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Impacts of Mexico's Proposed Ban of Genetically Modified Corn Imports on Global Markets

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This study analyzes the effects of the proposed Mexican import ban of GM corn on Mexican, US, and global corn markets. This import ban would have caused considerable trade reallocations. Mexico would have had to import from France, Colombia, and Indonesia to fill the void left by lost imports from the United States. In turn, the United States would have had to divert its lost export sales in Mexico to Japan, Colombia, South Korea, and itself. Because of these trade reallocations, Mexico would have imported from more expensive sources. The United States would have exported to distant countries. Welfare would have decreased in many countries, with Mexico incurring large losses.

Key words: corn trade, US–Mexico dispute, reallocations, welfare

Introduction

Then–Mexican President López Obrador issued a decree in February 2023 to phase out the use of genetically modified (GM) corn imports to protect human health, support food sovereignty, promote self-sufficiency, preserve native corn, maintain biodiversity, and safeguard agricultural environments (Obrador, 2023). The United States contended that Mexico's policy contradicts scientific evidence and violates sanitary and phytosanitary (SPS) measures of the United States–Mexico–Canada Agreement (USMCA) and, thus, is a disguised trade barrier (Office of the US Trade Representative, 2023). Since the United States is the world's leading corn producer and Mexico is the largest and most steady market for US corn exports, an import ban by Mexico would have had significant effects on the US corn industry. This study analyzes the effects of Mexico's proposed ban on GM corn imports on US, Mexican, and global corn markets.

In 2022/2023, the United States—by far the largest producer in the world market—produced 350 million metric tons (MMT) of corn; China, the second-largest world producer, produced 277 MMT (US Department of Agriculture, 2023). By contrast, Mexico produced only 28 MMT but utilized 50 MMT; consequently, Mexico relied on imports—mainly from the United States—to meet its excess demand (Devadoss, Hall, and Luckstead, 2024). China imported a very limited amount of corn from the United States until 2019 but has increased its imports since then.[1] Over the 3-year period

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[1] See Gale, Hansen, and Jewison (2016) and Dhoubhadel and Ridley (2024) for details on China's growing demand for US commodities.

2020–2022, Chinese imports averaged 14 MMT, whereas Mexican imports averaged 15.6 MMT.[2] Not only is Mexico the largest importer of US corn, but it is also a reliable market: Its imports have steadily increased over the last 2 decades (US Department of Agriculture, 2023). Consequently, any corn import restrictions by Mexico would cause serious economic disruptions to US, Mexican, and global corn markets.

As a member of the World Trade Organization (WTO), Mexico is compelled to follow the nondiscriminatory clause. Therefore, if Mexico had implemented this GM corn ban, then it would have applied to all WTO countries that produce GM corn. Thus, other major countries in the international corn market that predominately grow GM corn (e.g., Brazil, Argentina, and Canada) would also have been impacted by Mexico's ban (Smyth, 2014; Tomson, 2022). In the United States, 93% of total corn produced is GM corn (Williams et al., 2022); in Canada, nearly all corn produced is GM corn (Smyth, 2014). Argentina and Brazil also grow mostly GM corn (Tomson, 2022). In contrast, the European Union and other countries grow largely non-GM corn.

The US–Mexico corn dispute has been simmering since the implementation of the North American Free Trade Agreement (NAFTA) in 1994 for several reasons. First, corn is a staple food in Mexico, and Mexicans have traditionally utilized native corn and do not prefer US GM corn for tortilla preparation (Devadoss, Hall, and Luckstead, 2024). Second, the United States is the world's largest corn producer and finds Mexico to be a valuable export market for its yellow GM corn due to its contiguous location and low international transport costs. Third, Mexico contends that US farmers have an unfair advantage due to enormous production subsidies, which allow them to undercut Mexican corn prices (Fanjul and Fraser, 2003). In response to these concerns, Mexico negotiated under NAFTA a limit on imports of US corn during the period 1994–2009 (Vejar and Rosenweig, 2023). In December 2020, Mexican President López Obrador declared to stop importing bioengineered US corn by January 31, 2024 (Obrador, 2020). In February 2023, López Obrador amended his decree to allow for imports of US GM corn until substitutes are found to meet Mexican demand, with the intention to eventually ban bioengineered corn imports for use in animal feed and other food products meant for human consumption.

The United States vehemently opposed Mexico's ban on US GM corn imports on the grounds that the ban lacks scientific merit and violates USMCA. A review paper by Oliver (2014) found that several studies have confirmed that consumption of GM crops has posed no significant risks to human health or the environment. Since the introduction of bioengineered corn in the 1990s, GM corn has been traded without any SPS or other nontariff barriers. However, countries such as the European Union bans imports of GM corn. Mexico's ban is more recent and not consistent with the USMCA agreement. After holding several failed consultations and exhausting all available channels under the USMCA, the US government requested a dispute settlement panel to resolve this conflict. A dispute panel reviewed this case and found in December 2024 that Mexico's import restrictions were not based on science and violated the provisions of the USMCA. Since the panel ruled in favor of the United States, Mexico should import US GM corn without any restrictions. Therefore, the results of this study are based on a scenario where the proposed Mexican import ban would have been implemented. Such findings are useful to farmers, exporters, agribusiness firms, and—more importantly—policymakers to avoid any future disputes that can lead to trade barriers.

This study evaluates the effects of Mexico's proposed corn import barrier on bilateral trade and welfare of the United States, Mexico, and other major corn-producing and -trading countries. Our study contributes to the trade literature in five aspects: First, we estimate a world corn gravity model with a focus in corn trade; second, we quantify the impact of tariffs, with a focus on key bilateral links (i.e., US, Brazil, Argentina, and Canada) with Mexico on corn trades; third, we analyze the effects of NAFTA/USMCA on US corn exports to Mexico; fourth, we estimate the elasticity of substitution for corn; and fifth, we conduct simulation analyses of the impacts of Mexico's proposed import ban of GM corn and generate results of the effects of this import restriction on the world

[2] Japan is the third-largest importer of US corn, averaging about 12 MMT annually; Colombia, South Korea, and Canada are smaller export markets for US corn.

corn market. Because trade data do not separate GM corn from non-GM corn, we consider, based on the GM production data given above, that Mexico bans 93% of corn imports from the United States, 98% from Canada, and 90% from Argentina and Brazil, in line with the simulation analysis of Beckman et al. (2024).

The gravity model has been a workhorse for applied agricultural trade policy analysis over the past 2 decades. Studies have employed the gravity framework to analyze the effects of agricultural subsidies, nontariff measures, regional trade agreements (RTAs), and tariffs. Given the large number of studies in this area, we review recent key studies that are pertinent to our current work. Studies that examine the effects of domestic subsidies on agricultural trade include Tong, Pham, and Ulubaşoğlu (2019), Devadoss, Ugwuanyi, and Ridley (2022), and Kondaridze and Luckstead (2023). Many studies have focused on the impacts of nontariff measures (NTMs) on agricultural commodity trade: Dal Bianco et al. (2016), Santeramo and Lamonaca (2019, 2022a,b), and Ridley, Luckstead, and Devadoss (2024). Several studies have analyzed the effects of RTAs on commodity trade: Lambert and McKoy (2009), Sun and Reed (2010), Luckstead (2022), and Ridley and Shirin (2024).

Numerous studies have analyzed the adverse effects of tariffs on agricultural commodity trade. Raimondi and Olper (2011) observed that tariffs are major impediments to commodity trade and estimated that removal of tariffs would result in a 50% increase in grain trade.[3] Cipollina and Salvatici (2020) estimated that EU tariffs have lowered agricultural imports by 14%. Ridley, Luckstead, and Devadoss (2022) found that tariff retaliations among wine-trading countries lowered wine trade by nearly $340 million annually. Fontagné, Guimbard, and Orefice (2022) utilized tariff data to estimate trade elasticities for all goods at the 6-digit level of the Harmonized System.

The current study differs from the earlier studies that utilized gravity model for various policy analyses in that it examines quantitative import restriction policy of Mexico's limit on imports of US corn.

A few studies have examined the effects of sanctions on trade. Felbermayr et al. (2020) concluded that complete bilateral and export trade sanctions have significant negative but heterogeneous effects on trade. Larch et al. (2022) found that sanctions in the mining sector hamper trade by an average of 44%, but the effects vary significantly across mining industries, sanction episodes, direction of trade, and type of sanctions. Larch, Luckstead, and Yotov (2024) observed that sanctions have impeded agricultural trade by a magnitude of 73%, which is equivalent to the effect of a 38.8% tariff. These studies are closer to the current work because Mexico's corn import ban is similar to a sanction by an importing country. Importantly, our study is the first to utilize a gravity framework to simulate the impact of the Mexican import ban on GM corn.

Our paper relates to the work of Beckman et al. (2024), who utilized the Global Trade Analysis Project-Agroecological Zones (GTAP-AEZ) model to study the impact of Mexico's ban on GM corn on production, land allocations, prices, trade, and welfare. The advantage of the GTAP-AEZ model is that it allows land reallocation, interindustry links, and supply response in a general equilibrium setting. This model is calibrated to a single year (2014), collects elasticities of substitution from the literature, and controls only for observable bilateral trade costs. By comparison, the current study utilizes a structural gravity model to estimate parameters (including model- and data-specific elasticities of substitution for all trading countries) from panel data over 29 years (1991–2019). While land allocation, supply effects, and cross-commodity effects are muted, a major advantage of the gravity model is that it controls for both observed and unobservable bilateral and multilateral trade costs, and the multilateral costs adjust to the counterfactual ban on GM corn in the simulation analysis. Furthermore, the gravity model does not aggregate individual countries into regions, allowing us to study the effects on individual countries. Thus, GTAP and gravity approaches have their advantages and disadvantages, each providing valuable insights and policy perspectives.

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[3] Also see Luckstead, Devadoss, and Zhao (2024).

Gravity Model

We specify a gravity model to analyze the impacts of tariffs, NAFTA, free trade agreements (FTAs), and WTO on bilateral trade flows for corn. Following Anderson and van Wincoop (2003), the structural gravity equation is specified as

$$X_{ijt} = \frac{Y_{it}E_{jt}}{Y_t}\left(\frac{\psi_{ijt}}{\Pi_{it}P_{jt}}\right)^{1-\sigma}, \tag{1}$$

where X_{ijt} is the nominal value of exports (including domestic trade)[4] of commodity k from exporter i to importer j in year t, $Y_{it} = \sum_j X_{ijt}$ is the ith exporter's total value of production equal to the sum of exports to all countries (including itself), $E_{jt} = \sum_i X_{ijt}$ is the jth importer's total value of consumption equal to the sum of imports from all exporters (including itself), $Y_t = \sum_i Y_{it} = \sum_j E_{jt}$ is the total value of world production/consumption, ψ_{ijt} is the bilateral trade cost from i to j, Π_{it} is the outward multilateral resistance term (MRT) endured by exporter i, P_{jt} is the inward MRT capturing openness of importer j, and σ is the constant elasticity of substitution of imports across commodities and various sources.

The outward and inward MRTs, Π_{it} and P_{jt}, are defined as

$$\left(\Pi_{it}\right)^{1-\sigma} = \sum_j \left(\frac{\psi_{ijt}}{P_{jt}}\right)^{1-\sigma}\frac{E_{jt}}{Y_t} \quad \text{and} \quad \left(P_{jt}\right)^{1-\sigma} = \sum_i \left(\frac{\psi_{ijt}}{\Pi_{it}}\right)^{1-\sigma}\frac{Y_{it}}{Y_t}, \tag{2}$$

where Π_{it} represents the consumption-weighted average of all bilateral trade barriers endured by exporter i and P_{jt} captures the production-weighted averages of all bilateral trade costs imposed by importer j in the global trading system. Changes in bilateral trade costs for a given pair i and j will generate impacts on the i to j trading relationship (through the direct impacts on ψ_{ijt}) as well as all other trading relationships in the trading system (via the indirect impacts mediated by changes in P_{it} and Π_{jt}).

Bilateral factors embodied in ψ_{ijt} reflect both time-variant (e.g., tariffs and trade agreement membership) and time-invariant (geographical or cultural variables, e.g., distance, shared borders, common language between trade partners) determinants of trade:

$$\begin{aligned}\psi_{ijt} = \exp\Big\{&\log\left(\tau_{US,MEt}\right) + \log\left(\tau_{CA,MEt}\right) + \log\left(\tau_{BR,MEt}\right) + \log\left(\tau_{AR,MEt}\right) + \log\left(\tau_{ijt}^{N}\right) \\ &+ \beta_1 NAFTA_t + \beta_2 PTA_{ijt} + \beta_3 WTO_{ijt} + \lambda_{ij}\Big\},\end{aligned} \tag{3}$$

where $\tau_{US,MEt} = \tau_{ijt}I_{US}$, $\tau_{CA,MEt} = \tau_{ijt}I_{CA}$, $\tau_{BR,MEt} = \tau_{ijt}I_{BR}$, and $\tau_{AR,MEt} = \tau_{ijt}I_{AR}$ are the Mexican *ad valorem* tariffs (1 + tariff rate) on imports from the United States, Canada, Brazil, and Argentina in year t, respectively; I_{US}, I_{CA}, I_{BR}, I_{AR} are indicator variables equal to 1 when exports are from the United States, Canada, Brazil, and Argentina, respectively, to Mexico in year t and 0 otherwise; $\tau_{ijt}^{N} = \tau_{ijt}I_N$ is all other bilateral tariffs by commodity; I_N is an indicator variable equal to 1 when exports are not from the United States, Canada, Brazil, and Argentina to Mexico in year t and 0 otherwise; $NAFTA_t$ is a dichotomous variable equal to 1 when trade partners are the United States, Canada, and Mexico and $t > 1994$ and 0 otherwise; PTA_{ijt} is a dichotomous variable equal to 1 when i and j share membership in a preferential trade agreement (PTA) in year t and 0 otherwise; WTO_{ijt} is a binary variable equal to 1 if i and j are WTO members in year t and 0 otherwise; and λ_{ij} represents time-invariant bilateral trade friction variables between i and j. We expect tariffs for different bilateral links (e.g., US–Mexico, Canada–Mexico, Brazil–Mexico, and Argentina–Mexico) to have different impacts on trade flows if the elasticities of demand and supply differ between the

[4] A theoretically consistent gravity model calls for the inclusion of intracountry commodity trade (Larch, Wanner, and Yotov, 2018; Ridley and Devadoss, 2023).

bilateral links.[5] We include WTO membership and PTAs because they may impact both the trade volumes and bilateral trade barriers; if we omit them, the estimates on the relationship between trade and trade barriers could be biased (Anderson, Larch, and Yotov, 2018).[6]

By substituting the trade cost equation (3) into gravity equation (1) and including the stochastic error term, we obtain the empirical gravity equation:

$$X_{ijt} = \exp\Big\{\alpha_{0,t} + \alpha_1 \log\left(\tau_{US,MEt}\right) + \alpha_2 \log\left(\tau_{CA,MEt}\right) + \alpha_3 \log\left(\tau_{BR,MEt}\right) + \alpha_4 \log\left(\tau_{AR,MEt}\right) + \alpha_5 \log\left(\tau_{ijt}^{N}\right) + \alpha_6 NAFTA_t + \alpha_7 PTA_{ijt} + \alpha_8 WTO_{ijt} + \gamma_{it} + \eta_{jt} + \varsigma_{ij}\Big\} + \varepsilon_{ijt}, \tag{4}$$

where $\alpha_{0,t} = -\log(Y_t)$ is an intercept term capturing world output Y_t; α_1, α_2, α_3, and α_4 are tariff elasticities for US–Mexican, Canadian–Mexican, Brazilian–Mexican, Argentinian–Mexican links, respectively; $\alpha_5 = (1-\sigma)$ for other bilateral tariff links; $\alpha_6 = (1-\sigma)\beta_1$; $\alpha_7 = (1-\sigma)\beta_2$; $\alpha_8 = (1-\sigma)\beta_3$; $\gamma_{it} = \log(Y_{it}) - (1-\sigma)\log(\Pi_{it})$ is the exporter–commodity–year fixed effects; $\eta_{jt} = \log(E_{jt}) - (1-\sigma)\log(P_{jt})$ is the importer–commodity–year fixed effects; $\varsigma_{ij} = (1-\sigma)\lambda_{ij}$ is a country-pair fixed effect; and ε_{ijt} is a mean-zero error.

The exporter–year fixed effects, γ_{it}, and importer–year fixed effects, η_{jt}, control for all country–year observed domestic supply and demand factors (consumer income levels and nondiscriminatory regulatory barriers) and unobserved domestic factors (technology, multilateral resistance) that impact trade. The omission of these two terms can cause bias in the coefficient estimates of the gravity model (Anderson and van Wincoop, 2003). Furthermore, because estimates of the exporter–year and importer–year fixed effects are used to calculate the impacts of the underlying structural multilateral resistance terms, $(\Pi_{it})^{1-\sigma}$ and $(P_{jt})^{1-\sigma}$, they are critical to our gravity-based counterfactual analyses in accurately quantifying the effects of changes in Mexican import policy. The inclusion of ς_{ij} controls for time-invariant trade determinants and accounts for potential endogeneity from omitted variables connecting τ_{ijt}, PTA_{ijt}, and WTO_{ijt} with X_{ijt} (Baier and Bergstrand, 2007; Yotov et al., 2016).

Data and Sources

We collected data for corn bilateral trade flows, import tariffs, memberships in WTO, and memberships in PTAs for the period 1991–2019. We obtained bilateral trade flows for a total of 167 exporters and 181 importers from the International Trade and Production Database of the US International Trade Commission (Borchert et al., 2022). These bilateral trade flows also include domestic sales (i.e., intranational sales), which are important for estimating a theoretically consistent gravity model (Yotov et al., 2016). Since corn is widely traded in the world market, inclusion of most of the countries that produce, consume, or trade corn is important to comprehensively examine the potential trade reallocation effects of Mexico's GM corn import barrier. With 167 exporters, 181 importers, and 29 years of data, the maximum total number of observations used for estimation is 876,583,[7] which also includes zero trade flows for countries that do not engage in corn trade. We obtain *ad valorem* equivalent tariffs from the WITS TRAINS database (UN Council on Trade and Development, 2023). These data cover nondiscriminatory most favored nation (MFN) tariff rates for countries that engage in bilateral corn trade without PTAs and preferential tariff rates for any

[5] While separating tariff for different bilateral trade link does not follow the gravity model specification (i.e., trade theory predicts the average effect of tariffs is constant across all bilateral links), we deviate from this logic to analyze the differential effect of tariffs as part of our research objective. This approach is also similar to that of Chen and Novy (2022), who considered a flexible gravity equation that predicted variable trade cost elasticities both across and within country pairs.

[6] We exclude NTMs from the analysis because NTMs are not commonly imposed on primary commodity trade (e.g., corn).

[7] Since the estimation ignores singleton observations where bilateral trade values are perfectly correlated with one or more fixed effects, the actual number of observations used for the estimation will be less than the maximum number of potential observations.

Table 1. Summary Statistics

	Mean	Std	Min.	Max.
International trade ($millions)	25.29	906.69	0.00	114, 586.87
Bilateral tariff (%)	8.08	37.24	0.00	467.07
Mexican tariff on US Corn (%)	0.01	0.67	0.00	124.80
Mexican tariff on Argentinian corn (%)	0.01	0.69	0.00	124.80
Mexican tariff on Brazilian corn (%)	0.01	0.67	0.00	124.80
Mexican tariff on Canadian corn (%)	0.01	0.67	0.00	124.80
Member_WTO-joint (binary)	0.70	0.46	0.00	1.00
Agreement_FTA (binary)	0.24	0.43	0.00	1.00

bilateral corn trade within RTAs or nonreciprocal trade preferences. We collect data for memberships in WTO and in PTAs from US International Trade Commission's (USITC) dynamic gravity dataset (Gurevich and Herman, 2021).

Table 1 reports summary statistics for each of the variables utilized in the empirical analysis. The minimum value of corn bilateral trade flows is 0, which indicates that some countries did not engage in corn trade. The maximum value of corn sales is $114,586.87 million, which is domestic sales by China in 2015. Out of 159,297 observations for corn, 69.3% of them have zero corn trade. Corn *ad valorem* equivalent tariff data exhibit significant variation, ranging from 0% to 467.07%. The average tariff of 8.05% indicates that global corn import tariffs are generally lower than most other agri-food products. Out of 159,297 bilateral trade relationships, 67.0% have no tariff. However, a few countries do impose high corn import tariffs. South Korea imposed the maximum MFN tariff of 467.07% in 1996. Turkey implemented MFN tariffs of 130% between 2006 and 2014. China also imposed MFN tariffs of 114% in the 1990s. The Mexican tariff on imports of US, Canadian, Brazilian, and Argentinian corn ranged from 0% to 124.80%. The tariff of 124.80% in 2003 is due to Mexican tariff-rate quota policy with a 215% tariff for imports above 2.5 million tons, and the tariff remained very low after 2008 (Nadal and Wise, 2004). The binary variable for WTO membership indicates that 70% of the countries that trade corn are joint members of WTO. By contrast, only 24% of the countries that engage in corn trade are part of an FTA.

Empirical Analysis

We employ the Poisson pseudo-maximum likelihood (PPML) estimator proposed by Santos-Silva and Tenreyro (2006) to estimate the structural gravity equation (4). PPML has become standard in the gravity literature as it accommodates zero trade flows and provides consistent estimates when heteroskedasticity is present. We estimate two versions of specification (4). Model 1 does not contain country-pair fixed effects, which allows for cross-country variation in estimating the elasticity of substitution accurately (Fontagné, Guimbard, and Orefice, 2022). Model 2 isolates the impact of tariffs on bilateral trade over time and lets country-pair fixed effects absorb the cross-country variation. Furthermore, as widely known in the trade literature, the gravity equation yields biased estimates for RTAs and membership in WTO if country-pair fixed effects are excluded (Baier and Bergstrand, 2007). Consequently, Model 2, with country-pair fixed effects, corrects for endogeneity of policy variables due to unobserved heterogeneity. Table 2 reports the estimated coefficients for both the gravity models.

The coefficient estimate for the Mexican tariff on imports of US corn is significant and has the expected negative sign, implying that the high tariffs that Mexico imposed have curtailed corn imports from the United States. Mexico prefers self-sufficiency in corn because corn is a staple grain and it would like to rely less on imports for food security concerns, preserving native corn, and safeguarding agricultural environments. Consequently, before 2007, Mexico imposed high tariffs to restrict US corn imports. The estimates for the Mexican import tariff on US corn are −0.384

Table 2. Estimated Results of Corn Gravity Model Using PPML

Independent Variables	Model 1 (N = 161,323)	Model 2 (N = 157,866)
Mexican tariff on US corn	−0.384***	−0.021***
	(0.101)	(0.001)
Mexican tariff on Canadian corn	−1.222***	−0.055**
	(0.170)	(0.023)
Mexican tariff on Brazilian corn	−1.18***	−0.027***
	(0.212)	(0.003)
Mexican tariff on Argentinian corn	−1.108***	−0.017***
	(0.141)	(0.003)
Other bilateral tariffs	−0.667***	0.001**
	(0.144)	0.000
NAFTA	−1.791***	4.333***
	(0.686)	(0.102)
Joint membership in WTO	6.069***	1.433***
	(0.651)	(0.038)
Other preferential trade agreements (PTAs)	−0.328	0.243***
	(0.381)	(0.012)
Fixed effects		
Country-pair	no	yes
Importer–commodity–time	yes	yes
Exporter–commodity–time	yes	yes

Notes: The dependent variable is the value of unidirectional exports of corn. Robust standard errors are clustered by country-pair and are in parentheses.

in Model 1 and −0.021 in Model 2; these trade elasticity estimates are inelastic. The coefficient estimates of Mexican tariffs on corn imports from Canada, Brazil, and Argentina are also negative and highly significant in both models. These results highlight that tariffs imposed by Mexico on these four exporting countries have lowered corn imports. Because Model 1 does not absorb cross-country variation via the country-pair fixed effects, the coefficient estimates are at least an order of magnitude larger than those of Model 2 and provide tariff elasticities of −0.384, −1.222, −1.180, and −1.108 for US–Mexican, Canadian–Mexican, Brazilian–Mexican, and Argentinian–Mexican bilateral links, respectively. The estimates for other bilateral tariffs are negative and significant, with an elasticity of substitution of $1.667 (= 1 - (-0.667))$. Other gravity studies have also found small trade elasticities. For instance, Ridley, Luckstead, and Devadoss (2022) estimated a trade elasticity of −0.74 for bulk wine trade and Philippidis, Resano-Ezcaray, and Sanjuán-López (2013) found a trade elasticity of −0.9 for beverages. Boehm, Levchenko, and Pandalai-Nayar (2023) and Ridley, Luckstead, and Devadoss (2024) reported that trade elasticities from gravity equations that utilize country-pair fixed effects (which account for unobserved heterogeneity in policy variables, as in the current study) are generally smaller than those estimated by models without country-pair fixed effects. Since we include country-pair fixed effects in Model 2, this result implies that tariffs minimally impact individual bilateral trade links over time. This finding is not surprising because tariffs between a pair of countries do not change often (Fontagné, Guimbard, and Orefice, 2022).

Since the coefficient estimates for NAFTA and joint membership in WTO and other PTAs are potentially biased in Model 1 because of the exclusion of country-pair fixed effects, we focus on interpreting estimates of Model 2. NAFTA has the anticipated positive effect on Mexican imports from the United States; the coefficient estimate is highly significant, indicating that NAFTA increased corn trade by 7,517.246% $(= 100 \times (e^{4.333} - 1))$, which highlights the importance of NAFTA to expand corn trade among participating countries. This finding also aligns with the goal of the United States, as a major producer of corn, to enhance exports to Mexico because of the latter's close proximity and large market for corn.

The estimate for WTO membership is positive and significant, implying that WTO joint membership increases corn trade as these countries have to abide by WTO trade policies. Specifically, WTO joint membership increases corn trade by 319.125% ($= 100 \times (e^{1.433} - 1)$). Countries participating in PTAs, excluding NAFTA, also expand corn trade by a more modest 27.507% ($= 100 \times (e^{0.243} - 1)$) as revealed by the positive and significant estimate. The estimated results of NAFTA and other PTAs indicate that NAFTA had a much larger impact on corn trade than other PTAs because of the United States, as a leading corn producer, exports a significant volume of corn to its neighbor, Mexico, which is the leading corn importer.

In summary, bilateral tariffs imposed by Mexico on corn imports from the United States, Canada, Brazil, and Argentina, NAFTA, and joint membership in WTO and PTAs have significant influences on corn trade. We utilize Model 2 for the counterfactual analysis below because it includes country-pair fixed effects, yielding the most accurate estimates of bilateral trade costs.

Counterfactual Analyses

Some countries grow largely GM corn. For instance, in the United States, 93% of total corn production is GM corn (Williams et al., 2022); in Canada, almost all corn produced is GM corn (Smyth, 2014). Argentina and Brazil also grow mostly GM corn (Tomson, 2022). In contrast, EU countries grow largely non-GM corn. Because trade data do not separate GM corn versus non-GM corn, we consider that Mexico bans corn imports of 93% from the United States, 98% from Canada, and 90% from Argentina and Brazil, which are also similar to the simulation analysis of Beckman et al. (2024).

Mexico largely imports corn from the United States, Canada, Brazil, and Argentina. Mexico is the leading importer of US corn (averaging 15.6 million tonnes during 2020–2022) and also imports from Brazil (707,632 tonnes), Argentina (1,887 tonnes), and a limited quantity from Canada. Given the volume of Mexican imports from the United States, Argentina, and Brazil, the proposed import ban on GM corn would have had significant economic ramifications not only for these four countries' corn markets but also for the world corn market. Toward this goal, we follow the framework of Yotov et al. (2016) and Anderson, Larch, and Yotov (2018) to conduct simulation analyses, which comprise of a baseline and a counterfactual scenarios.[8] The baseline scenario maintains a status quo of policies in corn trade, and the counterfactual scenario implements Mexico's GM corn import ban. The simulation analyses utilize the estimates from the structural gravity of Model 2, reported in Table 2, which allows us to capture both direct bilateral effects resulting from the Mexican import barrier and indirect multilateral effects arising from changes in the multilateral resistance terms of other exporting and importing countries due to the Mexican trade restrictions.

First, we calculate the baseline (indicated by the superscript B) trade values (X_{ij19}^{B}) under the observed 2019 tariff imposed by Mexico on corn imports. Using the parameter estimates and 2019 values of the independent variables, the baseline trade flow is

$$X_{ij19} = \exp\left\{\text{Const}^B + \gamma_{i19} + \eta_{j19}\right\}, \tag{5}$$

where

$$\begin{aligned} \text{Const}^B = {} & \hat{\alpha}_{0,t} + \hat{\alpha}_1 \log\left(1 + \tau_{US,ME19}\right) + \hat{\alpha}_2 \log\left(1 + \tau_{CA,ME19}\right) \\ & + \hat{\alpha}_3 \log\left(1 + \tau_{BR,ME19}\right) + \hat{\alpha}_4 \log\left(1 + \tau_{AR,ME19}\right) + \hat{\alpha}_5 \log\left(1 + \tau_{ij19}^{N}\right) \\ & + \hat{\alpha}_6 NAFTA_{19} + \hat{\alpha}_7 PTA_{ij19} + \hat{\alpha}_8 WTO_{ij19} + \hat{\varsigma}_{ij}. \end{aligned} \tag{6}$$

[8] Also see studies by Ridley, Akhundjanov, and Devadoss (2023), Dhoubhadel, Ridley, and Devadoss (2023), and Choi et al. (2024), which implemented similar simulation for policy analysis.

We estimate equation (5) for parameters γ_{i19} and η_{j19} to capture the inward and outward multilateral resistance under the 2019 tariff. Using the estimated parameters, $\hat{\gamma}^B_{i19}$ and $\hat{\eta}^B_{j19}$, we predict bilateral trade flows under the baseline

$$X^B_{ij19} = \text{Const}^B + \hat{\gamma}^B_{i19} + \hat{\eta}^B_{j19}, \tag{7}$$

which will be compared to the counterfactual simulated values described below.

To examine the impacts of the proposed Mexican GM corn import restriction, we increase Mexican corn import tariffs on the United States, Brazil, Argentina, and Canada so that Mexican imports from these countries amount to a 93%, 90%, 90%, and 98% reductions from these four countries, respectively. We maintain all other policies at their 2019 level. At these high tariff levels, we run a simulation (superscripted by C in the equation below) that generates counterfactual bilateral trade flows in 2019 under *ceteris paribus* condition. We estimate the following equation by utilizing 2019 observed trade flows and setting the Mexican import tariff on US, Brazilian, Argentinian, and Canadian corn at their high level:

$$X_{ij19} = \exp\left\{\text{Const}^C + \gamma_{i19} + \eta_{j19}\right\} + e_{ij}, \tag{8}$$

where

$$\begin{aligned} \text{Const}^C = {} & \hat{\alpha}_{0,t} + \hat{\alpha}_1 \log\left(1 + \tau^C_{US,ME19}\right) + \hat{\alpha}_2 \log\left(1 + \tau^C_{CA,ME19}\right) \\ & + \hat{\alpha}_3 \log\left(1 + \tau^C_{BR,ME19}\right) + \hat{\alpha}_4 \log\left(1 + \tau^C_{AR,ME19}\right) + \hat{\alpha}_5 \log\left(1 + \tau^N_{ij19}\right) \\ & + \hat{\alpha}_6 NAFTA_{19} + \hat{\alpha}_7 PTA_{ij19} + \hat{\alpha}_8 WTO_{ij19} + \hat{\varsigma}_{ij} \end{aligned} \tag{9}$$

is computed using the coefficient estimates. We estimate equation (8) to obtain the estimates for the exporter–year ($\hat{\gamma}_{i19}$) and importer–year ($\hat{\eta}_{j19}$) fixed effects. These estimates represent, respectively, the outward and inward MRTs under high Mexican tariff (à la import ban) which capture the third-party or indirect trade impacts resulting from the tariff changes. Using the estimates, $\hat{\gamma}^C_{i19}$ and $\hat{\eta}^C_{j19}$, we obtain simulated trade values (X^C_{ij19}) due to the Mexican import ban:

$$X^C_{ij19} = \exp\left\{\text{Const}^C + \hat{\gamma}^C_{i19} + \hat{\eta}^C_{j19}\right\}. \tag{10}$$

The effect of the import ban on bilateral trade flows is given by $\Delta X^C_{ij19} = X^C_{ij19} - X^B_{ij19}$. Summation of these bilateral trade flows over all exporters yields $\Delta X^C_{j19} = \sum_i \Delta X^C_{ij19}$, which is the total impact of the Mexican corn import ban on the jth country's imports.

Based on Arkolakis, Costinot, and Rodríguez-Clare (2012), the welfare effects of Mexican trade policy on various countries are

$$W_{jt} = \left(\frac{\frac{X^C_{jj}}{E^C_j}}{\frac{X^B_{jj}}{E^B_j}}\right)^{\frac{1}{1-\sigma}}, \tag{11}$$

where W_{jt} is the change in welfare in country j, X^B_{jj} is domestic sales under the baseline, and X^C_{jj} is the domestic sales under the counterfactual. The above expression for welfare is equivalent to taking the ratio of real consumption (i.e., expenditures E_j divided by the price index P_j) in the counterfactual to real consumption in the baseline (Yotov et al., 2016).

Simulation Results

Because corn is a widely traded commodity globally, the proposed Mexican import restrictions on GM corn would have reverberated throughout the world market. Figure 1 illustrates the effects of

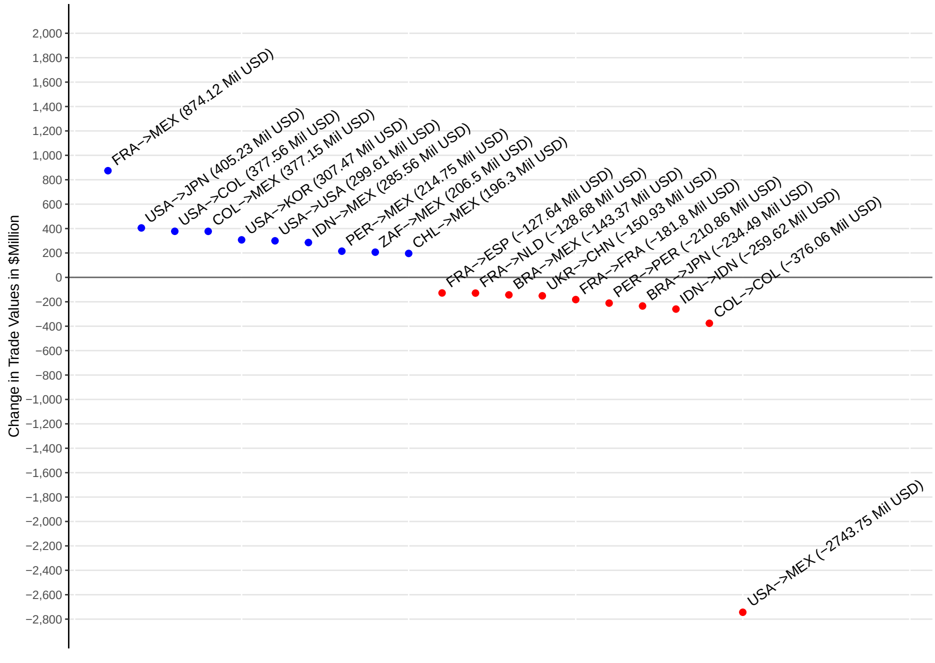

Figure 1. Ten Largest Increases (blue dots) and Decreases (red dots) in Bilateral Corn Trade

the Mexican policy on the ten largest bilateral corn trade expansions and contractions. These include the countries directly involved with this dispute (Mexico, the United States, Brazil, Argentina, and Canada) and also other "bystander" countries that experience significant impacts (e.g., decline in exports from France to Spain). Table 3 reports the results of major US export diversions and Mexican import reallocations due to this corn trade dispute. We discuss the results presented in Figure 1 and Table 3 concurrently. In Appendix Table A1, we present the results of the total trade changes for all countries and provide a brief discussion.

Because of the Mexican import ban of GM corn, Mexican imports from the United States decline by $2,743.745 million, from Brazil by $143.370 million, from Argentina by $16.761 million, and from Canada by $2.203 million. To fill the void left by the reduced imports from these countries, Mexico imports corn from France ($874.116 million), Colombia ($377.148 million), Indonesia ($285.559 million), Peru ($214.754 million), South Africa ($206.500), and other countries in smaller magnitudes. The remaining shortage is filled by Mexico selling more corn domestically, worth $45.880 million. Consequently, total Mexican imports are not drastically affected; lost imports from the United States, Brazil, Argentina, and Canada are largely negated by more expensive imports from other countries.

The United States largely diverts its export losses in the Mexican market to Japan ($405.234 million), Colombia ($377.556 million), South Korea ($307.466 million), China ($195.556 million), Peru ($143.135 million), Egypt ($131.925 million), Taiwan ($125.475 million), and other countries in smaller amounts. The United States also expands its domestic sales by $299.613 million. In addition, the United States increases its exports to other countries (e.g., Saudi Arabia, Canada, Ecuador, Indonesia, Vietnam) in smaller magnitudes. Expansion in exports to the top 20 major import countries (see Table 3) and domestic sales comprises about 87% of US export loss to Mexico. Because of these trade reallocations, total US exports are not impacted significantly: Export losses to Mexico are largely offset by US exports to other countries. However, US exports to these faraway countries incur higher transport costs.

The Mexican ban on GM corn impacts trade throughout the global corn market. Focusing on bilateral trade links, to increase exports to Mexico, France diverts its sales from Spain, Netherlands,

Table 3. Changes in US Bilateral Exports and Changes in Mexican Bilateral Imports

Δ in Mexican Bilateral Corn Imports		Δ in US Bilateral Corn Exports	
Exporter	**Δ in Exports ($ millions)**	**Importer**	**Δ in Exports ($ millions)**
United States	−2,743.745	Mexico	−2,743.745
France	874.116	Japan	405.234
Colombia	377.148	Colombia	377.556
Indonesia	285.559	South Korea	307.466
Peru	214.754	United States	299.613
South Africa	206.500	China	195.556
Chile	196.301	Peru	143.135
Hungary	177.609	Egypt	131.925
Ecuador	104.020	Taiwan	125.475
Austria	82.619	Saudi Arabia	64.103
Italy	81.561	Canada	45.889
Germany	61.210	Ecuador	37.105
Thailand	58.116	Indonesia	35.513
Spain	50.562	Vietnam	33.825
Mexico	45.880	Dominican Republic	31.995
Australia	20.251	Morocco	31.385
Netherlands	17.466	Namibia	28.771
Russia	16.837	Israel	27.363
Israel	12.944	Spain	26.883
China	9.402	Botswana	25.678
Honduras	2.853	France	25.529

and itself. Similarly, Colombia, Indonesia, and Peru reallocate their sales from domestic markets to Mexico. As the United States diverts some of its lost export sales in Mexico to Japan, Brazil loses some of its market share in Japan.

Table 4 reports the results of the welfare analysis for 45 major corn-trading countries. These welfare results are relative to that of Spain, which is considered as the reference country because Spain does not trade a significant amount of corn and therefore endures only modest trade effects in the counterfactual scenario. As a result of the Mexican policy, based on the full sample of countries, about 31 countries are benefiting, 17 countries are losing, and 16 countries are largely unaffected, with welfare changes near 0%. The large number of countries gaining from the proposed Mexican import ban of US corn signifies the massive value of corn reallocated from Mexico to other countries. Several importing countries (Chile, Colombia, Pure, France, Ecuador, Austria, Israel, Germany, and Italy) experience significant gains as they increase their imports because of lower price arising from US diversion of corn from Mexico. Countries that incur the largest welfare losses are Russia, Czech Republic, Mexico, Slovakia, and Switzerland. It is not surprising that Mexico loses significantly: Its import restrictions severely restrict cheaper corn from the United States, Brazil, Argentina, and Canada, which raises the price for Mexican consumers of the most important staple commodity in their diet. Although Mexico increases its imports from France, Colombia, and other countries to meet its demand, these countries' corn is more expensive than US, Canadian, Brazilian, and Argentinian GM corn because of less efficient production practices and the additional transport costs involved in shipping. Thus, the proposed Mexican trade policy would have been a food security concern for its citizens. Welfare in the United States and Brazil would have declined slightly—by 0.693% and 0.082%, respectively—because of increases in trade costs as they reallocate sales to their domestic markets and faraway countries. Interestingly, Canada and Argentina would have gained by Mexico's restriction of GM corn because their total exports expand as they sell to other international markets.

Table 4. Welfare Impacts of the Proposed Mexican Import Ban of US Corn

Country	%Δ in *Welfare*	Country	%Δ in *Welfare*
Chile	11,598.621	Argentina	0.168
Colombia	683.896	Morocco	0.102
Peru	32.542	Vietnam	0.089
France	25.747	Bangladesh	0.065
Ecuador	24.666	Qatar	0.042
Austria	17.799	Greece	0.032
Israel	16.138	Philippines	0.024
Germany	8.140	⋮	⋮
Italy	7.083	Fiji	−0.018
New Zealand	6.880	Macedonia	−0.052
Australia	5.893	Oman	−0.061
Thailand	4.104	Brazil	−0.082
Portugal	4.080	Kazakhstan	−0.094
Indonesia	2.538	Bulgaria	−0.194
Poland	1.955	Turkey	−0.241
Canada	1.763	Croatia	−0.365
Paraguay	1.097	Bosnia and Herzegovina	−0.551
Hungary	1.064	United States	−0.693
Zambia	0.972	Russia	−0.802
Costa Rica	0.691	Czech Republic	−0.817
Suriname	0.358	Mexico	−0.911
Georgia	0.348	Slovakia	−1.444
Uruguay	0.266	Switzerland	−3.852

Notes: These welfare results are relative to that of the baseline country (Spain). Countries with welfare changes of zero are excluded from the table.

Conclusion and Policy Implications

Even after intense negotiations and agreements through NAFTA and later USMCA, corn trade between Mexico and the United States remains contentious for food security reasons and because corn is a staple food in Mexico. Consequently, Mexico does not want to rely on corn imports from the United States and, in the past, has imposed tariffs and tariff-rate quotas over the years on corn imports from the United States. More recently, Mexico wanted to ban GM corn imports from the United States (and also from other GM corn-producing countries) altogether on the ground that GM corn poses health hazards.

This study analyzes the effects of this proposed Mexican import barrier on Mexican, US, and global corn markets. Had this import ban prevailed, it would have caused considerable trade reallocations across the countries. Specifically, Mexico would have imported from France, Colombia, Indonesia, Peru, South Africa, Chile, and other countries to fill the void left by lost imports from the United States. In turn, the United States would have diverted its lost export sales in Mexico to Japan, Colombia, South Korea, itself, China, Peru, Egypt, and Taiwan. Because of these trade reallocations, Mexico would have imported from more expensive corn exporters and would have incurred additional transport costs. The United States would have exported to faraway countries and would have incurred greater transport costs. Due to these inefficient reallocations, welfare would have decreased in many of these countries, with Mexico incurring one of the largest welfare losses due to consumers paying higher prices.

This study echoes the trade literature that overwhelmingly provides both theoretical and empirical evidence of the adverse effects of trade restrictions. The proposed Mexican ban on US corn would likely have caused harm to Mexico and the United States. Therefore, the resolution of this dispute helped to avoid a deeper trade conflict between Mexico and the United States.

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Appendix

The United States incurs total export losses of $299.613 million, which is 10.8% of what was lost in Mexico. Mexico's total imports fall by $45.880 million, which is 1.7% of lost imports of US corn. Colombia augments its exports ($376.062 million) by expanding its exports to Mexico. Indonesia, Peru, and France increase their exports by $259.623 million, $210.860 million, and $181.800 million, respectively. Many countries' total trade loss is zero because trade reallocations cause export gains to offset import losses. Brazil's total exports fall by $6.385 because its export shares in other countries are captured by the United States.

Table A1. Total Impacts of the Proposed Mexican Import Ban of GM Corn on Exports ($ millions)

Country	Exports	Country	Exports
Colombia	376.062	Bangladesh	0.501
Indonesia	259.623	Philippines	0.482
Peru	210.860	Uruguay	0.330
France	181.800	Georgia	0.155
Ecuador	90.561	Greece	0.088
Italy	82.314	Rwanda	0.016
Spain	67.774	Costa Rica	0.015
Chile	55.668	Morocco	0.013
Thailand	38.242	⋮	⋮
Germany	37.659	Macedonia	−0.011
Canada	33.785	Albania	−0.016
Austria	23.950	Kazakhstan	−0.115
Israel	12.698	Bulgaria	−0.187
China	10.026	Czech Republic	−0.611
Poland	7.494	Croatia	−0.753
Hungary	4.959	Bosnia and Herzegovina	−1.041
Portugal	4.884	Slovakia	−1.723
Zambia	4.234	Switzerland	−1.775
Australia	4.190	Turkey	−2.280
Argentina	4.164	Brazil	−6.385
New Zealand	3.155	Russia	−12.347
Paraguay	1.283	Mexico	−45.880
Vietnam	1.123	United States	−299.613