BRIGHT SPACE

# Designing a Roadmap for Effective and Sustainable Strategies for Assessing and Addressing the Challenges of EU Agriculture to Navigate within a Safe and Just Operating Space

# Unravelling the Global Impact of the EU Deforestation Regulation through a Bayesian Poisson High Dimensional Fixed Effects Structural Gravity Model

***Discussion paper***

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# 1 Introduction

International trade in agricultural and forestry commodities has been extensively documented as a cause of decline in natural vegetation and subsequently biodiversity, particularly in tropical and subtropical regions of the world (Balogh and Jámbor, 2020). Naturally, a considerable portion of trade in these commodities is directed to high-income economies and – contrary to stated sustainable development objectives – exacerbates their impact on biodiversity (Lenzen et al., 2012) as well as their global emission footprint (Escobar et al., 2020). In particular, the expansion of agricultural soybean production is historically evidenced as a driver of deforestation and has been identified as an notorious example of the geographic asymmetry between origin of cultivation and destination of final consumption (dos Reis et al., 2020). The increased interest on the soybean sector specifically is driven by i) Brazil emerging as the world largest producer & exporter of soybean products (OECD/FAO, 2021), ii) while hosting a vast share of the earth's tropical rainforests as well as other ecologically rich habitats (OECD, 2015), iii) which are increasingly understood to have been subject of environmental degradation partly through agricultural expansion (Song et al., 2021), and iv) the majority of worldwide soybean production is consumed as protein input by the livestock sector in developed & emerging economies such as the EU (European Commission, 2021).

In response to this growing body of evidence, the European Union (EU) passed the *European Union Deforestation Regulation* (EUDR) in 2023 with the stated objective of disconnecting consumption within the common market originating from recent deforestation in their source region. Ultimately, the EUDR is intended to contribute to conservation of global forest areas and to reduce the EU's footprint on forest degradation in general. Yet, the effectiveness of the EUDR in this regard crucially depends on its potential to alter trade flows to begin with. To this end, we employ a variant of one of the most widely used econometric frameworks in international trade policy analysis: the structural gravity model (Yotov et al., 2016). We combine the most recent developments in the literature and cast them in a Bayesian estimation framework. The resulting Bayesian Poisson High Dimension Fixed Effects (BPHDFE) structural gravity model we apply on an exhaustive dataset of sector/product-specifc bilateral flow observations of international soybean trade between 2009-2018 at the country level. With this setup we are able to recover an estimate of trade-demand elasticity representing recent dynamics in the international trade of the global soybean economy. Moreover, in a preliminary analysis, we attempt to narrow down the potential efficacy of the EUDR on trade flows between Brazil and the EU.

In what follows, the Section 2 gives an overview of the EUDR with a focus on the challenges arising from new barriers of trade mechanism in established econometric frameworks. Our BPHDFE structural gravity model is presented in detail in Section 3. Section 4 presents our counterfactual EUDR scenario setup & presents the results of our estimation. Section 5 closes with concluding and forward looking remarks.

# 2 The European Union Deforestation Regulation (EUDR)

The European Union Deforestation Regulation (EUDR) represents a significant legislative effort aimed at mitigating the impact of agricultural practices on global forests. The regulation, officially known as (EU) 2023/1115, focuses on the promotion of "deforestation-free" products, thereby seeking to reduce the EU's contribution to deforestation and forest degradation worldwide. This initiative aligns with broader environmental goals, including reducing greenhouse gas emissions and enhancing biodiversity conservation. The EUDR specifically targets a range of commodities which are historically linked to deforestation through agricultural expansion into forested areas, e.g. cattle, wood, cocoa, soy, palm oil, coffee, rubber, and some of their derived products, such as leather, chocolate, tyres, or furniture.

Starting to apply from 2025 onwards the EUDR aims to prevent the supply of these commodities when their production can be traced to recent deforestation. The burden of proof falls thereby on trading operators placing these products on the EU market (or exporting from it), who must be able to evidence that the source location of their traded products has not been subject to deforestation (or forest degradation) after 2020. Under the EUDR, any trade operator or importing agent wishing to place these targeted commodities on the EU market must demonstrate that their products do not originate from deforested or degraded forest areas post-2020. This mechanism necessitates the establishment of robust traceability systems to ensure compliance, effectively placing the onus on businesses to verify the sustainability of their supply chains.

To achieve this level of accountability, businesses must implement and maintain comprehensive documentation that traces the origin of the commodities they import. This documentation must place particular emphasis on avoiding any links to land that has been deforested or degraded since 2020. The stringent requirements outlined in the EUDR aim to close the loopholes that have historically allowed for the import of products associated with deforestation, thereby promoting a more sustainable market. The primary objective of the EUDR is to prevent the consumption and use of goods that contribute to deforestation at their source. By delineating between commodities produced in environmentally sensitive areas and those sourced from areas that have been established prior to 2020, the regulation aims to promote sustainable agricultural practices and encourage responsible sourcing. The EUDR mechanism appears as a promising trade policy instrument unilaterally targeting imports stemming from production encroaching on forest areas and differentiating it from less environmentally harmful (or pre-2020 established) production for export to the EU. However, its actual potential in ultimately preventing deforestation by creating economic disincentives for environmentally critical practices (and promoting sustainable agricultural expansion) is not yet well understood.

Despite these ambitious objectives, several challenges arise when attempting to assess the potential effects of the EUDR on international trade. First, the EUDR specifically targets a narrow part of each of the commodities under its coverage. Unlike traditional blanket trade policies, e.g uniform tariffs or broad trade agreements, the EUDR discriminates product by their origin. In a sense it acts as a trade barrier on a subset of the same commodity. Second, the effectiveness of the EUDR may depend on the dynamics of supply and demand within the EU market. For instance, if demand for soybean is increasing significantly, the regulation may only impede imports if the existing supply from pre-2020 production areas does not meet this demand. Broadly speaking, the EUDR might affect increases in import demand of the EU relative to 2020, but would not need to apply if EU demand remains constant (or is decreasing). Third, the EUDR carries the potential for exporting agents to adjust their production and export strategies in response to the regulation. Trade operators might shift their exports from pre-2020 production areas destined for other markets to the EU after, thereby muting the EUDR's impact on observed aggregate trade flows. Additionally, this possibility raises the concern the EUDR might lead to leakage effects (with regards to its objective on deforestation). Meaning the share of these commodities produced under environmentally problematic conditions would be flowing to other outlets, domestic or international, and thus blur the transmission channel of promoting sustainable agricultural production practices abroad as intended by EU policy makers to an unknown degree.

Any empirical assessment of estimating effects of policy interventions before their effective implementation (or prior to collecting a suitable amount of data points of interest under their effect), in particular, in trade policy analysis requires historic precedents that serves as a proxy to the trade policy under investigation. Ideally, the proxy variable represents as close of a mechanism or effect to its actual counterpart of interest and estimating its potential effect then rests on observed variation of the proxy variable across the cross-section and/or time. For instance, the potential expected effect of two economies entering a trade agreement is essentially drawn from the variation of other countries having entered such or similar agreements and their conditional change in the responding trade volume.

In light of this, the novelty of a trade policy mechanism such as the EUDR poses a challenge for econometricians as historic precedents are not observed or potentially suitable proxies have not been identified in the literature yet. One notable exception is Wolfmayr et al. (2024), they draw parallels with the preceding EU Timber Regulation (EUTR). The EUTR was implemented to combat illegal logging and ensure that timber products imported into the EU were sourced sustainably. They attempt to isolate the impact of the EUTR on trade from Brazilian timber products to the EU and find the EUTR reduced trade in timber products between Brazil and the EU by approximately 0.13% on average. This finding suggests that the EUDR could similarly influence trade in deforestation-linked commodities, although the specific impact likely varies based on the characteristics of the commodities and their sectors involved.

Despite the successful application of econometric frameworks estimating and assessing conventional trade policies, the literature on new barriers of trade, their mechanism, and efficacy is naturally only emerging yet. These limitations in mind, we employ a class of the most wide spread trade analysis tool in the econometric toolbox: a state-of-the art variant of the structural gravity model to assess the particular sensitivity of international soybean trade and use it to narrow down the breadth of potential outcomes of the EUDR on it.

# 3 Model Framework

The seminal derivation of Anderson and Van Wincoop (2003) put the standard gravity model, resting purely on its relative empirical reliability, on a solid theoretical foundation. Starting from $N$ representative (homogeneous) country-consumers endowed with Armington-style CES-functions [1 2], they obtain the now foundational *structural gravity model* and paved the way for the gravity framework emerging as a full-fledged general equilibrium (GE) trade-policy analysis tool (Yotov et al., 2016).

## 3.1 Theoretical Structure

Within this framework, nominal bilateral trade flows in good $k$, denoted as $X^k_{ij,t}$ for each exporter $i = 1, \ldots, N$ and importer $j = 1, \ldots, N$ pair at time $t = 1, \ldots, T$ can be described as follows:

$$X^k_{ij,t} = \frac{Y^k_{i,t} E^k_{j,t}}{Y^k_t} \times \left( \frac{\tau^k_{ij,t}}{\Pi^k_{i,t} P^k_{j,t}} \right)^{1-\sigma^k} \tag{1}$$

In this equation, the first component represents the size term, where $Y^k_{i,t}$ denotes the total production of the exporter, $E^k_{j,t}$ indicates the total expenditure of the importer, and $Y^k_t$ represents the world production of good $k$. This formulation highlights a fundamental insight: in the absence of trade costs, larger producers $i$ will export more to their trading partners,

[1]This implies, for homogeneous goods $k$ countries exhibit an elasticity of substitution between the varieties of all other countries $\sigma^k$.

[2]Moreover, Arkolakis et al. (2012) show how a large class of theoretical approaches on international trade culminate in gravity-type equations.

while larger markets $j$ will import more from all available sources. This relationship emphasizes the importance of market size and production capacity in determining trade flows between countries.

The second component of the equation captures the trade cost term, which introduces friction into what would otherwise be frictionless trade. In this context, $\tau_{ij,t}^k$ represents bilateral trade costs associated with the exchange of good $k$ between exporter $i$ and importer $j$. The structural terms $\Pi_{i,t}^k$ and $P_{j,t}^k$ signify the outward and inward multilateral resistance, respectively. These terms measure the ease of market access for exporters and importers, and they are critical for understanding how trade costs influence bilateral trade relationships.

The multilateral resistance terms can be expressed mathematically as follows:

$$(\Pi_{i,t}^k)^{1-\sigma^k} = \sum_j \left(\frac{\tau_{ij,t}^k}{P_{j,t}^k}\right)^{1-\sigma^k} \frac{E_{j,t}^k}{Y_t^k} \tag{2}$$

$$(P_{j,t}^k)^{1-\sigma^k} = \sum_i \left(\frac{\tau_{ij,t}^k}{\Pi_{i,t}^k}\right)^{1-\sigma^k} \frac{Y_{i,t}^k}{Y_t^k} \tag{3}$$

Both these equations illustrate how multilateral resistance relate strictly to the bilateral trade costs in conjunction with all other trading partners. This connection underscores the complexity of international trade, as these multilateral resistance terms account for the relative competitiveness of exporters and the market accessibility of importers.

In summary, the gravity model framework provides a structured approach to understanding bilateral trade dynamics by incorporating both the size of economies and the impact of trade costs. By integrating these elements, the model effectively showcasing the factors influencing trade flows, highlighting the importance of both local production and global market conditions in shaping international trade patterns.

## 3.2 From Theory to Empirical Specification

To derive an empirical specification from the structural gravity equation, we begin by taking the logarithm of the equation presented earlier. By rearranging the terms, we arrive at the following expression:

$$\ln(X_{ij,t}^k) = \ln(Y_{i,t}^k) - (1-\sigma^k)\ln(\Pi_{i,t}^k) + \ln(E_{j,t}^k) - (1-\sigma^k)\ln(P_{j,t}^k) - \ln(Y_t^k) + (1-\sigma^k)\ln(\tau_{ij,t}^k) \tag{4}$$

In this equation, each term reflects different aspects of the trade dynamics between exporter $i$ and importer $j$ at time $t$. The variables $Y_{i,t}^k$ and $E_{j,t}^k$ denote the total production of the exporter and total expenditure of the importer, respectively, while $\Pi_{i,t}^k$ and $P_{j,t}^k$ represent the multilateral resistance terms. The term $Y_t^k$ refers to the world production of good $k$, and $\tau_{ij,t}^k$ signifies the bilateral trade costs.

Next, we can summarize the importer- and exporter-specific terms and relabel the cross-sectional constant per time step $\ln(Y_t^k)$ . This leads us to a more concise formulation:

$$\ln(X_{ij,t}^k) = \theta_{i,t}^k + \theta_{j,t}^k + \nu_t^k + (1-\sigma^k)\ln(\tau_{ij,t}^k) \tag{5}$$

In this specification, $\theta_{i,t}^k$ and $\theta_{j,t}^k$ represent exporter- and importer-time fixed effects, absorbing $\ln(Y_{i,t}^k) - (1-\sigma^k)\ln(\Pi_{i,t}^k)$ and $\ln(E_{j,t}^k) - (1-\sigma^k)\ln(P_{j,t}^k)$, respectively, as well as capturing other unobserved characteristics that may influence trade flows from the perspective of both the exporting and importing countries (Olivero and Yotov, 2012). And $\nu_t^k$ captures global-time fixed effects, accounting for broader trends affecting all trade relationships in a given time period.

Utilizing observed $E_{j,t}^k$ & $Y_{i,t}^k$, Anderson and Yotov (2012) demonstrate how estimates of directional country-fixed effects retrieve the unobserved multilateral resistance terms $\Pi_{i,t}^k$ & $P_{j,t}^k$ with remarkable accuracy. This finding underscores not only the robustness of including importer-time and exporter-time fixed effects, but also spares us more involved approaches to approximate them (Baier and Bergstrand, 2009).

Finally, we also include country-pair fixed effects $\mu_i j$ to absorb all time-invariant factors affecting trading conditions in a given exporter & importer-dyad, e.g. distance, shared cultural, historic or other unobserved ties effecting their bilateral trade volume. Egger and Nigai (2015) illustrate the importance of dyad-fixed effects in accounting for unobserved yet systematic trading costs while Agnosteva et al. (2014) find their estimates can consistently be decomposed into the mentioned standard time-invariant gravity variables.

In summary, we model trade in the soybean sector $X_{ij,t}$ as Poisson distributed with conditional mean $\lambda_{ij,t}$ emerging from our fixed-effects specification of the structural gravity model derived above[3]:

$$\lambda_{ij,t} = \exp\left(\theta_{i,t}^k + \theta_{j,t}^k + \nu_t^k + \mu_{i,j} + \beta\tilde{\tau}_{ij,t-1}B_{i,j}\right), \tag{6}$$

[3] $\lambda_{ij,t} = E[X_{ij,t}|i,j,t,\tilde{\tau}_{ij,t-1}]$

where $\tilde{\tau}_{ij,t-1}$ denote time-varying costs of trade which enter our model lagged to factor in potential adjustment period and endogeneity effects of bilateral trade flows to simultaneous changes in trade cost measurements (Bergstrand et al., 2015). Assuming the data generating process follows a Poisson distribution allows us to estimate the model structurally consistent in its multiplicative form while also leveraging information contained in zero trade flows (Silva and Tenreyro, 2006) We opt for a Bayesian estimation and inference strategy as follows:

$$X_{ij,t} \sim \text{Poisson}(\lambda_{ij,t})$$
$$\lambda_{ij,t} = \exp\left(\theta^k_{i,t} + \theta^k_{j,t} + \nu^k_t + \mu_{i,j} + \beta\tilde{\tau}_{ij,t}\right)$$
$$\theta^k_{i,t}, \theta^k_{j,t}, \nu^k_t, \mu_{i,j}, \beta \sim \mathcal{N}(0,1)$$

For identification purposes we fix the intra-national bilateral fixed effects $\mu_{ii}$ and one of the global-time fixed effects (i.e. $\nu^k_{T/2}$) equal to 0. Therefore, the bilateral trade cost fixed effects have to be interpreted relative to the set baseline of *domestic trade costs*.

We employ our Bayesian Poisson High Dimensional Fixed Effects (BPHDFE) structural gravity model on a bilateral trade dateset of the soybean sector and proxy time-varying shifts in trade costs by tariff rates. Our choice of data sources are presented next and discussed briefly.
[4]

# 4 Data

In our analysis, we utilize a robust structural fixed-effects framework, which allows us to derive meaningful insights from relatively sparse data requirements. The choice of data sources and variables is crucial to ensure the validity and reliability of our model outcomes. For our response variable $X_{ij,t}$, which represents bilateral trade flows in the soybean sector at the country-level (measured in $1,000 current USD), we rely on the **ITPD-E-R02** database provided by the *United States International Trade Commission* (USITC; Borchert et al., 2022). Other product- or sector-specific datasets on international trade lack exact measurements on domestic trade. In the context of trade, domestic trade simply refers to domestic production which is (without detours) consumed domestically. The IDPD dataset reconciles these raw administrative data on bilateral trade for direct input in gravity style models. Recent findings in the international trade literature emphasize the importance of including intra-national trade flows in structural gravity models to more precisely identify the effects of bilateral trade costs (see, e.g., Dai et al., 2014). And Anderson and Yotov (2016) show added insights on trade diversion dynamics when considering domestic as well as international trade quantities.

To represent time-varying trade costs in our model, we utilize bilateral *effectively applied ad-valorem* tariff rates sourced from the *World Integrated Trade Solution (WITS)* database. These tariff rates are obtained at the product level and are enter our model defined as:

$$\tilde{\tau}_{ij,t-1} = \ln(1 + \text{tariff}_{ij,t-1})$$

Considering that tariffs act as direct price shifters on international trade and according to literature the parameter estimate $\beta$ associated with the tariff variable $\text{tariff}_{ij,t}$ can then recover the trade-demand elasticity implied by theory directly, i.e. effective trade-demand elasticity is given by $\beta = 1 - \sigma$ (Heid et al., 2021; Fontagné et al., 2022).

Our choice to neglect binary indicator information of various levels of trade related agreements is motivated by our sample span and on the structural properties of our fixed-effects model. Since these agreements are generally time-invariant over the period we are studying, they can be effectively subsumed by the bilateral fixed effects. This approach simplifies the model without sacrificing accuracy, as the fixed effects account for any unobserved heterogeneity between trading partners that could otherwise confound our results. In effect, our sample span covers yearly observations in the period of 2009-2018 ($T = 10$). We exclude as exporters any country who never shows up as a producer during the sample span [5]. After this our sample contains $I = 141$ and $J = 191$ unique exporters $i$ and importers $j$ respectively, for a total of $IJ = 26931$ bilateral trade pairs. All-in all our sample panel then covers $N = 269310$ observations of bilateral and unilateral trade flows in the soybean sector of which 95% are zero trade flows.

[4]The model is developed and coded in `rstan` Stan Development Team (2024) and for our preliminary results, we rely on 500 parameter draws from the variational Bayes approximation of the full posterior Attias (2013).

[5]Given a specific exporter $\bar{i}$ this criteria is given by

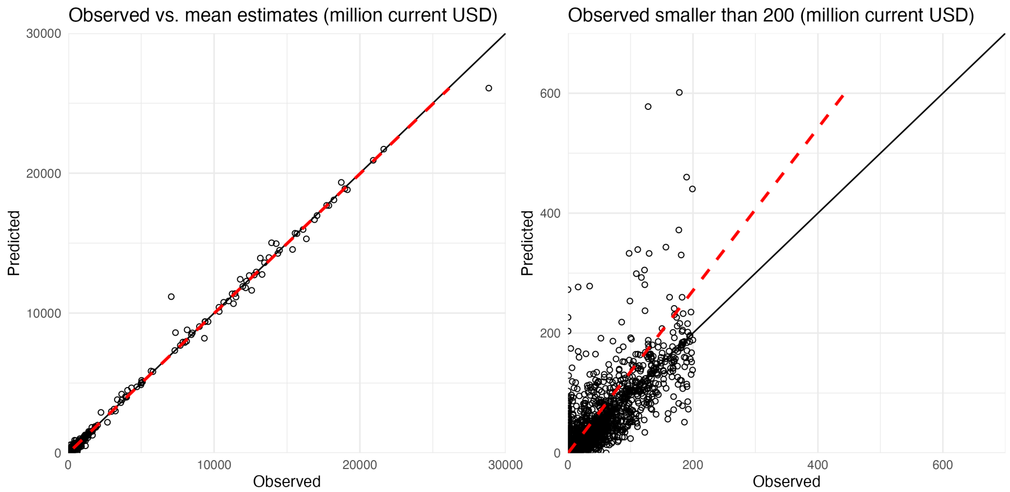
$$\sum_{t=2009}^{2018} X_{\bar{i},j,t} = 0$$

.

# 5 Results

Considering our estimated model object carries posterior samples of roughly 30000 fixed effects parameters, we summarize its performance and show in 1 the model fit of our structural gravity specification. The left-hand side panel shows that BPHDFE structural gravity model performs rather well when considering the full sample of observed $X_{ij,t}$. However, examining observed bilateral trade flows below 200 million USD$, we detect the estimated model object biasing its predicted values upwards, a gap we notice to be increasing with resolution on $X_{ij,t}$. This might be suggestive of Poisson-style estimation in the gravity context being afflicted when zero observations are excessively present in the data, as is the case here (for a recent discussion on this, see Mnasri and Nechi, 2021).

Figure 1: BPHFDE structural gravity model fit scatter plot




Hollow dots depict observed values of $X_{ij,t}$ (y-axis) and their mean predicted counterparts $\hat{X}_{ij,t}$ (x-axis) from the BPHDFE structural gravity model. The black line represents hypothetical perfect fit where $X_{ij,t} = \hat{X}_{ij,t}$. The dashed red line illustrates the fit of regressing observed on predicted quantities. The data points in the left panel cover the full sample, whereas the right panel zooms in on observations $X_{ij,t} < 200$ million current USD$.

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Turning to our parameter on the tariff coefficient (and the implied trade-elasticity of substitution $\sigma$) we obtain from our estimation a mean estimate of $\hat{\beta}^{\tau} = -0.5046$ with a credible interval of $CI_{99\%} = [-0.5182, -0.4913]$. This implies soybean trade flows are on average associated with an (inverse) change of $0.5\%$ to bilateral trade costs (or import prices) shifts by $\pm 1\%$.

To simulate a potential effect of the EDUR as well as to demonstrate the effect of our tariff-elasticity we conduct a first-stage counterfactual analysis with our estimated model object. We restrict our analysis to the trading-pair Brazil $\rightarrow$ EU between 2014-2018, i.e. $t^{CF} = (2014, \ldots, 2018)$. Over this time frame we subject the bilateral trade flows $\hat{X}_{BRA,EU,t^{CF}}$ to additional frictions of trade as described next.

The first counterfactual scenario utilizes the EUTR estimate from Wolfmayr et al. (2024, discussed in Section 2) and applies it as a proxy to the EUDR on the soybean sector as modelled here. We take this estimate as a lower bound approximation and also highlight how shifting the EUTR elasticity downwards moves the posterior distribution of our counterfactual $\hat{X}^{CF}_{BRA,EU,t^{CF}}$ predictions. In our model framework this implies manipulating our counterfactual subset of parameter draws $\lambda_{BRA,EU,t^{CF}}$ as follows[6]:

$$\text{Counterfactual I:} \quad ln\lambda^{CF}_{BRA,EU,t^{CF}} = ln\lambda^{baseline}_{BRA,EU,t^{CF}} + \beta^{Wolfmayr}_{EUTR} \times s_{EUTR},$$

where $s_{EUTR} \in c(1, 3, 5, 10)$ is a scalar factor shifting the potential impact of the EUDR. In the second counterfactual scenario we manipulate the tariff rate in $\tilde{\tau}_{ij,t-1}$ directly to illustrate the soybean sector specific trade sensitivity to price changes as implied by our estimates. To this end, we obtain $\lambda^{CF}_{BRA,EU,t^{CF}}$ as follows:

$$\text{Counterfactual II:} \quad ln\lambda^{CF}_{BRA,EU,t^{CF}} = \theta^{k}_{i,t} + \theta^{k}_{j,t} + \nu^{k}_{t} + \mu_{i,j} + \beta\tilde{\tau}^{CF}_{ij,t},$$
$$\tilde{\tau}^{CF}_{ij,t} = \ln(1 + \text{tariff}_{ij,t-1} + s_{tariff}),$$

where $s_{tariff} \in (0.01, 0.03, 0.05, 0.1)$ are scalar values representing hypothetic additional ad-valorem tariffs levied by the EU of 1,3,5,and 10% on soybean imports from Brazil. In practice we then obtain counterfactual predictions $\hat{X}^{CF}_{BRA,EU,t^{CF}}$

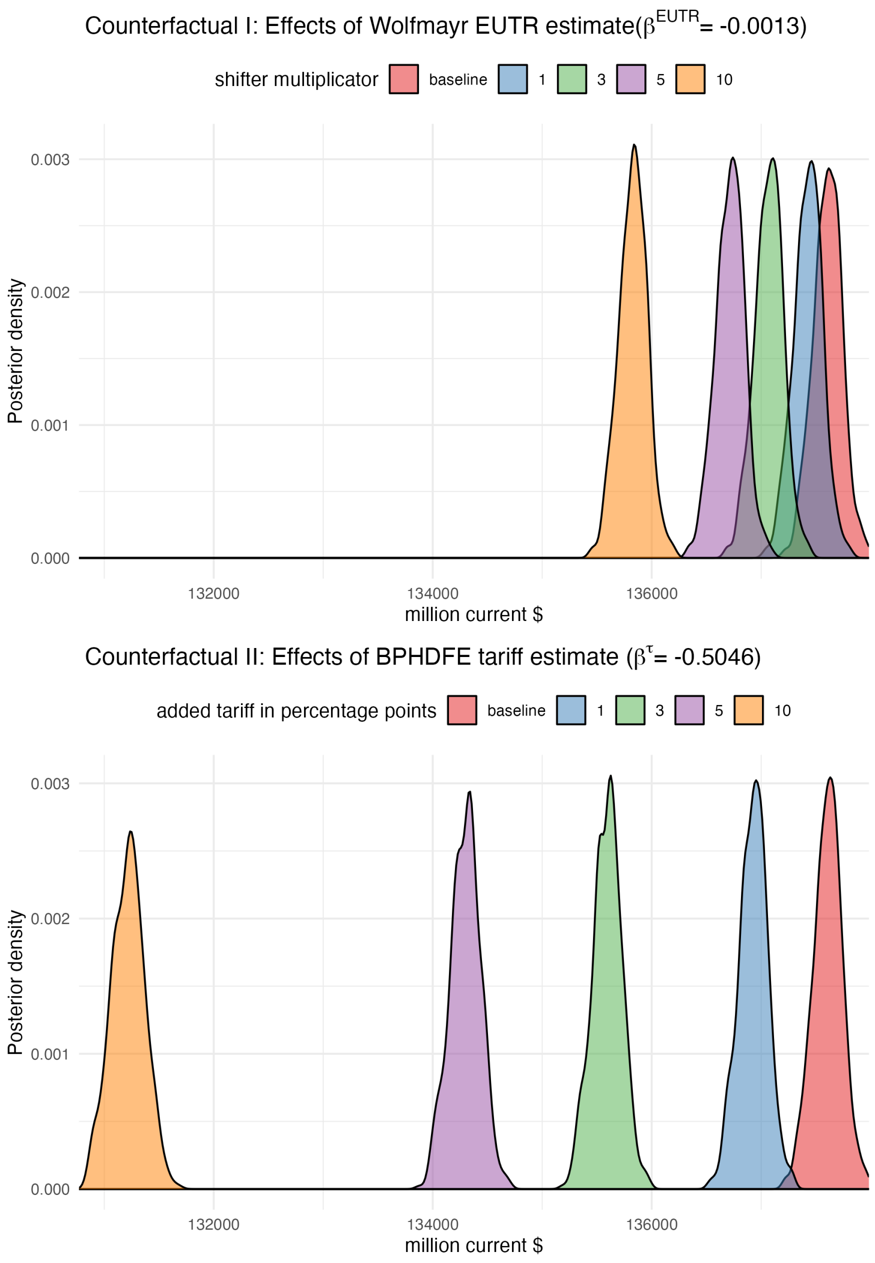
[6] $\beta^{Wolfmayr}_{EUTR} = -0.0013$

via

$$\hat{X}^{CF}_{BRA,EU,t^{CF}} \sim \text{Poisson}(e^{ln\lambda^{CF}_{BRA,EU,t^{CF}}}),$$

from each of our posterior draws and both counterfactual scenarios as well as their respective shifter values separately. We then compute the posterior densities of each set of $\hat{X}^{CF}_{BRA,EU,t^{CF}}$ - draws aggregated over the counter factual time frame $t^{CF} = (2014, \ldots, 2018)$. Figure 2 reports the results of this exercise.

Figure 2: Counterfactual analysis




The top plot depicts the counterfactual posterior density from a hypothetical EUDR level impact as motivated by(Wolfmayr et al., 2024) result of the EUTR effect. The bottom plot depicts the same for our tariff rate shock. The x-axis represents volume of trade in million current USD$. The values are aggregated bilateral trade flows from Brazil to all EU country and over the time span 2014-2018. Color shading represents the baseline (without additional friction) density in red, and the respective shifters of the applied shocks.

Starting with the Counterfactual I scenario (top plot), we notice the actual effect of the EUTR estimate as found in Wolfmayr et al. (2024), i.e. $\beta_{EUTR} \times 1$ (blue shaded density), hardly triggers a credibly different response from the baseline case (red shaded density) as their respective posterior densities exhibit a considerable overlap. We suspect this result might be indicative of deviations in sample size, model specification and, of course, the sector/product analyzed between Wolfmayr et al. (2024) and our approach, or also influenced by characteristics of the soybean sector observations leading to increased noisiness in the model. Nevertheless, this finding highlights, on the one hand, the associated fuzziness in naively porting proxy estimates resulting in one modelling approach into another. On the other hand, it showcases how taking the full model uncertainty into account is exactly necessary to reveal such obliqueness. Naturally, shifting the initial shock estimate downwards will eventually result in more distinctly different posterior densities. To assess with strong confidence that the EUDR leads to a significant reduction in bilateral trade (between Brazil and the EU) requires in our case the assumption of a 5-times increased effectiveness of the EUDR compared to the EUTR-proxy.

Turning to our Counterfactual II (bottom plot), we can observe how different tariff rates imposed by the EU impact soybean trade originating in Brazil. As main take-away here is, and assuming the EUTR as the best-available proxy, we can narrow down the corresponding tariff-rate equivalent. This might be useful when translating our empirical results to models which represent trade-elasticity more generally and policy analysis rests on proxying their implied effect as added bilateral trade costs. Read in this manner, the bottom plot in Figure 2 provides an idea how a tariff rate triggers similar effects to our EUTR counterfactual. Concretely, an additional tariff rate of $3\%$ already begins to exceed our most extreme effect of $\beta_{EUTR} \times 10$, whereas a 1-percent increase exhibits an effect of our $\beta_{EUTR} \times 3$ counterfactual case. Subsequently, if an hypothetical analyst puts most belief on the lower bound as the actual Wolfmayr-estimate a equivalent tariff rate would need to be well below $1\%$.

# 6 Concluding remarks & outlook

We present a state-of-the art variant of the structural gravity model and infer on it in a Bayesian fashion. Our BPHDFE structural gravity model identifies trade-demand elasticity as encoded in a recent sample of bilateral trade flows covering the global soybean sector exhaustively. We demonstrate that our model fits the observations remarkably well, however, we also demonstrate how this performance deteriorates for a subset of lower magnitude observations. A well-know affliction of Poisson-style gravity estimation when the frequency of zeros is high.

Nevertheless, we identify that on average bilateral soybean trade flows reduce by $0.5\%$ if bilateral trade costs increase by $1\%$. Moreover, our counterfactual exercises suggest i) unsuspected uncertainty implications of trade policy analysis when porting proxy estimates from one study into similar modelling frameworks, and ii) a visual exploration of our estimated tariff-elasticity and how our EUTR proxy effect to the EUDR relates to tariff-equivalents.

That being said, there are remaining limitations to the present study. First, how to capture the unqiue EUDR mechanism in established trade analysis frameworks remains a challenge as discussed in Section 2. Second, for now the preliminary counterfactual analysis presented here neglects diversion effects from bilateral changes in trading conditions to other trading-pairs as well as larger general equilibrium effects (which might be especially relevant in the context of leakage effects from environmentally motivated trade policies). Which it technically is equipped to conduct, however, the extra steps necessary are computationally burdensome. Third, to our knowledge similar theoretically founded frameworks considering (or estimating) cross-product trade-demand elasticities are yet to be developed. However, partial elasticities commonly estimated in the literature, such as done here, are likely contaminated in unknown direction and degree by their omission.

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