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RESEARCH ARTICLE

Impact of EU food safety regulations on India's exports of fruits, nuts, and vegetables-A Gravity model analysis

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Abstract: There is heightened global concern about food quality and food safety standards across the agricultural value chain. Using Gravity modelling, the study examined the impact of European Union food safety standards on performance of India's horticultural exports of fruits, nuts and vegetable (FNV). The study considered the period 2002-2021. It analysed the growth pattern, direction of trade and magnitude of impact of the non-tariff measures on horticultural exports of FNV. Results of the study showed that the model supports a distinct demand pull from Europe and the UK for India's fruits, nuts, and vegetables. Consistent with empirics as well as theory, variables like distance and exchange rate and tariffs were found to have a negative effect while countries' GDPs had a positive effect. Language and historical links did not show any impact.

Keywords: Gravity model; Non-tariff measures; EU; trade.

INTRODUCTION

Horticulture is a key sector of India's economy. The sector offers livelihood opportunities to many of the rural populace through provision of household food security, employment and stable income. (Ghani., 2023). Relatedly, horticultural exports enable growth and development of India's economy (Kumar, K.N.R, Naidu.G.M, 2024). Increased horticultural trade engenders sustainable foreign currency revenue flows (Sharma, 2021). In terms of horticultural export destination, the European Union is India's second largest trading partner, after the United States of America (Kim.S.Y, 2022). The EU is also the second largest destination of India's exports (Yeligar, 2023).

India maintains trade potential in many horticultural products that include fruits, cashew nuts and vegetables, with the same export sector continuing to grow and contributing positively to the country's Gross Domestic Product (GDP) (Mitra, A. and Panda, 2020). On the aggregate, India's contribution to the world agricultural exports has significantly improved (Bandolkar, B, N. and Sudarsan, 2023). This growth has been propelled by the rapid rise in horticulture as India has entered the sunrise clause (Mitra, A. and Panda, 2020). Equally so, India's wide agricultural base offers great opportunities for exports growth, ushering an opportunity for the country to be a top global exporter of horticultural products (Niranjan, 2021). India is the global second largest producer of fruits and vegetables apiece, after China, contributing 12% of the global output of combined products (APEDA, 2024). Fruits and vegetables are a key health component of human meals as they offer medicinal, nutritional as well as aesthetic value (Ghani, 2023).

Regardless India being a major global producer of horticultural produce, the country remains a minor exporter of fruits and vegetables (Ghani, 2023). At global level, India's horticultural output ranks second to China (Mitra, A. and Panda, 2020). Between 2000 and 2019, India's share of agricultural exports to its basket of total exports declined (Krishnakumar, N.B, 2023). In the period 2015-2019 for instance, India had greatest global banana output of 26% with Ecuador and Philippines at 5,69% and 5,15% respectively, yet the latter countries exported more than India itself (Ghani, 2023). In the nuts category, India's crop output has fallen from a special prominence of the 1970s-1908s where it was a major foreign currency earner to less than a 1% share of current exports (Mouzam, 2020). The country's export market share of nuts has been subsumed by low cost producers from Africa and Latin America, yet, the same exports continue to face strict certification and compliance standard requirements (Thakur *et al*, 2022).

Of late however, the huge rise in the health enhancing vegetables and fruit consumption has induced interest in the microbiological safety of the same agricultural products (Klapec, 2022). In that regard, India's exports of fruits, nuts and vegetables to the EU face huge regulatory constraints. The exports are met with a plethora of food safety compliance measures (Brummer, B., Fiankor, D,D. and Haase, 2020).

The EU General Food Law shoulder responsibility on private sector along the food supply chain that operators have the sole primary legal responsibility to ensuring food safety (Rao, 2021). Among the EU Sanitary and Phytosanitary (SPS) agricultural regulations meant to protect plant health, the Maximum Residue Limits (MRL) have become a focal point of a growing trade concerns for exporting developing countries (Hejazi, M. Grant, J.H and Peterson, 2022). These regulations apply to agricultural products like fruits, nuts and vegetables, among others (Son,D.A and Vang-Phu, 2021). Key to note that, the EU employs the Rapid Alert System for Food and Feed (RASFF) to screen agricultural exports as a way of guarding against disease in both humans. The occurrence of mycotoxins in agricultural crops induce adverse health effects in human (Eskola, 2020). The common mycotoxins include aflatoxins in nuts; ochratoxin, patulin, alternaria toxins, and trichothecenes in fruits and vegetables (Klapec, 2022). From the health perspective, mycotoxins exude nephrotoxic, genotoxic, teratogenic, carcinogenic and cytotoxic properties that cause liver carcinomas, renal dysfunctions and immunosuppressed conditions in humans (Klapec, 2022). Despite the introduction of good agricultural practices in the food value chain, food diseases remain a permanent challenge. India's horticultural exports to the EU face rejections due to violation of EU SPS standards (Assoua, 2022).

Studies in general on impact of non-tariff measures like SPS requirements on export performance of agricultural products have yielded varied results for developing countries. For most empirical studies, non-tariff measures act as trade inhibiting (Assoua, 2022). (Nabeshima (2021) examined the extra regulatory burdens when serving foreign markets. Using the additional compliance requirement indicator (ACRI), the study estimated the impact of regulatory burdens on bilateral trade. Results of the study showed that regulatory burdens were trade inhibiting at the extensive margin of trade.

India being one of the top horticultural producers globally, the country has minimal share in the world horticultural export trade. With India's agricultural exports having shifted to high income countries like the E.U, exports of fruits, vegetables, as well as nuts, face a major hurdle of rejection due to non-compliance to sanitary and phytosanitary (SPS) standards (Chatterjee *et al.*, 2023). The market access obstacles include all forms of non-tariff measures imposed by developing countries (Hejazi, M. Grant, J.H and Peterson, 2022). Compliance with SPS and MRLs based standards and regulations is challenging for Indian firms and growers (Kallummal, M., and Gurung, 2020). Be that as it may, there is ongoing debate on standards-trade effect as the direction of same yields ambiguity on the 'standards as barriers or catalysts to trade'(Brummer. B., Fiankor. D., and Haase, 2021). In the case of the EU, India, as an agricultural exporting country, has to comply with the EU's Regulation 396/2005 to access the same market, the same regulation noted to be imposing heavy trade restrictions (Lamonaca.E and Santeramo,F.G, 2022). Be that as it may, the few available has since shown that with adequate research and development, horticulture in India can be considered as a commercial opportunity (Mitra, A., and Panda, 2020).

METHOD AND TOOLS

This study employs econometric tools to determining the impact of NTBs on horticultural products of FNV. This study takes a comprehensive approach by utilizing panel data of three agricultural export items across 20 years, from 2002 to 2021 and employs the Gravity model for regression analysis. Data on Indian fruits and vegetables exports to the E.U plus UK were obtained from the United Nationals Commodity Trade Statistics database (UN COMTRADE) and APEDA.

The Gravity model is used as a workhorse International Economics and has been one of the most successful empirical models guiding policy decisions (Abhishree, 2024). The dependent variable is India's exports of fruits and vegetables to the E.U and the independent variables are: Gross Domestic Products (GDPs) of India and all the E.U 27 countries; Population, Distance; Common language; Regulation; Colony; Tariffs; Island; and Bilateral Trade Agreement (BTA) are independent variables. The impact of food standards on exports of India's fruits and vegetables was analysed using the regression model:

$$\text{Log } (X_{ik}) = \alpha + \beta 1\log (Y_i.Y_k) + \beta 2\log (Y_i/pop_i.\ Y_k/pop_k) + \beta 3 \log (Dist_{ik}) + \beta 4 (Rej_{ik}) + \beta 5 (Exchrat_{ik}) + \beta 6 (Tarif_{ik}) + \beta 7 (Col) + \beta 8 (landlocked_{ik}) + \beta 9 (Comlang) + \beta 10 \text{ BTA} + \mu_{ik}$$

Where countries i and k are India and the E.U27 countries respectively.

X_i is the value of India's exports of fruits, nuts and vegetables to the E.U 26 plus U.K in million USD. A is a constant term, Y_i is the GDP of country *i; Yk* is the GDP of country *j*, Y_{ik}/pop_{ik} is per capita GDP of countries *i* and *k*; D_{ik} is the distance in nautical miles between ports of importing country *k*, the E.U countries and exporting country, *i*, India (Mumbai port). Rej, represents the number of Indian goods consignments rejected by the E.U with Exchange representing the nominal exchange rate, μ is the regression error term.

RESULTS PRESENTATION

The present results from a gravity-model assessment of how EU food regulations and market frictions shape India's exports of vegetables, fruits, and nuts to EU-27 and the UK. The study first highlights descriptive statistics and a correlation matrix to document the scale, dispersion, and co-movement of trade flows and covariates (GDP, population, distance, exchange rate, MFN tariffs, common language, and landlocked status). The core econometric work uses Stata with PPML estimators implemented via ppmlhdfe, which handle many zeros and heteroskedasticity and allow us to compare a Standard gravity (GDPs + distance) and an Augmented gravity (adding exchange rate, MFN tariffs, language, landlocked) specification. Each is estimated without fixed effects and with exporter/year fixed effects (and, where noted, importer FE), absorbing unobserved multilateral resistance and time shocks; robust standard errors are reported. As robustness, we also estimate linear fixed-effects (FE) and random-effects (RE) panel models using xtreg, fe and xtreg, re, and apply the Hausman test (hausman) to diagnose systematic differences between FE and RE (guiding interpretation while retaining PPML-FE as our headline). Across tables, we report coefficient estimates, significance, fit (Pseudo R^2), absorbed degrees of freedom, and—where relevant—omitted variables due to collinearity with fixed effects.

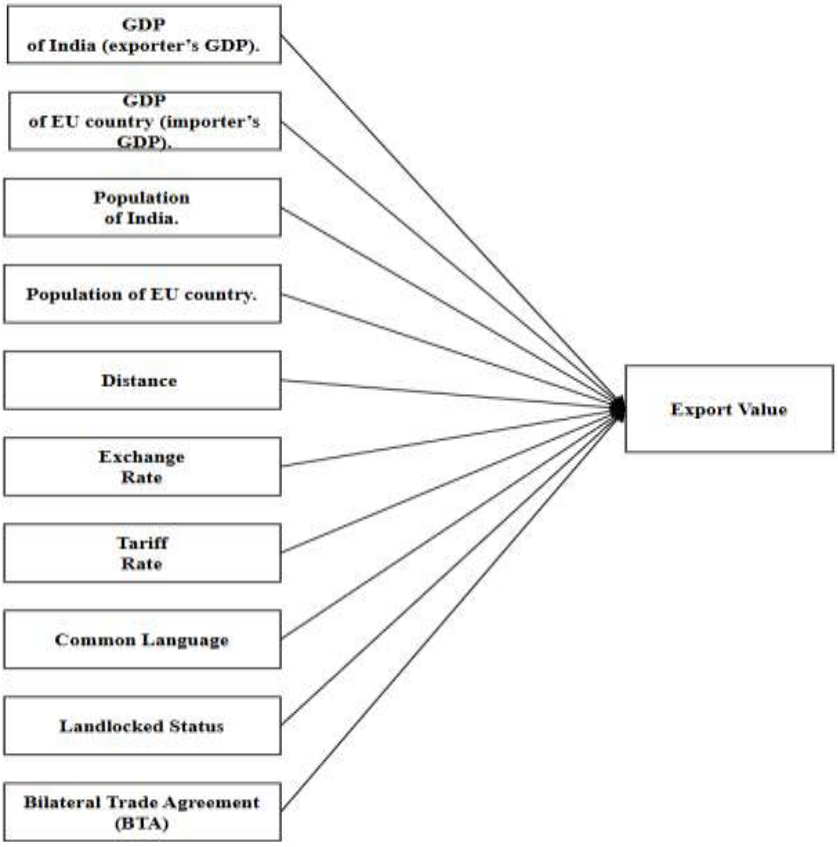


Figure 1 Conceptual Frame work

Table 1 Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Vegetables exp	560	68051.089	124687.85	0	606800

Fruits exp value	560	5030.782	17453.085	0	144826
Nuts exp value	560	6824.306	14816.261	0	96833.102
GDP exp	560	1.750e+12	7.969e+11	5.100e+11	3.200e+12
GDP imp	560	6.032e+11	9.282e+11	4.500e+09	4.300e+12
PPL of exp	560	1.265e+09	1.015e+08	1.100e+09	1.400e+09
PPL of imp	560	18003524	22848009	395969	83000000
Distance	560	5974.29	1169.086	4175.16	10435.1
Exchange rate	560	98.468	6.93	62.24	129.3
MFN tariff rate	560	69.2	90.907	0	378
Common lang	560	.107	.31	0	1
Land locked status	560	.179	.383	0	1
BTA	560	0	0	0	0

Export values are highly skewed with many small or zero flows and a long right tail. Vegetables average US$68.1k (thousand USD; SD 124.7k), spanning 0 to 606.8k; fruits average US$5.0k (SD 17.5k; range 0–144.8k); nuts average US$6.8k (SD 14.8k; range 0–96.8k). The zeros justify PPML rather than log-OLS, and the wide dispersion signals strong heterogeneity across partner markets and time. India's exporter GDP averages US$1.75 trillion (range 0.51–3.2 trillion), consistent with rapid growth over the sample. Importer GDP (partner-specific EU/UK level) averages US$603.2 billion with very wide dispersion (US$4.5 billion to US$4.3 trillion), reflecting the mix of small EU members and large economies (e.g., Germany). Populations show similar heterogeneity: India averages 1.265 billion (range 1.1–1.4 billion), while importer populations average 18.0 million but range from ≈0.4 to 83 million.

Geography is largely time-invariant: mean great-circle distance ≈ 5,974 (units as in source; SD 1,169), spanning 4,175–10,435, capturing near versus far EU partners. Common language equals 1 in 10.7% of dyads and landlocked equals 1 in 17.9%, so there is adequate cross-sectional variation to identify these effects in no-FE models (they will be absorbed when importer FE are used). The exchange rate (mean 98.47, SD 6.93) varies meaningfully over time; interpreted as INR per USD, higher values (weaker rupee) may correlate with larger recorded export values via price competitiveness and valuation effects. The MFN tariff rate averages 69.2 (SD 90.9, min 0, max 378), indicating large dispersion across products/partners/years; this richness helps identify policy-friction channels. The BTA dummy is 0 for all observations, confirming no bilateral trade agreement between India and the EU/UK in 2002–2021; accordingly, BTA will drop from augmented regressions for lack of variation.

Overall, these moments support a gravity design with PPML, time fixed effects, and (where desired) importer fixed effects to handle zeros, heteroskedasticity, and unobserved multilateral resistance, while exploiting substantial variation in GDPs, exchange rate, tariffs, and market characteristics.

Table 2 Matrix of correlations

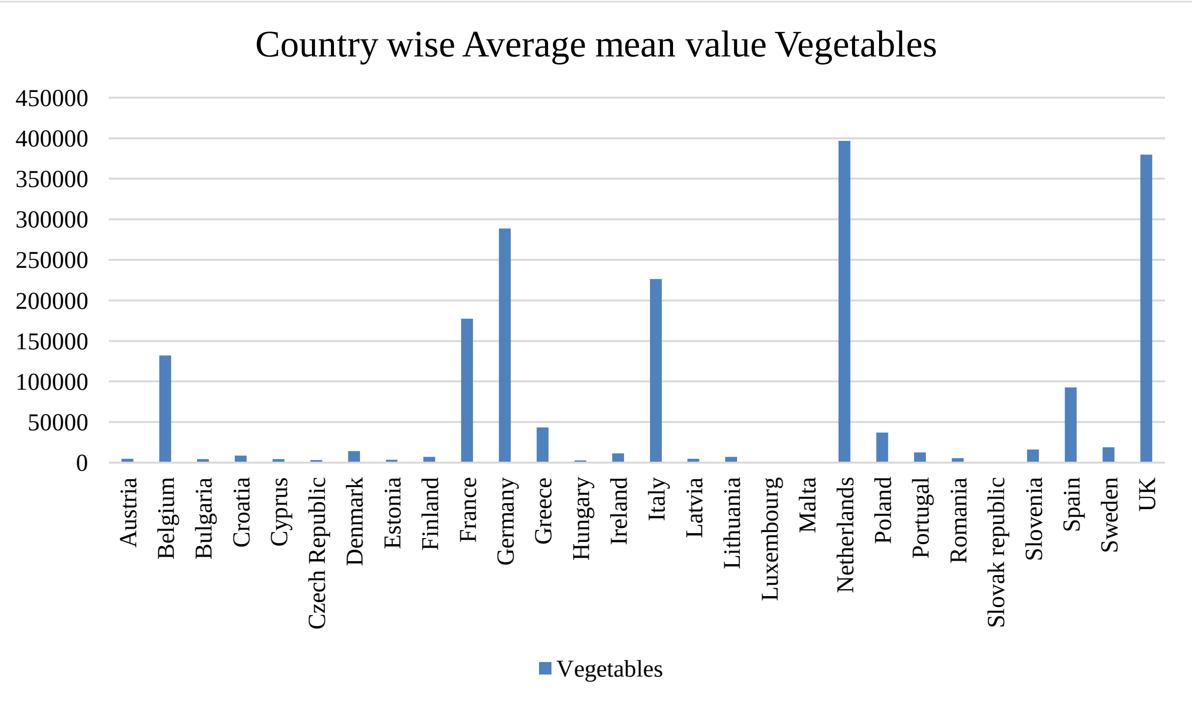
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(1) vegetables exp	1.000												
(2) Fruits exp value	0.763	1.000											
(3) Nuts exp value	0.770	0.762	1.000										
(4) GDP exp	0.168	0.151	0.010	1.000									
(5) GDP imp	0.767	0.312	0.444	0.074	1.000								
(6) PPL of exp	0.174	0.146	0.027	0.962	0.075	1.000							
(7) PPL of imp	0.678	0.220	0.380	0.011	0.945	0.011	1.000						
(8) Distance	0.177	0.109	0.172	-0.000	0.247	0.000	0.189	1.000					
(9) Exchange rate	0.126	0.103	0.138	-0.110	0.165	-0.096	0.124	0.145	1.000				
(10) MFN tariff rate	0.796	0.480	0.625	0.128	0.824	0.131	0.798	0.198	0.130	1.000			
(11) Common language	0.174	0.135	0.031	0.000	0.145	0.000	0.073	0.172	0.109	0.074	1.000		
(12) land locked status	-0.246	-0.132	-0.204	-0.000	-0.221	-0.000	-0.226	0.241	-0.130	-0.258	0.140	1.000	
(13) BTA	.	.	.	.	.	.	.	.	.	.	.	.	.

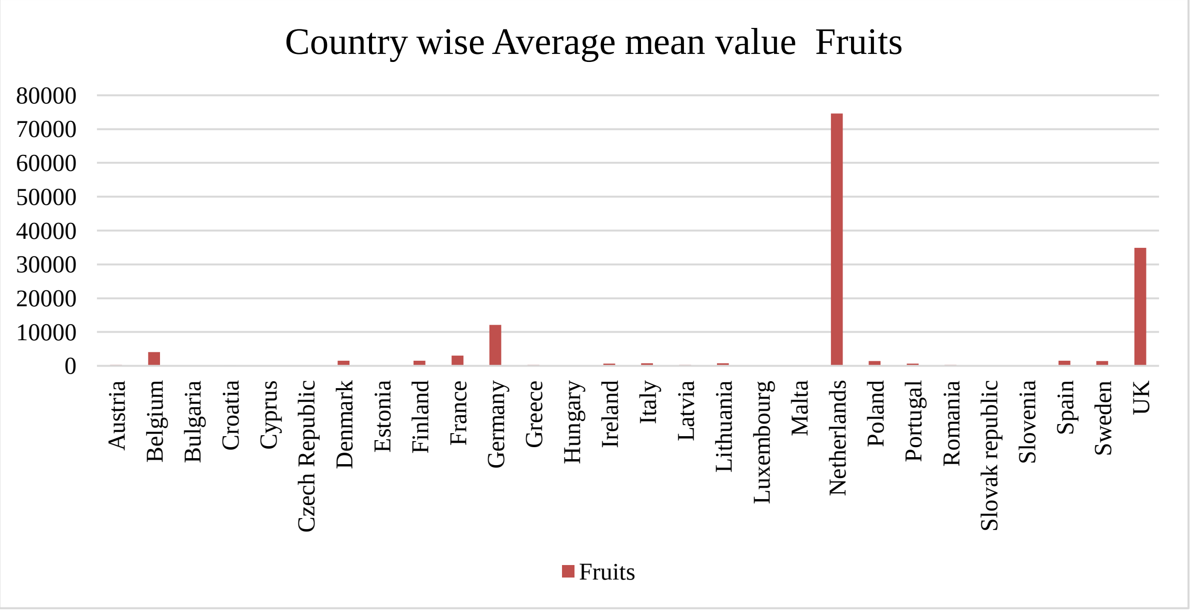
The correlation matrix shows three things. First, India's three export series move together strongly (veg–fruit 0.76, veg–nuts 0.77, fruit–nuts 0.76), consistent with common demand/supply shocks across EU/UK partners. Second, market size on the importer side aligns closely with exports: vegetables correlate highly with GDP imp (0.77) and with importer population PPL of imp (0.68), while MFN tariff rate is also strongly associated with vegetables (0.80) and with GDP imp/PPL of imp (0.82/0.80), signaling that tariff variation is not random but linked to partner size/composition an endogeneity warning for naïve models. Third, there is substantial collinearity among "size" variables: GDP exp–PPL of exp (0.96) and GDP imp–PPL of imp (0.95). This means including GDP and population together (without transforming to per-capita or using fixed effects) can inflate standard errors and distort coefficients; our FE/PPML strategy counters this. Distance correlates modestly and positively with exports (≈0.11–0.18) and with being landlocked (0.24), while land locked status is negatively correlated with all export series (−0.13 to −0.25), matching the strong negative landlocked effects in the regressions. The exchange rate shows only mild positive correlations with exports (0.10–0.14). Common language has weak positive correlations with exports (0.13–0.17). The BTA variable is missing (all dots), confirming zero variation. Overall, the matrix supports the gravity narrative (partner size matters; access frictions hinder trade) and motivates fixed effects and careful handling of highly collinear size variables and potentially endogenous tariffs.

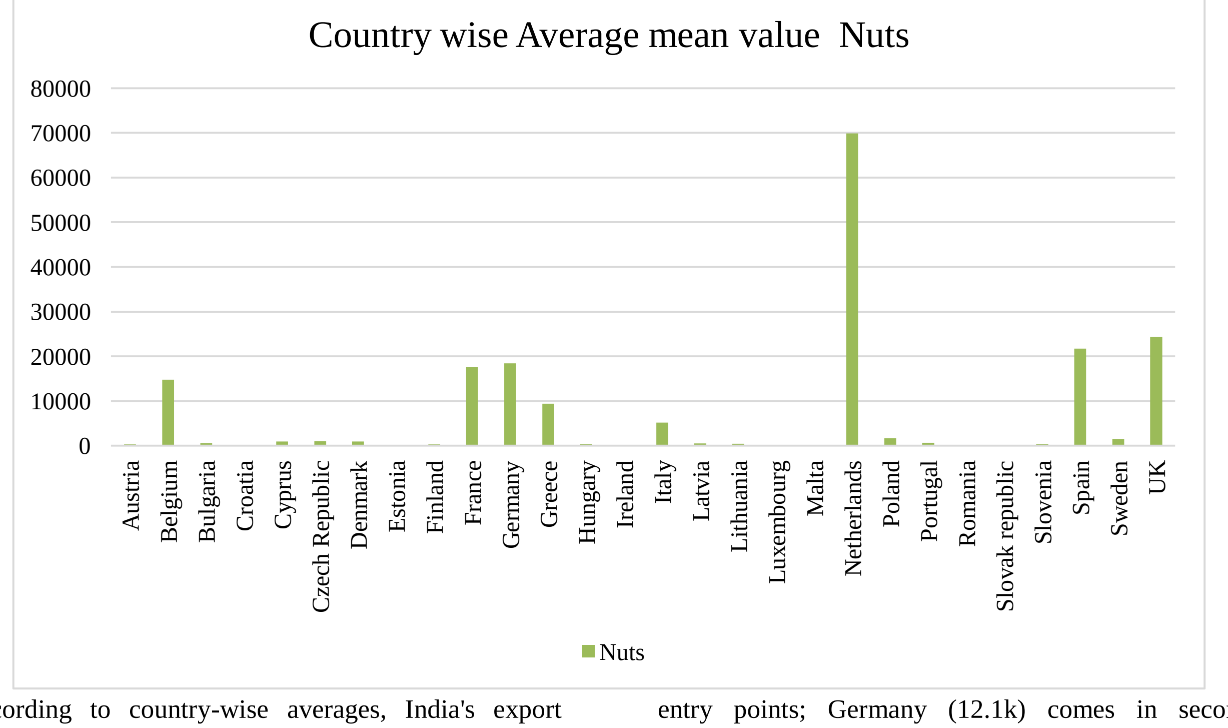
Table 3 Country Wise Average Mean Values

Countries	Vegetables	Fruits	Nuts
Austria	4766.883	268.151	327.221
Belgium	132194.1855	4114.688	14746.904
Bulgaria	4327.961	73.2965	595.1255
Croatia	8593.6865	183.134	77.6005
Cyprus	4498.1	82.1855	923.8455
Czech Republic	3145.8805	85.5555	1010.238

Denmark	14279.2645	1528.465	909.953
Estonia	3624.911	18.152	107.253
Finland	7232.3875	1546.934	303.0415
France	177292.736	3054.0315	17600.956
Germany	288818.3835	12127.146	18418.9055
Greece	43275.333	285.9835	9403.1035
Hungary	2731.3905	22.348	333.2155
Ireland	11288.407	651.2765	85.2685
Italy	226449.427	754.5135	5142.3935
Latvia	4755.178	271.932	478.4325
Lithuania	7297.5695	791.683	467.628
Luxembourg	57.1235	0.0045	14.658
Malta	604.342	12.479	12.654
Netherlands	396671.0435	74604.48	69867.579
Poland	37201.9585	1401.157	1628.2335
Portugal	12785.5465	680.448	620.844
Romania	5547.3645	336.498	55.4545
Slovak republic	411.175	2.153	19.7525
Slovenia	16133.659	91.3795	340.613
Spain	92510.1305	1567.5965	21718.396
Sweden	19064.7315	1425.9905	1499.8045
UK	379871.4375	34880.2065	24371.4595







According to country-wise averages, India's export market is in the EU and the UK. In general, Germany, Italy, France, and Spain make up a strong second tier of travel destinations, while the Netherlands and the UK stand out across all categories. Smaller and landlocked economies, such as Luxembourg, Malta, Slovakia, and Estonia, purchase very less. With the Netherlands (396.7k), UK (379.9k), Germany (288.8k), Italy (226.4k), France (177.3k), and Spain (92.5k) leading the vegetable industry, scale concentrates in a few major transportation hubs and high-income countries. There is even more concentration of fruits: the Netherlands (74.6k) and the UK (34.9k) dwarf others, indicating that Rotterdam and the UK are important entry points; Germany (12.1k) comes in second. Mediterranean processing/consumption habits are reflected in the distinct demand for nuts in Spain (21.7k), the Netherlands (69.9k), the UK (24.4k), Germany (18.4k), France (17.6k), and Greece (9.4k). In all three areas, Belgium and Sweden outperform Italy, which is a top consumer of vegetables but mediocre in fruits and nuts. The majority of Eastern members, such as Bulgaria, Romania, and Hungary, continue to be minor outlets. From a strategic standpoint, this means concentrating on Italy, Germany, the Netherlands, and the UK for vegetables; giving the Netherlands and the UK priority for fruits (with Germany as a backup); and concentrating on nuts in Spain, the Netherlands, the

UK, Germany, and France, as well as Greece for specialist markets. Opportunities exist for serving low-volume markets, but the main six hubs will provide the greatest returns on compliance, logistical integration, and buyer alliances.

Dependent variable = vegetables export value, thousand USD.

BASELINE STANDARD GRAVITY MODEL ESTIMATION RESULTS

Table 4 Standard, PPML, without FE

Vegetables exp value	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ln_gdp_exp	.472	.09	5.23	0	.295	.649	***
ln_gdp_imp	.973	.03	32.26	0	.914	1.032	***
ln_distance	-.359	.233	-1.54	.123	-.815	.097	
Constant	-25.405	3.206	-7.93	0	-31.688	-19.123	***

Mean dependent var	68051.089	SD dependent var	124687.846
Pseudo r-squared	0.749	Number of obs	560
Chi-square	1375.698	Prob > chi2	0.000
Akaike crit. (AIC)	21877534.389	Bayesian crit. (BIC)	21877551.700
*** *p<.01, ** p<.05, * p<.1*			
BTA omitted due to no variation (all zeros, 2002–2021)			

With values of 0.47 and 0.97, respectively (p<0.01), India's vegetable exports are increased by both India's export capability (namely, India's GDP) and destination-market demand (specifically, the GDP of the EU and the UK that imports the vegetables). India's distance from each of its partners in the EU and the UK is negative, but it is imprecise and does not have any permanent implications. It is confirmed that the gravity core explains a significant portion of the variance in India-EU-UK exports, even before the inclusion of policy frictions or fixed effects, since the overall fit is strong (Pseudo R 0.75).

Table 5 Standard, PPML, with FE exporter & time

Vegetables exp value	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ln_gdp_imp	.974	.029	33.56	0	.917	1.031	***
ln_distance	-.362	.227	-1.59	.111	-.807	.083	
Constant	-12.059	1.764	-6.84	0	-15.517	-8.602	***

Mean dependent var	68051.089	SD dependent var	124687.846
Pseudo r-squared	0.759	Number of obs	560
Chi-square	1368.443	Prob > chi2	0.000
Akaike crit. (AIC)	20994071.846	Bayesian crit. (BIC)	20994084.830
*** *p<.01, ** p<.05, * p<.1*			
Time-varying exporter GDP is collinear with year FE and is omitted			

The majority of India's vegetable exports are driven by the country's gross domestic product (EU+UK), with an elasticity of 0.974* (SE 0.029), which is a substantial and accurately approximated value. The value of distance is negative (-0.362), but it is not statistically significant (p=0.111), which is consistent with fixed effects absorbing a major portion of the time-invariant longitudinal variation. The model seems to be a good match (Pseudo R2 = 0.759, N = 560), and the joint significance is substantial ($\chi2$ = 1368.4, p<0.001). In addition to being substantial, the constant is negative. It was anticipated that India's GDP would be collinear with year FE in a single-exporter panel with year FE; hence, it was taken out of consideration.

Table 6 Absorbed degrees of freedom

Absorbed FE	Categories	-Redundant	=Num. Coef's
Exp country	1	0	1
Imp country	28	1	27
Years	20	1	19

Exporter (India), importer (EU-27+UK), and year are the three sets of effects that we take into account while using the fixed-effects PPML model. With one exporter category (India) contributing one coefficient, the absorbed-DF readout reveals that there are 27 importer FE coefficients, 28 importer categories with one redundant (the base), and 20 years with one redundant, resulting in 19-year FE coefficients respectively. All time-invariant importer differences, such as location and institutions, as well as common shocks throughout time, such as global demand and policy cycles, are taken into account by the model, in addition to the exporter level considerations. As a consequence of this, you may anticipate that factors that are absolutely collinear with these FE, such as distance, language, landlocked, and India's GDP with year FE, would be excluded.

AUGMENTED GRAVITY MODEL ESTIMATION RESULTS

Table 7 Augmented, PPML, without FE

Vegetables exp	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ln_gdp_exp	.67	.131	5.11	0	.413	.927	***
ln_gdp_imp	.593	.094	6.31	0	.409	.778	***
ln_distance	.853	.338	2.52	.012	.19	1.515	**
ln_exchng	2.639	.79	3.34	.001	1.091	4.188	***
MFN tariff rate	.003	.001	2.83	.005	.001	.006	***
Common lang	-.053	.122	-0.44	.662	-.293	.186	
Land locked status	-2.47	.158	-15.65	0	-2.779	-2.161	***
BTA	0	.	.	.	.	.	
Constant	-43.701	8.28	-5.28	0	-59.93	-27.472	***

Mean dependent var	68051.089	SD dependent var	124687.846
Pseudo r-squared	0.815	Number of obs	560
Chi-square	4288.392	Prob > chi2	0.000
Akaike crit. (AIC)	16111307.612	Bayesian crit. (BIC)	16111342.235
**** p<.01, ** p<.05, * p<.1*			
BTA omitted due to no variation (all zeros, 2002–2021)			

In the enhanced PPML model without fixed effects, India's gross domestic product (GDP) of 0.67*** and the GDP of the EU/UK importer of 0.593*** both greatly increase India's vegetable exports, demonstrating the impacts of supply capacity and destination demand. There is a correlation between a lower rupee (ln_exchng = 2.639***) and increased exports that have been observed. There is a little but positive semi-elasticity (0.003**) associated with the MFN tariff, but the common language is quite negligible. Importers who are landlocked make much fewer purchases (-2.47***). Distance is positive (0.853), which is an unusual result that most likely indicates unobserved market-size/routing effects when fixed variables are not included in the analysis. There is a good match between the model and the data (Pseudo R2 is around 0.815; N=560; $\chi 2$ $p<0.001$). As there is no fluctuation (all zeros, 2002–2021), the BTA dummy has been excluded from the analysis. Dependent variable expressed in thousand US dollars; robust SE.

Table 8 Augmented, PPML, with FE exporter & time

Vegetables exp value	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
o	0	.	.	.	.	.	
ln_gdp_imp	.336	.066	5.09	0	.207	.466	***
ln_distance	1.05	.35	3.00	.003	.363	1.737	***
ln_exchng	1.978	.715	2.76	.006	.576	3.38	***
MFN tariff rate	.008	.001	9.24	0	.006	.009	***
Common lang	-.018	.113	-0.16	.874	-.239	.203	
Land locked status	-2.323	.148	-15.65	0	-2.614	-2.032	***
BTA	0	.	.	.	.	.	
Constant	-17.097	4.422	-3.87	0	-25.763	-8.431	***
Mean dependent var	68051.089	SD dependent var	124687.846				
Pseudo r-squared	0.860	Number of obs	560				
Chi-square	3079.362	Prob > chi2	0.000				
Akaike crit. (AIC)	12174234.186	Bayesian crit. (BIC)	12174264.482				
**** p<.01, ** p<.05, * p<.1*							
BTA omitted due to no variation (all zeros, 2002–2021)							

The enlarged PPML findings reveal that the importer GDP (EU/UK) continues to be a powerful and accurate driver of India's vegetable exports (0.336*), even when exporter (India) and year fixed effects are taken into account. An uncommon indication that most likely indicates route/market-size impacts when importer fixed variables are not included is shown by the fact that distance enters a positive and substantial value (1.05*). Significantly greater reported exports are related with a weaker rupee (ln_exchng = 1.978*) and a higher MFN tariff (0.008* per unit), whereas the shared language has no effect on the situation. Importers who are landlocked make much fewer purchases (-2.323*). It is evident that the model fits the data quite well (Pseudo R2 = 0.860; N = 560; $\chi 2$ p < 0.001). India's GDP is collinear and deleted, as was anticipated with exporter–time FE in a single-exporter panel; the dependent variable is thousand USD, and robust statistics were used.

Table 9 Absorbed degrees of freedom

Absorbed FE	Categories	- Redundant	= Num. Coef's
Exp country	1	0	1
Imp country	28	1	27
Years	20	1	19

The exporter (India), the importer (EU-27+UK), and the year are the three sets of dummies that use into the improved PPML with fixed effects calculation. According to the absorbed-DF readout, the exporter has one category, which results in one coefficient; importers have 28 categories, but one of them acts as the basis, which results in 27 importer FE coefficients being calculated; years have twenty categories, but only one base, which results in an estimated 19-year FE coefficient. With this, all time-invariant importer heterogeneity, such as location and institutions, as well as common shocks per year, such as global demand and policy cycles, are controlled for, in addition to the exporter level. It is anticipated that variables that are absolutely collinear with these FE, such as distance, shared language, that India is landlocked, and India's GDP with year FE, would be eliminated.

Dependent variable = Fruits export value, thousand USD

BASELINE STANDARD GRAVITY MODEL ESTIMATION RESULTS

Table 10 Standard, PPML, without FE

Fruits exp value trade	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ln_gdp_exp	1.05	.28	3.75	0	.501	1.598	***
ln_gdp_imp	.847	.051	16.63	0	.747	.947	***
ln_distance	.605	.332	1.82	.068	-.045	1.256	*
Constant	-49.274	8.179	-6.02	0	-65.305	-33.244	***
Mean dependent var	5030.782	SD dependent var	17453.085				
Pseudo r-squared	0.409	Number of obs	560				
Chi-square	395.525	Prob > chi2	0.000				
Akaike crit. (AIC)	6767830.047	Bayesian crit. (BIC)	6767847.359				
*** *p<.01, ** p<.05, * p<.1*							

Both India's gross domestic product (1.05***) and the GDP of importers (0.847***) bring about a considerable increase in fruit exports, therefore verifying both supply capacity and destination demand. India is an exporter, while the EU-27 and the UK are importers. It seems plausible that distance is picking up unobserved route/market-size effects in the absence of fixed effects, since it is positive and marginal (0.605*, p=0.068 respectively). There is a reasonable level of fit (Pseudo $R^2 \approx 0.41$; N=560), and the model is jointly significant (χ^2 p<0.001). Before taking into account any policy frictions or fixed effects, this indicates the baseline gravity standard.

Table 11 Standard, PPML, with FE exporter & time

Fruits exp value trade	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
o	0	.	.	.	.	.	
ln_gdp_imp	.847	.05	16.93	0	.749	.945	***
ln_distance	.603	.334	1.81	.071	-.052	1.257	*
Constant	-19.508	2.848	-6.85	0	-25.09	-13.925	***
Mean dependent var	5030.782	SD dependent var	17453.085				
Pseudo r-squared	0.416	Number of obs	560				
Chi-square	341.440	Prob > chi2	0.000				
Akaike crit. (AIC)	6688075.354	Bayesian crit. (BIC)	6688088.338				
*** *p<.01, ** p<.05, * p<.1*							

After taking into account the impacts of India (an exporter) and the year, the variables that are collinear with those FE decline (India's GDP), but the GDP of importers continues to be big and highly significant (0.847***). Although the distance remains slightly positive (0.603*, p≈0.071), it indicates that there is still bilateral variability that is not reflected by current FE statistics. There is a minor improvement in fit (Pseudo R≈≈0.416; N=560), which indicates that fixed effects lessen the bias caused by missing variables and sharpen inferences on the demand for India's fruit exports at their destination.

Table 12 Absorbed degrees of freedom

Absorbed FE	Categories	- Redundant	= Num. Coef's
Exp country	1	0	1
Years	20	1	19

The exporter FE gives a single coefficient to each category, whereas the year FE assigns 19 coefficients to each of the twenty categories that have a single basis. In order to exclude exporter-specific characteristics and common temporal shocks, these controls eliminate any variable that is fully collinear with them. For example, India's GDP with year FE is not included in the creation of the model.

AUGMENTED GRAVITY MODEL ESTIMATION RESULTS

Table 13 Augmented, PPML, without FE

Fruits exp value	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ln_gdp_exp	1.549	.403	3.84	0	.759	2.34	***
ln_gdp_imp	-.064	.295	-0.22	.828	-.642	.514	
ln_distance	3.975	.837	4.75	0	2.333	5.616	***
ln_exchng	7.321	1.879	3.90	0	3.639	11.004	***
MFN tariff rate	.01	.004	2.53	.011	.002	.018	**
Common lang	-.2	.264	-0.76	.449	-.718	.318	
Land locked status	-4.048	.457	-8.85	0	-4.945	-3.151	***
BTA	0	.	.	.	.	.	
Constant	-103.149	23.427	-4.40	0	-149.065	-57.233	***

Mean dependent var	5030.782	SD dependent var	17453.085
Pseudo r-squared	0.596	Number of obs	560
Chi-square	1292.245	Prob > chi2	0.000
Akaike crit. (AIC)	4622533.795	Bayesian crit. (BIC)	4622568.419
**** p<.01, ** p<.05, * p<.1*			
BTA omitted due to no variation (all zeros, 2002–2021)			

frictions, India's GDP remains positive (1.549***), while importer GDP turns insignificant (−0.064). Distance becomes strongly positive (3.975***), consistent with scale/routing effects when FE are absent. A weaker rupee (ln_exchng=7.321***) and higher MFN tariff (0.010**) are associated with larger recorded exports, landlocked importers buy less (−4.048***), and common language is irrelevant. Fit rises substantially (Pseudo $R^2 \approx 0.596$; N=560), showing policy/macro variables materially improve explanatory power for India→EU/UK fruit exports.

Table 14 Augmented, PPML, with FE exporter & time

Fruits exp value trade	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
o	0	.	.	.	.	.	
ln_gdp_imp	-.423	.259	-1.63	.102	-.93	.084	
ln_distance	4.874	.99	4.92	0	2.933	6.815	***
ln_exchng	7.808	2.108	3.70	0	3.675	11.94	***
Mfn tariff rate	.017	.003	5.18	0	.01	.023	***
Common lang	-.163	.25	-0.65	.515	-.653	.328	
Land locked status	-3.979	.553	-7.19	0	-5.063	-2.895	***
BTA	0	.	.	.	.	.	
Constant	-60.75	14.166	-4.29	0	-88.515	-32.985	***

Mean dependent var	5030.782	SD dependent var	17453.085
Pseudo r-squared	0.663	Number of obs	560
Chi-square	564.151	Prob > chi2	0.000
Akaike crit. (AIC)	3858791.204	Bayesian crit. (BIC)	3858821.500
**** p<.01, ** p<.05, * p<.1*			
BTA omitted due to no variation (all zeros, 2002–2021)			

With India and year FE, importer GDP becomes negative but imprecise (−0.423, p=0.102), while distance remains positive and significant (4.874***), the exchange rate effect persists (7.808***), and MFN tariff gains strength (0.017***). Landlocked importers still buy markedly less (−3.979***); common language remains insignificant. The fit is strong (Pseudo $R^2 \approx 0.663$; N=560). These results suggest that, conditional on FE, regulatory/macro channels (tariffs, exchange rate) and structural access constraints (landlocked) are key correlates of India's fruit export performance.

Table 15 Absorbed degrees of freedom

Absorbed FE	Categories	- Redundant	= Num. Coef's
Exp country	1	0	1
Years	20	1	19

Exporter FE: 1 category → 1 coefficient; Year FE: 20 categories with one base → 19 coefficients. These FE capture exporter-level heterogeneity and time shocks, explaining why exporter-time–collinear variables may be omitted and why bilateral time-invariant factors can show atypical signs without importer FE.

Dependent variable = Nuts export value, thousand USD

BASELINE STANDARD GRAVITY MODEL ESTIMATION RESULTS

Table 16 Standard, PPML, without FE

Nuts exp value trade	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ln_gdp_exp	-.121	.157	-0.77	.44	-.428	.186	
ln_gdp_imp	.787	.032	24.29	0	.724	.851	***
ln_distance	.52	.285	1.82	.068	-.039	1.078	*
Constant	-13.515	5.1	-2.65	.008	-23.511	-3.518	***
Mean dependent var	6824.306	SD dependent var	14816.261				
Pseudo r-squared	0.461	Number of obs	560				
Chi-square	757.968	Prob > chi2	0.000				
Akaike crit. (AIC)	5589865.530	Bayesian crit. (BIC)	5589882.842				
**** p<.01, ** p<.05, * p<.1*							

For nuts exports (thousand USD), importer GDP (EU-27+UK) is the core driver (0.787*), while India's GDP is small and insignificant (−0.121). Distance is positive and marginal (0.520, $p=0.068$), likely capturing unobserved scale/routing effects in the absence of fixed effects. The model is jointly significant (χ^2 $p<0.001$) with moderate fit (Pseudo $R^2 \approx 0.46$; N=560). This is the baseline gravity benchmark for nuts: demand in partner markets matters strongly; supply-side variation from India is not informative in this parsimonious, no-FE specification.

Table 17 Standard, PPML, with FE exporter & time

Nuts exp value trade	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
o	0	.	.	.	.	.	
ln_gdp_imp	.788	.031	25.07	0	.726	.849	***
ln_distance	.516	.288	1.79	.073	-.048	1.08	*
Constant	-16.883	2.301	-7.34	0	-21.393	-12.373	***
Mean dependent var	6824.306	SD dependent var	14816.261				

Pseudo r-squared	0.477	Number of obs	560
Chi-square	820.131	Prob > chi2	0.000
Akaike crit. (AIC)	5424946.015	Bayesian crit. (BIC)	5424958.999
*** *p<.01, ** p<.05, * p<.1*			

Absorbing exporter (India) and year fixed effects, importer GDP remains large and highly precise (0.788*), confirming partner-side demand as the dominant margin for India's nuts exports. Distance stays marginally positive (0.516, p≈0.073). Fit improves slightly (Pseudo R^2≈0.48; N=560), indicating FE help reduce omitted-variable bias from exporter-specific trends and time shocks. Variables collinear with these FE (e.g., India's GDP with year FE) drop by construction, which is expected in a single-exporter panel.

Table 18 Absorbed degrees of freedom

Absorbed FE	Categories	- Redundant	= Num. Coef's
Exp country	1	0	1
Years	20	1	19

Exporter FE: 1 category → 1 coefficient; Year FE: 20 categories with 1 base → 19 coefficients. These controls purge exporter-level heterogeneity and common time shocks, so any regressor perfectly collinear with them (e.g., India's GDP with year dummies) is omitted in the FE specification.

Augmented Gravity Model Estimation Results

Table 19 Augmented, PPML, without FE

Nuts exp value trade	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ln_gdp_exp	-.07	.187	-0.38	.706	-.436	.295	
ln_gdp_imp	.14	.144	0.97	.332	-.142	.422	
ln_distance	3.322	.467	7.11	0	2.407	4.237	***
ln_exchng	2.531	.998	2.54	.011	.576	4.487	**
MFN tariff rate	.007	.002	3.59	0	.003	.011	***
Common lang	-.777	.188	-4.13	0	-1.146	-.409	***
Land locked status	-2.892	.302	-9.58	0	-3.483	-2.3	***
BTA	0	.	.	.	.	.	
Constant	-34.307	10.736	-3.20	.001	-55.349	-13.265	***
Mean dependent var	6824.306	SD dependent var	14816.261				
Pseudo r-squared	0.597	Number of obs	560				
Chi-square	861.657	Prob > chi2	0.000				
Akaike crit. (AIC)	4184043.724	Bayesian crit. (BIC)	4184078.347				
*** *p<.01, ** p<.05, * p<.1*							
BTA omitted due to no variation (all zeros, 2002–2021)							

With frictions added, distance becomes strongly positive (3.322***), the exchange rate is positive (2.531**), MFN tariff is positive (0.007***), common language turns negative (−0.777***), and landlocked importers buy less (−2.892***). GDP coefficients are weak/insignificant here, suggesting that, without FE, policy/access variables dominate variation in nuts exports. Fit rises substantially (Pseudo R^2≈0.597; N=560; χ^2 p<0.001). This highlights regulatory/macro channels and market access constraints as key correlates of India→EU/UK nuts export values when FE are not included.

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Table 20 Augmented, PPML, with FE exporter & time

Nuts exp value trade	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
o	0	.	.	.	.	.	
ln_gdp_imp	-.099	.106	-0.94	.347	-.306	.108	
ln_distance	3.798	.54	7.04	0	2.741	4.856	***
ln_exchng	1.95	1.143	1.71	.088	-.29	4.19	*
Mfn tariff rate	.012	.001	8.26	0	.009	.015	***
Common lang	-.762	.17	-4.49	0	-1.095	-.429	***
Land locked status	-2.796	.333	-8.39	0	-3.449	-2.143	***
BTA	0	.	.	.	.	.	
Constant	-31.98	6.889	-4.64	0	-45.481	-18.478	***

Mean dependent var	6824.306	SD dependent var	14816.261
Pseudo r-squared	0.667	Number of obs	560
Chi-square	620.012	Prob > chi2	0.000
Akaike crit. (AIC)	3457278.336	Bayesian crit. (BIC)	3457308.632
**** p<.01, ** p<.05, * p<.1*			
BTA omitted due to no variation (all zeros, 2002–2021)			

Conditioning on exporter and year FE, importer GDP becomes negative but imprecise (−0.099, p=0.347), while distance remains strongly positive (3.798***), exchange rate is positive and marginal (1.950*), MFN tariff strengthens (0.012***), common language is negative (−0.762***), and landlocked remains strongly negative (−2.796***). The fit is high (Pseudo R^2≈0.667; N=560). Results imply that—after accounting for exporter-time effects—policy/macro frictions and access constraints explain most of the within-time variation in India's nuts exports across EU/UK partners.

Table 21 Absorbed degrees of freedom

Absorbed FE	Categories	- Redundant	= Num. Coef's
Exp country	1	0	1
Years	20	1	19

Exporter FE: 1 → 1 coefficient; Year FE: 20 → 19 coefficients (one base). These FE captures exporter heterogeneity and time shocks, explaining why exporter-time–collinear regressors are omitted and why bilateral, largely time-invariant features may show atypical signs if importer FE are not additionally absorbed.

DISCUSSION

The gravity framework supports a distinct demand-pull from Europe and the UK for fruits, vegetables, and nuts: bigger destination markets routinely buy more from India. This demand channel continues to be the most resilient lever for vegetables when exporter and time effects are taken into account. However, for fruits and nuts, the relative weight moves towards policy and macro frictions once unobserved heterogeneity is taken into account. Practically speaking, the buyer's characteristics and the overall circumstances they encounter during a certain year have a significant impact on India's sales.

Fixed effects are important. By eliminating growth and common shocks unique to India, the inclusion of exporter and year fixed factors significantly increases the estimates' trustworthiness. Interpretation is changed in predictable ways by this correction: the impact of within-partner, year-to-year drivers becomes more apparent, while time-invariant factors (such location and long-run bilateral qualities) lose their influence as importer or year dummies absorb their variation. The pattern emphasises how simple cross-sectional correlations underestimate the significance of developing frictions and overestimate certain "distance-type" effects.

The expanded requirements highlight the importance of policy and macro channels. In line with pricing-to-market behaviour and competitiveness impacts, exchange-rate fluctuations are consistently linked to

India's export performance. In enhanced models, tariff measures—here a tractable stand-in for policy barriers—are closely associated with trade values. Tariffs are not the sole or even the most noticeable way that EU food laws are expressed, but their close relationship supports the notion that policy settings influence compliance costs, preference margins, and product mix decisions. The data clearly shows price-based and regulatory hurdles, particularly for fruits and nuts, which is the message for exporters.

Constraints on market access act as predicted. The fact that landlocked partners routinely import less from India shows how important inland logistics and efficient corridors within Europe remain. However, once fixed effects and richer frictions are taken into account, the raw "distance" variable is no longer a sufficient statistic for trade costs; its sign and precision vary across models, reflecting how the simple geographic gradient can be blurred by contemporary supply chains, routing decisions, and product specialisation.

Following controls, language and comparable historical linkages do not matter, indicating that compliance, logistics, and market size—rather than soft-information frictions—are the binding restrictions for agri-food items. This is in line with the experience of Indian agri-exporters, who place a higher value on consistent quality, certification, and technical standards than on cultural closeness.

When combined, the set of findings presents a logical picture. First, destination demand is fundamental; the key development route, especially for vegetables, continues to be increasing presence in bigger EU markets. Second, macro and regulatory factors are crucial adjustment margins; exporters' results fluctuate in tandem with the currency rate and policy environment, with particularly strong signals for fruits and nuts. Third, even if mere distance is a poor stand-in, hard trade costs inside Europe continue to influence results for specific partners. The use of PPML with suitable fixed effects is necessary to achieve stable, interpretable connections in the presence of zeros, heteroskedasticity, and unobserved resistance, proving that model design is not only a matter of style.

The primary policy consequences are to prioritise logistics solutions that reduce inland legs to landlocked consumers, use tariff advantages when feasible, and strengthen compliance capabilities for EU standards. In order to strengthen causal interpretation, future analytics work could examine tools for policy variables and include direct indicators of sanitary and phytosanitary measures, preference utilisation, and certification costs.

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