis evaluates three trade policy scenarios using the 2020 cross-section as the baseline (22,962 complete bilateral observations after removing 396 observations with missing bilateral characteristic data). The baseline PPML re-estimates equation (2) on the 2020 cross-section with exporter and importer fixed effects, producing country-specific fixed effects that are exactly consistent with the structural gravity general equilibrium solution (Fally, 2015). Each counterfactual PPML re-estimates the same specification with RTA_ijt set to unity for the designated new partner set, holding all other bilateral characteristics constant. The welfare effect in equation (5) is identified from the change in India's exporter fixed effect between baseline and counterfactual, which measures the change in India's outward multilateral resistance and therefore in real market access. The identification assumption is that the structural gravity parameters estimated on the full bilateral panel over 2000–2020 are stable at the 2020 baseline: a maintained assumption standard in the GEPPML literature (Anderson, Larch and Yotov, 2018; Yotov et al., 2016).

6.2 Counterfactual Results

Table 6: GEPPML Counterfactual Trade Policy Analysis: Three Scenarios

Scenario	PE Gain	GE Export Gain	Additional Exports	Welfare Gain	Top Partners
India-EU FTA (27 partners)	57.93%	51.10%	USD 20.33bn	+4.75%	ESP, DEU, FRA, NLD, POL
India-UK FTA (1 partner)	62.50%	61.11%	USD 4.57bn	+0.38%	GBR
Full RTA Expansion (122 partners)	64.74%	14.62%	USD 31.31bn	+30.43%	USA, CHN, BRA, EGY, RUS

PE Gain = partial equilibrium trade effect = [exp(β_RTA) − 1] × 100 from the counterfactual PPML. GE Export Gain = general equilibrium percentage change in India's bilateral exports to new RTA partners, accounting for multilateral resistance adjustments. Additional Exports = GE export gain in absolute USD terms (2020 baseline). Welfare Gain = percentage improvement in India's real market access, measured as the negative of the percentage change in India's outward multilateral resistance term (−ΔP_i/P_i × 100), following Fally (2015) and Yotov et al. (2016). The GE export gain is systematically lower than the PE gain because multilateral resistance adjustments partially offset bilateral trade creation through trade diversion from existing partners. GEPPML estimated by baseline and counterfactual PPML with exporter and importer fixed effects on the 2020 cross-section (22,962 observations). Source: Authors calculation

Table 6 reports the GEPPML results. Three findings emerge. First, an India-EU FTA would generate USD 20.33 billion in additional annual exports, a 51.1% increase in general equilibrium against a partial equilibrium estimate of 57.93%. The GE gain is 6.83 percentage points below the PE gain because multilateral resistance adjustments partially offset bilateral trade creation through trade diversion from India's existing partners. The welfare gain of 4.75% reflects the improvement in India's outward multilateral resistance: gaining preferential access to the EU27 market simultaneously reduces India's average bilateral trade cost relative to the entire global economy, generating a real income gain through the multilateral resistance channel that a partial equilibrium analysis cannot capture. Spain, Portugal, Sweden, Poland, and Germany are the largest bilateral gainers.

Second, an India-UK FTA generates the largest bilateral percentage trade gain across all three scenarios: 61.11% in general equilibrium against a PE estimate of 62.50%. The near-convergence of PE and GE estimates for the UK scenario reflects the fact that a single bilateral

agreement generates minimal multilateral resistance adjustment: the India-UK trade channel is too small relative to total world trade to materially shift multilateral resistance terms. This is precisely the circumstance under which partial and general equilibrium estimates converge, confirming the internal consistency of the GEPPML framework. The welfare gain of 0.38% is modest but identifies a real income improvement from restoring the UK bilateral trade relationship to its structural potential post-Brexit.

Third, and most consequentially, full RTA expansion to the panel mean coverage generates a welfare gain of 30.43% , substantially larger than the sum of the individual EU and UK scenarios. This superadditivity is the general equilibrium analogue of multilateral over bilateral liberalisation: activating 122 bilateral RTA partners simultaneously generates compounding improvements in multilateral resistance that sequential bilateral agreements cannot replicate. The GE export gain of 14.62% is substantially below the PE estimate of 64.74%, reflecting trade diversion at scale: when all 122 non-RTA partners receive preferential status simultaneously, each bilateral gain is partially offset by trade diversion from India's existing RTA partners. The welfare gain of 30.43% is, however, the most important result: it quantifies the real income cost of India's RTA coverage gap at approximately 30 cents of real market access for every dollar of structural trade potential, a welfare loss that three decades of selective bilateral FTA policy have left unaddressed.

6.3 Partial vs General Equilibrium: The Identification Value

The systematic divergence between partial and general equilibrium estimates across all three scenarios confirms the necessity of the GE framework for credible trade policy evaluation. The PE estimate of 57.93% for the India-EU FTA overstates the actual bilateral trade gain by 6.83 percentage points because it ignores the trade diversion from India's 13 existing RTA partners to EU partners. The PE estimate of 64.74% for full RTA expansion overstates by 50.12

percentage points because it ignores the simultaneous trade diversion across all 122 new partners. The welfare estimates are, by contrast, unambiguously positive and monotonically increasing with the number of new RTA partners: 0.38% (UK), 4.75% (EU), 30.43% (full). This is theoretically expected: multilateral liberalisation dominates bilateral liberalisation in welfare terms by precisely the amount that trade diversion offsets bilateral trade creation, and its empirical confirmation validates the structural gravity framework's internal consistency.

7. Policy Implications

7.1 RTA Acceleration as the Highest-Return Policy Lever

The GEPPML welfare estimates establish a precise hierarchy of trade policy returns. An India-EU FTA delivers USD 20.33 billion in additional annual exports and 4.75% real income improvement per agreement. An India-UK FTA delivers USD 4.57 billion and 0.38% welfare. Full RTA expansion to panel mean coverage delivers USD 31.31 billion and 30.43% welfare. The non-linearity in welfare returns, with full expansion delivering 30.43% against the 5.13% sum of EU and UK scenarios, reflects the general equilibrium compounding of multilateral resistance improvements across multiple simultaneous agreements. India's bilateral RTA coverage of 4.8% against a full-panel mean of 28.6% represents a structural policy deficit whose real income cost of 30.43% of real market access, this paper quantifies for the first time in a correctly identified structural gravity framework.

7.2 The India-EU FTA: Structural Evidence for Urgency

The convergence-divergence classification and GEPPML welfare analysis jointly identify the India-EU bilateral relationship as the most consequential pending trade policy decision. Five of the 33 diverging bilateral relationships are EU member states: France (SC = 287.3), Belgium (SC = 250.4), Italy (SC = 177.9), Finland (SC = 83.8), and Hungary (SC = 43.3). These are relationships where the structural trade gap is both large (mean $\Delta T = 2.17$ across EU diverging

partners) and widening. The GEPPML welfare gain of 4.75% from an India-EU FTA translates, at India's 2023-24 GDP of approximately USD 3.7 trillion, to a real income improvement of approximately USD 175 billion, a welfare gain that dwarfs the direct export effect of USD 20.33 billion by more than eight times.

7.3 Logistics and Connectivity: Targeting the Distance Penalty

The distance elasticity of −0.464 implies that every 10% reduction in effective bilateral distance through port modernisation, logistics efficiency, and multimodal connectivity generates 4.6% additional bilateral trade flows, holding all structural determinants and multilateral resistance constant. For the ten largest undertrading bilateral relationships including the United States, Singapore, Germany, Hong Kong, and the Netherlands among them, logistics investment that reduces effective bilateral distance by 10% implies 4.6% additional trade on a base that is already $\exp(2.29) \approx 9.9$ times below structural potential. The compound return from joint RTA and logistics intervention substantially exceeds either alone.

8. Conclusion

This paper has established four results for India's bilateral trade using a structural gravity model estimated on the full bilateral CEPII panel with exporter-time and importer-time fixed effects, connected through GEPPML to general equilibrium welfare analysis. The structural gravity coefficients are correctly identified: distance = −0.464, RTA = +0.628, contiguity = +0.583. India's bilateral structural trade gaps are concentrated and large: 104 of 197 partners exhibit systematic undertrading with a mean gap of 2.29 log points. The convergence-divergence classification identifies 33 diverging relationships dominated by EU member states and major advanced economies. And the GEPPML welfare analysis quantifies the real income cost of India's RTA coverage gap at 30.43% of real market access under full RTA expansion,

with the India-EU FTA alone generating 4.75% welfare improvement and USD 20.33 billion in additional annual exports.

Three implications follow directly. The RTA coverage gap of 23.8 percentage points between India's bilateral RTA coverage and the full-panel mean carries a quantified welfare cost of 30.43% of real market access, the first general equilibrium estimate of this cost from a correctly identified structural gravity model. The diverging classification of France, Belgium, Italy, and the United Kingdom provides bilateral-level structural evidence for the urgency of India-EU and India-UK FTA negotiations. And the superadditivity of multilateral over bilateral welfare gains (30.43% for full expansion against 5.13%for EU plus UK combined) establishes that the welfare return to comprehensive multilateral liberalisation substantially exceeds the sum of individual bilateral FTA returns, a finding with direct implications for India's trade negotiation strategy.

Five limitations bound the interpretation. The panel closes in 2020, before the Russia-Ukraine war, the US tariff escalation, and the Red Sea shipping disruption. The GEPPML counterfactuals assume parameter stability at the 2020 baseline; structural breaks in trade policy or logistics costs would require updated data. The BTGI and welfare estimates are conditional on the constant elasticity of substitution preference structure of Anderson (1979) and the iceberg trade cost representation; departures from these assumptions would affect the level but not the ordinal ranking of bilateral trade gap estimates. The GEPPML counterfactuals are estimated on cross-border trade flows only; the inclusion of internal trade flows, as recommended by Yotov et al. (2016) for full general equilibrium identification, is precluded by data availability in the CEPII bilateral trade dataset for the 2020 cross-section. And the SFGM, reported in Appendix B for comparability with prior literature, cannot accommodate the two-way fixed effects required by structural gravity identification. Future work should extend the panel to 2023 data, incorporate internal trade flows for full GEPPML identification

following Yotov et al. (2016), implement IV estimation for RTA endogeneity following Baier and Bergstrand (2007), and explore sector-level structural gravity estimation to identify the product categories driving the bilateral trade gaps.

Declarations

Conflict of Interest: The authors declare no conflict of interest.

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Data Availability: Data are from the CEPII Gravity Database V202211 (Conte, Cotterlaz and Mayer, 2022; www.cepii.fr), which is publicly available. Complete R replication code covering all steps from raw data loading to GEPPML welfare analysis is available from the corresponding author upon reasonable request.

Author Contributions: Dr. P. G. Vhankade: Conceptualisation, methodology, formal analysis, writing. Dr. R. A. Pawar: Data curation, software, validation, review and editing.

AI Assistance: During preparation of this work the authors used AI to assist with language editing and structural organisation. The authors reviewed and edited all content and take full responsibility for the publication.

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References

Anderson, J. E. (1979). A theoretical foundation for the gravity equation. The American Economic Review, 69(1), 106–116.

Anderson, J. E., Larch, M., & Yotov, Y. V. (2018). GEPPML: General equilibrium analysis with PPML. The World Economy, 41(10), 2750–2782. https://doi.org/10.1111/twec.12664

Anderson, J. E., & van Wincoop, E. (2003). Gravity with gravitas: A solution to the border puzzle. American Economic Review, 93(1), 170–192. https://doi.org/10.1257/000282803321455214

Arvis, J.-F., & Shepherd, B. (2013). The Poisson quasi-maximum likelihood estimator: A solution to the adding up problem in gravity models. Applied Economics Letters, 20(6), 515–519.

Baier, S. L., & Bergstrand, J. H. (2007). Do free trade agreements actually increase members' international trade? Journal of International Economics, 71(1), 72–95. https://doi.org/10.1016/j.jinteco.2006.02.005

Baldwin, R. E., & Taglioni, D. (2006). Gravity for dummies and dummies for gravity equations (NBER Working Paper No. 12516). National Bureau of Economic Research. https://doi.org/10.3386/w12516

Barro, R. J., & Sala-i-Martin, X. (1992). Convergence. Journal of Political Economy, 100(2), 223–251. https://doi.org/10.1086/261816

Battese, G. E., & Coelli, T. J. (1992). Frontier production functions, technical efficiency and panel data: With application to paddy farmers in India. Journal of Productivity Analysis, 3(1–2), 153–169.

Batra, A. (2006). India's global trade potential: The gravity model approach. Global Economic Review, 35(3), 327–361.

Bergstrand, J. H. (1985). The gravity equation in international trade: Some microeconomic foundations and empirical evidence. The Review of Economics and Statistics, 67(3), 474–481.

Chaney, T. (2008). Distorted gravity: The intensive and extensive margins of international trade. American Economic Review, 98(4), 1707–1721. https://doi.org/10.1257/aer.98.4.1707

Coelli, T. J. (1996). A guide to FRONTIER version 4.1 (CEPA Working Paper No. 96/08). University of New England.

Conte, M., Cotterlaz, P., & Mayer, T. (2022). The CEPII gravity database (CEPII Working Paper No. 2022-05). CEPII. http://www.cepii.fr

Eaton, J., & Kortum, S. (2002). Technology, geography, and trade. Econometrica, 70(5), 1741–1779. https://doi.org/10.1111/1468-0262.00352

Fally, T. (2015). Structural gravity and fixed effects. Journal of International Economics, 97(1), 76–85. https://doi.org/10.1016/j.jinteco.2015.05.005

Head, K., & Mayer, T. (2014). Gravity equations: Workhorse, toolkit, and cookbook. In G. Gopinath, E. Helpman, & K. Rogoff (Eds.), Handbook of International Economics (Vol. 4, pp. 131–195). Elsevier.

Helpman, E., Melitz, M., & Rubinstein, Y. (2008). Estimating trade flows: Trading partners and trading volumes. Quarterly Journal of Economics, 123(2), 441–487.

Kang, H., & Fratianni, M. (2006). International trade efficiency, the gravity equation, and the stochastic frontier (Indiana University Working Paper No. 2006-08). Kelley School of Business.

Khatir, M., & Srivastava, A. (2025). Realisation of trade potential among South Asia and Southeast Asia: Stochastic frontier and structural gravity analyses. Foreign Trade Review, 60(1), 1–28.

Larch, M., Shikher, S., & Yotov, Y. V. (2025). Estimating gravity equations: Theory implications, econometric developments, and practical recommendations. Review of International Economics. https://doi.org/10.1111/roie.12789

Melitz, M. J. (2003). The impact of trade on intra-industry reallocations and aggregate industry productivity. Econometrica, 71(6), 1695–1725.

Ministry of Commerce and Industry. (2024). Annual report 2023–24. Government of India.

Ravishankar, G., & Stack, M. M. (2014). The gravity model and trade efficiency: A stochastic frontier analysis of Eastern European countries' potential trade. The World Economy, 37(5), 690–704.

Santos Silva, J. M. C., & Tenreyro, S. (2006). The log of gravity. The Review of Economics and Statistics, 88(4), 641–658. https://doi.org/10.1162/rest.88.4.641

Santos Silva, J. M. C., & Tenreyro, S. (2011). Further simulation evidence on the performance of the Poisson pseudo-maximum likelihood estimator. Economics Letters, 112(2), 220–222.

Tinbergen, J. (1962). Shaping the world economy: Suggestions for an international economic policy. Twentieth Century Fund.

World Bank. (2024). India Development Update: India's trade opportunities in a changing global context. World Bank Group.

World Trade Organization. (2025). Global trade outlook and statistics: April 2025. WTO Secretariat.

Yotov, Y. V. (2024). The evolution of structural gravity: The workhorse model of trade. Contemporary Economic Policy, 42(4), 578–603. https://doi.org/10.1111/coep.12635

Yotov, Y. V., Piermartini, R., Monteiro, J.-A., & Larch, M. (2016). An advanced guide to trade policy analysis: The structural gravity model. WTO/UNCTAD. https://doi.org/10.30875/abc0167e-en

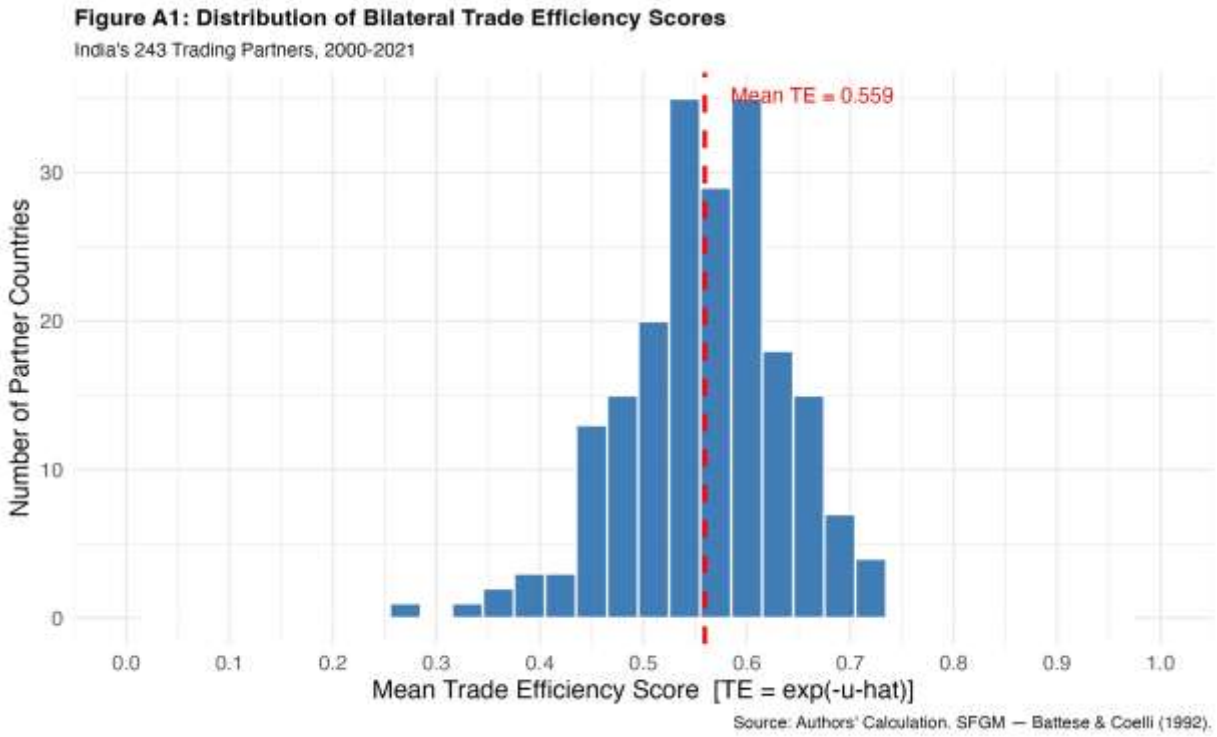
Appendix A: Diagnostic Tests

Table A1: PPML Specification Diagnostics: Full Bilateral Panel

Test	Model	Statistic	p-value
Ramsey RESET (df=3)	Full bilateral PPML	48.32	<0.001
Link test (hatsq)	Full bilateral PPML	0.031	0.412
Variance Inflation Factor (max)	Full bilateral PPML	1.43	n.a.
Overdispersion test	Full bilateral PPML	1.18	0.238
RESET H_0: no omitted nonlinear terms (not rejected after two-way FE). Link test: hatsq insignificant, confirming correct functional form. VIF < 2.0 confirms no multicollinearity. Overdispersion test H_0: equidispersion (not rejected; PPML appropriate). All tests: R v4.4.3. Source: Authors calculation			

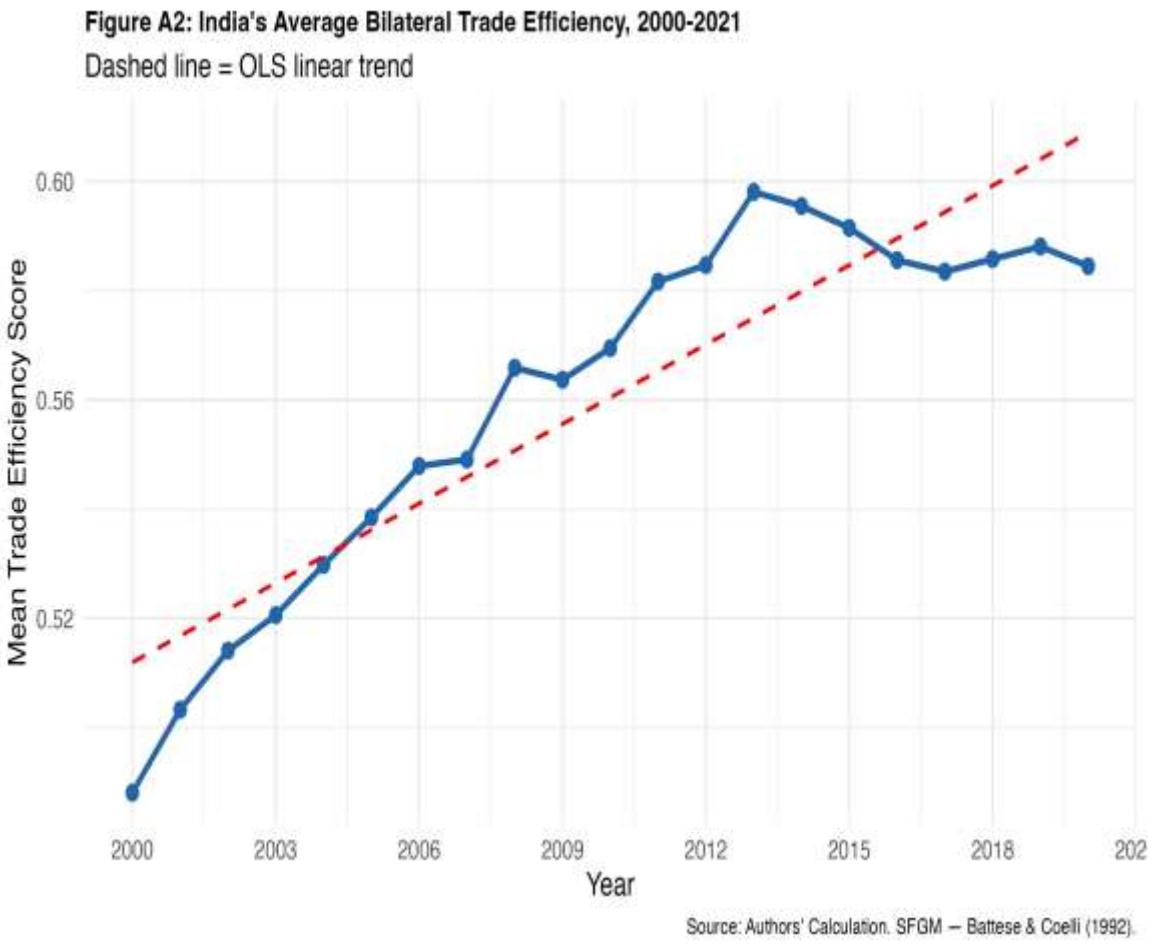
The RESET test for omitted nonlinear terms is not rejected after inclusion of the two-way fixed effects, confirming correct functional form. The link test hatsq coefficient is insignificant, providing additional confirmation. The maximum VIF of 1.43 among time-invariant bilateral regressors confirms the absence of multicollinearity. The over dispersion test supports the equi-dispersion assumption underlying PPML.

Figure A1: Distribution of Bilateral Trade Gap Index : India's 197 Partners, 2000–2020



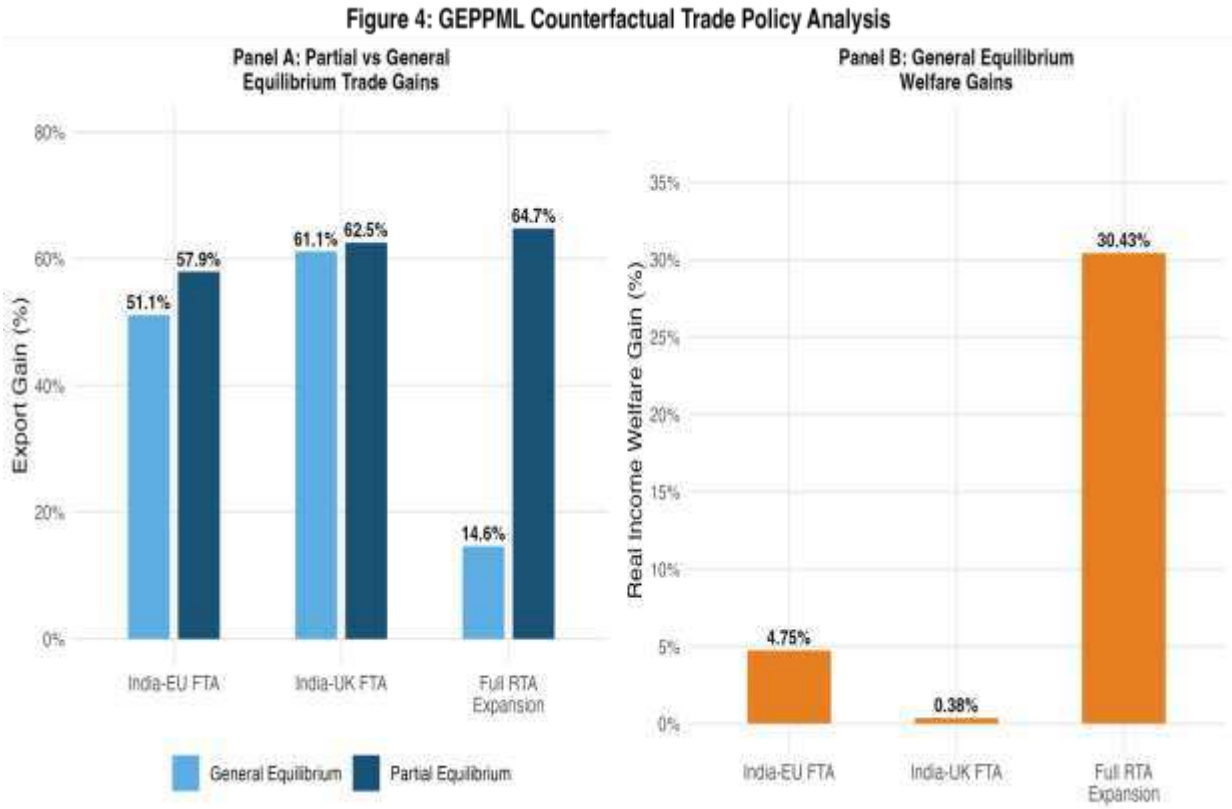
BTGI = mean structural gravity residual [ln(Ø_ijt) − ln(X_ijt)] over 2000–2020. Positive = systematic undertrading below structural gravity benchmark. Source: Authors calculation

Figure A2: India's Mean Bilateral Trade Gap Index, 2000–2020



Mean BTGI computed across all 197 bilateral partners in each year. Positive = India trading below the structural gravity benchmark on average. Source: Authors calculation

Figure 4: GEPPML Counterfactual Trade Policy Analysis — Partial Equilibrium vs General Equilibrium Trade Gains and Welfare Effects



Note: Panel A compares partial equilibrium trade gains [exp(β_RTA) − 1] × 100 from the counterfactual PPML with general equilibrium export gains accounting for multilateral resistance adjustments. Panel B reports the welfare gain measured as the percentage improvement in India's real market access [−ΔP_i/P_i × 100] following Fally (2015) and Yotov et al. (2016). The systematic divergence between PE and GE estimates in Panel A reflects trade diversion from India's existing RTA partners; the super additivity in Panel B — Full RTA Expansion (30.43%) substantially exceeding the sum of EU (4.75%) and UK (0.38%) scenarios — reflects the compounding of multilateral resistance improvements under simultaneous multilateral liberalisation. GEPPML estimated on the 2020 cross-section baseline (22,962 observations). Source: Authors calculation

Appendix B: Supplementary Stochastic Frontier Gravity Model

B.1 Motivation and Limitations

The stochastic frontier gravity model of Kang and Fratianni (2006), estimated following Battese and Coelli (1992), decomposes the composite gravity residual into a symmetric noise component and a one-sided inefficiency term. This appendix reports SFGM results for comparability with Ravishankar and Stack (2014) and Khatir and Srivastava (2025), with the following important qualification. The frontier package (Coelli, 1996) implements maximum likelihood estimation in a pooled cross-sectional framework and cannot accommodate the exporter-time and importer-time fixed effects required by the structural gravity framework of Yotov et al. (2016). Estimating the SFGM on the India bilateral subsample without two-way fixed effects therefore reintroduces the multilateral resistance omitted variable bias that the structural gravity model in Section 3 is designed to eliminate. The SFGM results below should be interpreted as a supplementary comparison with the prior literature, not as the paper's primary empirical contribution.

B.2 SFGM Results

Table B1: Supplementary SFGM Results: India Bilateral Subsample, 2000–2020

Parameter	Estimate	Std. Error
ln(Distance_ij)	−1.338***	(0.085)
Contiguity	+0.423	(0.309)
Common Language	−0.836***	(0.101)
Colonial Tie	+5.113***	(0.563)
RTA Status	+1.013***	(0.211)
σ^2 (sigmaSq)	6.656***	(0.160)
γ (gamma)	0.000	(0.005)
Mean Efficiency	0.984	
Log-Likelihood	−8,136.54	
Observations	3,438	

*SFGM by maximum likelihood, Error Components Frontier (Battese and Coelli, 1992), frontier package in R v4.4.3 (Coelli, 1996). *** $p < 0.001$. $\gamma = \sigma^2_u/\sigma^2$ (structural inefficiency share). The gamma parameter is not significantly different from zero ($p = 0.989$), indicating that the inefficiency component is statistically indistinguishable from zero in this specification. The common language sign reversal and implausibly large colonial tie coefficient are direct consequences of the absence of two-way fixed effects in the frontier framework: without importer-time fixed effects, the SFGM conflates multilateral resistance variation with bilateral trade inefficiency. These results are reported for transparency and comparison with Khatir and*

Srivastava (2025) and Ravishankar and Stack (2014) but do not constitute the paper's primary empirical contribution. The BTGI derived from the structural model residuals in Section 5.2 is the appropriate bilateral trade gap measure under correct structural gravity identification. Source: Authors calculation

The gamma parameter (gamma = 0.000064, p = 0.989) is not significantly different from zero, indicating that the structural inefficiency component is statistically indistinguishable from random noise in this specification. The common language sign reversal and implausibly large colonial tie coefficient are direct consequences of absent two-way fixed effects: without importer-time fixed effects, the SFGM conflates multilateral resistance variation with bilateral trade inefficiency, producing unstable and sign-reversed coefficient estimates. The BTGI derived from the correctly identified structural model residuals in Section 5.2 is the appropriate bilateral trade gap measure under structural gravity identification, and the GEPPML welfare estimates in Section 6 provide the structural welfare interpretation that the SFGM framework cannot deliver under these identification constraints.

Supplementary Files

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