INTRODUCTION

Food insecurity continues to be a lurking global problem. To overcome this challenge, appropriate agricultural production technologies should be adopted. The introduction of genetically modified organisms (GMOs) in 1994 sparked persistent disagreements among countries. Some countries have strongly opposed it while adoption continues to grow slowly in others. The United States is one of the largest producers and exporters of GMOs. This paper examines the cost of U.S. trade partners’ GMO regulatory index (GMORI) on U.S. corn and soybean exports. Using a multilevel mixed-effects model, a 1% increase in the GMORI leads to US$ 71.8 million and US$ 144 million loss in U.S. corn and soybean export revenue, respectively. A 1% increase in Japan's GMORI leads to US$20 million and US$ 9 million loss while that of China leads to US$ 2.4 million and US$ 74 million loss in revenue for U.S. corn and soybean export sectors, respectively. The findings suggest that even though GDP, geographical distance, exchange rate, and price ratios are important factors, the restrictions imposed by countries on GMOs have significant effects on U.S. corn and soybean exports. The study draws the conclusion that the restrictions imposed by countries on GMOs have differential cost implications on U.S. corn and soybean exports. Despite this prognosis, previous studies have shown that global adoption of GMOs continue to grow, though slowly. Hence, it is recommended that the United States continues with the information dissemination effort to enhance the adoption rate and have a consistent measure of adoption evaluation rate among trade partners.

KEYWORDS
agriculture, corn, genetically modified organisms regulatory index, mixed-effects model, soybean, trade costs
Economic Research Service (USDA ERS) indicated that GM corn and soybean covered about 90% of their respective productions in 2017. This high proportion implies that GMO restrictions and bans by trade partners may have unfavorable consequences on U.S. corn and soybean exports. Figure 1 shows the percentages of GM corn and soybean produced in the United States from 2000 to 2017.

The objective of this study is to estimate the cost of trade partners’ GMORI on U.S. corn and soybean exports. U.S. soybean export has seen a decline in recent times (Figure 2). Anderson et al. (2001) explained that the differences in views on environmental issues and consumers’ right to know about food ingredients are unlikely to disappear in the foreseeable future. Furthermore, there have been several geopolitical disputes in agricultural trade related to productivity differences and the genetic modification technique (Brester et al., 2019). The high productivity and efficiency associated with this technique enabled some countries to export at cheaper prices relative to the prices at the destination countries (Brookes et al., 2010; Smyth et al., 2015).

1.1 Aggregate demand for GMOs: To eat or to shun?

GMOs are organisms that do not occur naturally but through technologically and scientifically aided methods. The food and agricultural organization (FAO) defines biotechnology to encompass a wide range of technologies which can be applied for a range of purposes. The advantages of GMOs are improved yields, enhanced nutritional value, longer shelf life, and resistance to drought, frost, or insects. Currently, there is no conclusive consensus on the health hazards of GMOs (Costa-Font et al., 2008; Gurău & Ranchhod, 2016). Despite the advantages and expected growth in cultivation, the main concerns that have been raised are human health, ecological, poor communities, and animal welfare concerns (Touyz, 2013).

There has been a number of trade-related international disputes over the years. For disputes directly related to GMOs, the first formal complaint to the WTO was in 2000. In this dispute, Egypt placed a prohibition on the import of canned tuna with soybean oil from Thailand based on the suspicion of the use of GM soybean oil. Subsequently, there have been a handful of other disputes related to GMOs. Notably, the U.S. requested consultation with the EU in 2003 concerning a moratorium applied by the EU on the approval of biotech products that had restricted imports of agricultural and food products from the United States. During the negotiation process, both parties requested the arbitrator to suspend its work pursuant to their agreed procedures. In accordance with this request, the arbitrator suspended the arbitration proceedings.

Despite the potential losses expected from GMO trade restrictions, rigorous research quantifying these losses on U.S. agricultural exports has been limited. Disdier and Fontagne (2010) quantified the trade impact of EU measures on GMOs on the United States, Canada, and Argentina. Their study revealed that average yearly revenue losses due to EU moratorium of GMOs between 2003 and 2005 were US$ 1.97 billion, US$349.6 million, and US$52.2 million for the three countries, respectively. However, Peterson et al. (2013) explained that empirically assessing sanitary and phytosanitary regulations has proven difficult because most data sources indicate only the existence of a regulation but provide no information on the type or importance of the respective measure. The study by Disdier and Fontagne (2010) encounters this limitation, it measures GM restrictions as a dummy where 1 represents a moratorium placed on the import of a commodity by the EU and zero otherwise. The limitation to this approach is that it fails to emphasize the extent of restriction. For instance, one restriction may be related to labeling policies while another may be related to risk assessment procedures or limitations in approval procedures.

Vigani et al. (2012) introduced a method of measuring GM restrictions to quantify the effect of GMO regulation on bilateral trade flows of agricultural products. They employed the composite index of GMO regulations using a gravity model to show that bilateral differences in GMO regulation negatively affect trade flows. The data in their study comprised of 3 years, from 2005 to 2007. Despite the
robust results and inference obtained, the study used the bilateral trade among 60 countries. Therefore, the inferences cannot be solely attributed to the effects of GMO regulations on U.S. exports. Secondly, there have been significant developments in the biotechnology sector over the period (Zhang et al., 2016). These could have significant effects on GMO trade. For instance, GMO information dissemination has improved between 2007 and now (FAO, 2012). According to Disdier and Fontagne (2010), GM areas had increased to 125 million hectares in 25 countries by 2008. On the other hand, more countries have introduced formal regulations concerning GMOs (see the EU webpage from more details). Hence, GMO regulations are likely to have changed for the countries over the period.

Qaim and Kouser (2013) highlighted three possible pathways through which GMOs could impact food security. They indicated that GMOs could increase the quantity of production, thus making food available at global and local levels. Nielsen et al. (2003) asserted that the potential benefits from GMOs may not be realized if consumers in some countries reject GMOs. Furthermore, restrictions like these can also lead to monetary losses to the exporter. Weyerbrock and Xia (2000) mentioned the possibility of U.S. losing US$4.97 billion of its exports due to questionable regulations from the EU. With regard to this, understanding the cost implications of restrictions to GMOs on the United States is important.

Echoing the conclusions of Olper (2016), I deem some of the methods employed by previous studies to be too simplistic to explain the impact of these restrictions on U.S. corn and soybean exports. In light of the limitations revealed in the aforementioned literature, the contributions of this study are twofold; first, I fill this knowledge gap by extending the GMORI developed for 60 countries to include 120 countries who are major trade partners for U.S. corn and soybean. Following this, a multilevel mixed-effects model is estimated in a gravity model framework to obtain the effects of this regulatory index on U.S. corn and soybean exports. The primary advantage of using this index is related to policy. The GMORI combines a set of indicators relevant to the extent of resistance to GMOs based on weights. These indicators are approval process, risk assessment, labeling requirements/policies, traceability rules, coexistence strategies, and membership in international agreements. The advantage of using this index is that it enables decisions to be made on any of the component indicators. For example, if a country with a restrictive index of 0.90 has the desire to reduce its restriction index, it can decide to eliminate the required GMO approval procedures from its trade operations. Secondly, a dollar estimate of the impact of the GMORI is computed based on the obtained coefficient and average U.S. corn and soybean exports. This value is computed for all U.S. destinations and further segregated for its top 10 destinations. The advantage of this segregation is to help reveal trade partners where losses due to GMORI are large and formulate pragmatic tailor-made remediation policies. For instance, the United States can choose specific countries based on these expected losses to pursue the improvement of approval processes or traceability rules. Being specific with these remediation policies is beneficial to reduce the expenditure incurred.

The results suggest that even though GDP, geographical distance, exchange rate, and price ratios are important factors, the restrictions imposed by countries on GMOs have significant effects on U.S. corn and soybean exports. The study draws the conclusion that the restrictions imposed by countries on GMOs have differential cost implications on U.S. corn and soybean exports. Despite this prognosis, previous studies have shown that global adoption of GMOs continues to grow, though slowly. Hence, it is recommended that the United States continues with the information dissemination effort to enhance the adoption rate.

The remainder of the paper is organized as follows. Section 2 presents the methodology and data used for the study. This section also discusses the conceptual and empirical frameworks of the study. The empirical results are presented in Section 3, followed by conclusions and policy implications in Section 4.
2 | METHODOLOGY AND DATA

2.1 | Conceptual Framework

The conceptual framework classifies the determinants of trade into three groups: traditional gravity model variables, price variables (Anderson & Wincoop, 2003), GMORI and trade agreements (Rose, 2004). The traditional gravity model variables are the gross domestic product (GDP) of the trading partners and the geographical distance between the trading partners. The price variables are exchange rate and price ratios between the trading partners. According to Anderson and Wincoop (2003), prices differ between locations due to trade costs that are not directly observable, and therefore, it is essential for empirical studies to identify these costs. The GMORI represents the nontariff barrier while the existence of a bilateral or multilateral trade agreement between the United States and destination represents the trade agreements. Figure 3 presents a diagrammatic representation of this relationship.

2.2 | Empirical model specification

The data used comprises of a set of variables which accounts for a hierarchy of exporter and importer variations. To assess the impact of GMORI on U.S. exports, I employ a robust multilevel mixed-effect model which is based on the restricted maximum likelihood approach. This is a generalization of a linear regression that allows for the inclusion of random effects in addition to the overall error terms. The general linear model is presented in matrix notation as

\[ Y = X\beta + Z\gamma + \epsilon \]  

(1)

where \( Y = \{y_{ij,1}, \ldots, y_{ij,T}\} \) is an \( n \times 1 \) vector of responses which represent agricultural commodity exports from exporter \( i \) to importer \( j \) in time \( t \), \( X = \{x_{ij,1}, \ldots, x_{ij,T}\} \) is an \( n \times p \) matrix of exogenous variables for the fixed effects \( \beta \). \( Z \) is the \( n \times q \) matrix of covariates for the random effects \( \gamma \), while the \( n \times 1 \) vector of errors which is given by \( \epsilon \) is assumed to be multivariate normal with mean 0 and variance matrix \( \sigma^2_R \). From the random part of Equation 1, \( Z\gamma + \epsilon \) is assumed to have a variance–covariance matrix \( G \) (variance components) and is orthogonal to such that.

\[ \text{Var} \begin{bmatrix} \gamma \\ \epsilon \end{bmatrix} = \begin{bmatrix} G & 0 \\ 0 & \sigma^2_R \end{bmatrix} \]  

(2)

The hierarchical structure of the data presents a natural form of clustering. The primary advantage of the mixed model formulation is that it makes specifications of random effect terms easier. Secondly, it enables a generalization to more than one set of random effects. For instance, if importers are nested within exporters, then the mixed-effect model can be generalized to allow random effects at both the exporter and importer-within-exporter levels. Hence, I organize the mixed-effect model as a series of \( M \) independent cluster of exporters given as

\[ y_{ij} = X_{ij}\beta + Z_{ij}\gamma_j + \epsilon_j \]  

(3)

for \( j = 1, \ldots, M \), with cluster \( j \) consisting of \( n_j \) observations. The response variable \( y_{ij} \) represents the rows of \( y \) corresponding with the \( j \)th cluster of importers, with \( X_{ij} \) and \( \epsilon_j \) defined analogously to Equation 1. The random effects of \( y_{ij} \) are now viewed as \( M \) realizations of a \( q \times 1 \) vector that is normally distributed with mean 0 and \( q \times q \) variance matrix \( \Sigma \). The matrix is the \( n \times q \) design matrix for the \( j \)th cluster random effects. From Equation 1, I obtain,

\[ Z = \begin{bmatrix} Z_1 \\ Z_2 \\ \vdots \\ Z_M \end{bmatrix}, \quad \gamma = \begin{bmatrix} \gamma_1 \\ \vdots \\ \gamma_M \end{bmatrix}, \quad G = I_M \otimes \sum, \quad R = I_M \otimes \Lambda \]  

(4)

To estimate the model empirically, the mixed-effects model is presented in equation 5 as

\[ \ln EX_{ijt} = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln GDP_{jt} + \beta_3 \ln Dist_{ijt} + \beta_4 \ln Excrate_{ijt} + \beta_5 \ln Pratio_{ijt} + \beta_6 \ln GMORI_{jt} + \beta_7 \text{Bilateral}_{ijt} + \beta_8 \text{Multilateral}_{ijt} + \mu_t + \epsilon_{ijt} \]  

(5)

where \( EX_{ijt} \) is the exports of commodity from exporter \( i \) to importer \( j \) in year \( t \); \( GDP_{it} \) is the GDP for exporter \( i \) in year \( t \); \( GDP_{jt} \) is the GDP for importer \( j \) in year \( t \); \( Dist_{ijt} \) is the distance from exporter \( i \) to importer \( j \); \( Excrate_{ijt} \) is the exchange rate between exporter \( i \)’s currency and importer \( j \)’s currency in year \( t \); \( Pratio_{ijt} \) is the price ratio between domestic price of the commodity for exporter \( i \) and price received on the international market (i.e., from importer \( j \) in year \( t \); \( GMORI_{jt} \) is the genetically modified organisms regulatory index of the importer \( j \); \( \text{Bilateral}_{ijt} \) is a dummy taking a value of 1 if \( i \) and \( j \) are in a bilateral trade agreement or zero otherwise; \( \text{Multilateral}_{ijt} \) is a dummy taking a value of 1 if \( i \) and \( j \) are in a multilateral trade agreement or zero otherwise.

FIGURE 3 Conceptual framework for the cost effects of U.S. corn and soybean exports Source: Authors’ construct
a multilateral trade agreement or zero otherwise; $\mu_p$ is the random error effects of the importer clusters; and $\epsilon_{ij}$ is the random error term. A summary of the descriptions, measurements, and “a priori” expectations can be found in Table 1.

### 2.3 Expected losses due to changes in GMORI of major trade partners

The expected losses ($E_L$) from an increase in the GMORI of the importer are computed in this section. To estimate this value, the average yearly exports by the United States to the top 10 partners of the two crops were obtained. The formula for the expected losses is given by:

$$E_L = \frac{\beta_6 \mu_{\text{exp}}}{100} \quad (6)$$

where $E_L$ is the expected loss from a change in GMORI; $\beta_6$ is the estimated coefficient of GMORI from the multilevel mixed-effects model in Equation 5, and $\mu_{\text{exp}}$ is the average yearly export of the commodity from United States to the destination.

### 2.4 Data sources and construction of variables

The dataset for the empirical analysis was obtained from different data sources. These are as follows: (a) United States Department of Agriculture’s Foreign Agricultural Service (USDA FAS), (b) Centred’Etudes Prospectives et d’informations Internationale (CEPII), (c) International Monetary Fund (IMF), (d) Bureau of Economic Analysis (BEA), (e) USDA National Agricultural Statistics Services (NASS), (f) Office of the United States Trade Representative (USTR), (g) Federal Reserve of St. Louis (FRED St. Louis Fed).

The USDA FAS contains global agricultural trade transactions from 1960 with detailed information on geographical region, country, U.S. state of origin and destination of each transaction. It also contains the type of commodity and its subclasses by harmonized commodity description and coding system (HS code). These are presented as six-digit (HS6), eight-digit (HS8), and ten-digit (HS10) classifications. The data are aggregated at either annual or monthly intervals. The beginning year of the data is dependent on the level of trade, that is, country to country, U.S. to country, or U.S. state to country. I obtained the yearly export values of corn and soybean from the USDA FAS database. This contained the total states export for corn and soybean from 2004 to 2017. The state GDP was obtained from the BEA.

To obtain the characteristics of the trade destinations, the gravity variables dataset which was constructed by the CEPII research expertise on world economy was used. The GDP of the destinations and the distance between countries were obtained from the CEPII. The distance of interest is the distance between the United States and selected destinations. The exchange rate between the U.S. dollar and the destination currencies was obtained from the IMF. The international prices of corn and soybean were obtained from FRED St. Louis while the domestic prices within United States were obtained from NASS. All the variables except for the trade agreements status were logged.

The USTR publishes the records of U.S. trade agreements of all forms (preferential and nonpreferential). It presents documents of regulations binding the trade agreement. This includes the periods of accession and ratifications. The free trade agreements (FTA) status of the destinations with the United States was obtained from the USTR. This was recorded in the constructed dataset as a dummy, taking a value of 1 where there is

| TABLE 1 | List of Variables and their “a priori” expectations |
|-----------------|-----------------------------------------------|
| Variable        | Description                                    |
| InEX<ij>        | Log value of exports from origin i to destination j in time t |
| lnGDP<jt>       | Log of GDP of destination j in time t           |
| lnGDP<i>        | Log of GDP of origin i in time t                |
| lnDist<ij>      | Log of distance between origin i and destination j |
| Pratio<ij>      | Ratio between price at destination j and origin i in time t |
| Excrate<ij>     | Exchange rate between origin i and destination j in time t |
| lnGMORI<jt>     | GMO Regulatory Index for destination j          |
| Bilateral<ij>   | Bilateral FTA between origin i and destination j in time t |
| Multilateral<ij>| Multilateral FTA between origin i and destination j in time t |
| Measurement     | US$                                           |
| “a prior” expectation |                                |
| Dependent Variable |                                    |
| +                |                                               |
| -                |                                               |
| -                |                                               |
| -                |                                               |
| -                |                                               |
| 0–1(highest restriction) |                                      |
| Dummy (1: yes, 0 otherwise) |                                  |
| Dummy (1: yes, 0 otherwise) |                                  |
an existing trade agreement in a particular year and zero otherwise. The variables from the various data sources were then merged based on their common items. The data cleaning process involved the removal of countries that were not common across all the data sources and minor trade partners. Following this, a total of 120 destinations were obtained.

2.5 Construction of genetically modified organisms regulatory index

The GMORI was constructed for 120 countries based on Vigani and Olper (2013) framework. The advantage derived by using this method is that it consists of different aspects of the limitation to GM trade. Varied sources of data were employed for the construction. This index was built by obtaining information for six main regulatory categories. These are (a) approval process, (b) risk assessment, (c) labeling, (d) traceability, (e) coexistence, and (f) member of international agreements. A Likert scale scoring of these categories was then used to construct this index. The categorical scoring ranges from 0 (lowest condition) to the highest condition’s correspondent number. Based on their scale, the scores for each of the categories are provided in Table 2. The expected total sum of the scale is 20. Hence, the overall GMORI was obtained as a normalized unweighted sum obtained by each country. The GMORI values range from 0 to 1

| Regulatory Categories                                      | Scores |
|------------------------------------------------------------|--------|
| (1) Approval Process                                       |        |
| Absence of GMO approval procedures                         | 0      |
| Mandatory approval process, but not yet enforced           | 1      |
| Mandatory approval process adopting the principle of substantial equivalence | 2      |
| Mandatory approval process adopting the precautionary principle | 3      |
| Countries declared “GM-free”                               | 4      |
| (2) Risk Assessment                                        |        |
| Absence of GMO risk analysis                               | 0      |
| Proposed risk assessment, but not yet enforced             | 1      |
| Mandatory risk assessment                                  | 2      |
| Countries declared “GM-free”                               | 3      |
| (3) Labeling                                               |        |
| Absence of labeling policies                               | 0      |
| Voluntary GMO labeling                                     | 1      |
| Mandatory GMO label without threshold or with threshold > 1% | 2      |
| Mandatory GMO label with threshold ≤ 1%                    | 3      |
| Countries declared “GM-free”                               | 4      |
| (4) Traceability                                           |        |
| Absence of GMO traceability nor IP system                  | 0      |
| GMO traceability not yet enforced or is in place an IP system | 1      |
| Mandatory GMO traceability                                 | 2      |
| Countries declared “GM-free”                               | 3      |
| (5) Coexistence                                            |        |
| Absence of coexistence strategies                          | 0      |
| GMO coexistence policies not yet enforced                  | 1      |
| Partial guidelines on GMO and non-GMO coexistence          | 2      |
| Exhaustive guidelines on GMO and non-GMO existence         | 3      |
| Countries declared “GM-free”                               | 4      |
| (6) Membership in International Agreements on Biotechnology|        |
| No adherence to international agreements                   | 0      |
| Adherence to a single international agreement              | 1      |
| Adherence to both international agreements                 | 2      |

*A vivid description of the six categories can be found in Vigani and Olper’s (2013) “GMO standards, endogenous policy and the market for information”.*
after normalization, where higher values indicate higher restrictiveness to GMO cultivation and commercialization. Majority of the scoring was based on the FAO GM foods platform. The scoring revealed that Zimbabwe is the most restrictive country to GMOs among U.S. trade partners while North Macedonia has basically no regulations or restrictions to genetically modified foods. The GMORI for all the trade partners employed in this study are presented in Table 3. Furthermore, a quartile distribution is presented as a bar graph in Figure 4. From this figure, 47 of the U.S. trade partners have a GMORI between 0 and

| Country              | GMORI | Country            | GMORI | Country          | GMORI |
|----------------------|-------|--------------------|-------|------------------|-------|
| North Macedonia      | 0.00  | Senegal            | 0.20  | Korea, Rep.      | 0.45  |
| Brunei Darussalam    | 0.05  | Tajikistan         | 0.20  | Russian Federation | 0.45 |
| Sierra Leone         | 0.05  | Trinidad and Tobago | 0.20 | Saudi Arabia     | 0.45 |
| Costa Rica           | 0.10  | Honduras           | 0.25  | Brazil           | 0.50  |
| United Arab Emirates | 0.10  | Nigeria            | 0.25  | Bulgaria         | 0.50  |
| Algeria              | 0.15  | Paraguay           | 0.25  | China            | 0.50  |
| Bangladesh           | 0.15  | Bahrain            | 0.30  | Croatia          | 0.50  |
| Hong Kong            | 0.15  | Bolivia            | 0.30  | Lithuania        | 0.50  |
| Madagascar           | 0.15  | Canada             | 0.30  | China            | 0.50  |
| Malawi               | 0.15  | Dominican Republic | 0.30 | Australia        | 0.55  |
| Morocco              | 0.15  | Egypt              | 0.30  | Cyprus           | 0.55  |
| Mozambique           | 0.15  | El Salvador        | 0.30  | Czech Republic   | 0.55  |
| Namibia              | 0.15  | Georgia            | 0.30  | Latvia           | 0.55  |
| Nepal                | 0.15  | Ghana              | 0.30  | Switzerland      | 0.55  |
| Nicaragua            | 0.15  | Guatemala          | 0.30  | Norway           | 0.60  |
| Niger                | 0.15  | Iran, Islamic Rep. | 0.30 | Poland           | 0.60  |
| Peru                 | 0.15  | Pakistan           | 0.30  | Spain            | 0.60  |
| Rwanda               | 0.15  | Panama             | 0.30  | United Kingdom   | 0.60  |
| Seychelles           | 0.15  | Philippines        | 0.30  | Germany          | 0.65  |
| Sri Lanka            | 0.15  | Qatar              | 0.30  | Greece           | 0.65  |
| Turkey               | 0.15  | Singapore          | 0.30  | New Zealand      | 0.65  |
| Uganda               | 0.15  | South Africa       | 0.30  | Romania          | 0.65  |
| Ukraine              | 0.15  | Tunisia            | 0.30  | Slovak Republic  | 0.65  |
| Venezuela, RB        | 0.15  | Vietnam            | 0.30  | Slovenia         | 0.65  |
| Albania              | 0.20  | Yemen, Rep.        | 0.30  | Sweden           | 0.65  |
| Azerbaijan           | 0.20  | Chile              | 0.35  | Austria          | 0.70  |
| Burundi              | 0.20  | Iceland            | 0.35  | Estonia          | 0.70  |
| Cambodia             | 0.20  | Indonesia          | 0.35  | Finland          | 0.70  |
| Cameroon             | 0.20  | Jordan             | 0.35  | Japan            | 0.70  |
| Congo, Dem. Rep.     | 0.20  | Kuwait             | 0.35  | Belgium          | 0.75  |
| Cote d’Ivoire        | 0.20  | Lebanon            | 0.35  | Denmark          | 0.75  |
| Ecuador              | 0.20  | Malaysia           | 0.35  | France           | 0.75  |
| Gabon                | 0.20  | Mexico             | 0.35  | Hungary          | 0.75  |
| Israel               | 0.20  | Tanzania           | 0.35  | Italy            | 0.75  |
| Jamaica              | 0.20  | United States      | 0.35  | Netherlands      | 0.75  |
| Kenya                | 0.20  | Argentina          | 0.40  | Portugal         | 0.75  |
| Liberia              | 0.20  | Armenia            | 0.40  | Benin            | 0.85  |
| Mali                 | 0.20  | Kazakhstan         | 0.40  | Gambia           | 0.85  |
| Mauritius            | 0.20  | Malta              | 0.40  | Zimbabwe         | 1.00  |
| Mongolia             | 0.20  | Thailand           | 0.40  |                  |       |
| Oman                 | 0.20  | Colombia           | 0.45  |                  |       |
0.25, while 44 of them fall between 0.26 and 0.50. The number of countries that fall between 0.51 and 0.75 is 27 while only 3 countries have GMORI from 0.76 to 1.

3 RESULTS AND DISCUSSIONS

3.1 Descriptive statistics

The descriptive statistics of the variables employed are presented in Table 4. From 2004 to 2015, the average of U.S. corn export is US$ 6.2 million while the average of soybean export is US$ 18.6 million based on 120 destinations. The average international price over the period is US$190 and US$383 per metric tonne for corn and soybean, respectively. The average local currency unit (LCU) per U.S. dollar of the trading partners is 609 LCU/US$ for corn and 1,180 LCU/US$ for soybean trading destinations. The average GMORI for U.S. corn trade partners for corn was 0.38 and ranged between 0 and 1. For U.S. soybean trade partners, the average GMORI was 0.39 and ranged between 0 and 0.75. The averages of the two crops (0.38 and 0.39) imply that the extent of restrictions by the trade partners is below the average level of restrictions. To estimate the potential cost to the United States for an increase in trade partner’s GMORI, I used the average over all its trade partners over the period for both corn and soybean. The average yearly U.S. corn and soybean exports are presented in Table 5.

3.2 Final model results

This section discusses the results from the maximum likelihood estimation of the multilevel mixed-effects model with only importer random effect. Because the importer is the only random effect, the covariance structure was estimated as identity by the model. The model then gave two variance components: level-one error (residual error) and level-two error (importer random effects error). The results for corn and soybean are presented in Tables 6 and 7, respectively. The discussion is segregated into three: (a) The first focusses on the effects of the variables used in the traditional gravity model framework. Among the several gravity model variables, this study focusses on the origin GDP, destination GDP, geographical distance, exchange rate, and the price ratio of the global price to the price at the origin. This is shown by model 1 on the two tables for each of the commodities. The use of these variables serves as a measure of robustness for the model. (b) The second group consists of the GMORI. Model 2 on the two tables shows the addition of this variable for both commodities. (c) The third group consists of the trade agreement relationships between the origin and the destination countries. The addition of this group is shown by model 3 on the two tables. Model 3 yields the full model. Hence, the discussion is based on model 3.

3.2.1 Traditional gravity model variables

The results for models 1, 2, and 3 reveal consistent directions for the estimates of traditional gravity model variables. The level-one error for Model 3 in Table 6 is 6.077 while the level-two error is 1.169. The chi-square probability level of 0.00 signifies the overall goodness of model fit. In Model 3 of Table 7, the level-one error is 6.239 while the level-two error is 3.448. An overall chi-square probability of 0.00 was also observed for this model. The Wald chi-square degrees of freedom are 5, 6, and 8 for models 1, 2, and 3, respectively. Based on these degrees of freedom, the null hypothesis of

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**FIGURE 4** Distribution of genetically modified organism index
the model fit was tested against chi-square critical values of 11.07, 12.59, and 15.51 at 0.05 -value, respectively, for each of the models.

The magnitudes are also similar across the models. From Model 3 in Table 6, a coefficient of \(-0.173\) for the origin GDP implies that a 1% increase in the GDP of the origin will lead to about 17% decrease in corn exports. This negative impact of the origin's GDP growth on corn trade reflects the fact that the origin's GDP growth may be driven relatively more by other sectors rather than corn. The coefficient of 0.44 for the destination's GDP implies that a 1% increase in the destination's GDP will lead to a 44% increase in corn imports. Table 7 Model 3 shows the coefficient of origin GDP to be 0.296, implying that a 1% increase in origin GDP will lead to a 30% increase in soybean exports. A 1% increase in the destination's GDP will lead to a 92% increase in soybean imports from the origin. The distance is negative for both crops and consistent with the “a priori” expectation (Thuong, 2018).

A 1% appreciation in the destination's currency increases exports by 16% and 25% for corn and soybean, respectively, at a 1% significant level. This result is consistent with existing literature (Hondroyiannis et al., 2008). Based on economic theory, an appreciation of the importing country's currency relative to the US dollar increases the purchasing power of the country.

### 3.2.2 | Genetically modified organisms regulatory index

The debate to accept or not to accept GM foods continues to divide scientists, researchers, and countries. Some of the concerns are genuine, based on human health, ecological, poor communities, and animal welfare concerns. Others may be hidden behind the objective of protecting relatively less productive agricultural industries and archaic production methods. With regard to these concerns, some extent of restrictions has hampered the trade of GM foods among countries. The United States is one of the major producers of GM foods. About 90% of corn and soybean produced in the United States are genetically modified. Based on the restrictions by some countries to GM foods, this is expected to have a negative impact on U.S. agricultural exports.

| Variable                  | Mean  | Std. Dev. | Minimum | Maximum |
|---------------------------|-------|-----------|---------|---------|
| Export Value (Million US$)| 6.2   | 62        | 0       | 2,499   |
| Global Price              | 190.13| 63.84     | 98.41   | 298.41  |
| Exchange Rate (LCU/ US$)  | 609.64| 2.613     | 0.27    | 2,9011.49 |
| GMORI                     | 0.38  | 0.19      | 0       | 1       |
| State GDP (Billion US$)   | 438   | 435       | 2       | 2,481   |
| Destination GDP (Billion US$)| 699 | 1,280    | 0.4    | 11,000  |
| Domestic Price            | 168.03| 57.07     | 70.45   | 310.94  |
| Bilateral                 | 0.1   | 0.30      | 0       | 1       |
| Multilateral              | 0.13  | 0.34      | 0       | 1       |
| Export Value (Million US$)| 18.6  | 202       | 0       | 7,085   |
| Global Price              | 382.98| 105.13    | 217.45  | 537.76  |
| Exchange Rate (LCU/ US$)  | 1,179.91| 3,845.47 | 0.27    | 2,9011.49 |
| GMORI                     | 0.39  | 0.19      | 0       | 0.75    |
| State GDP (Billion US$)   | 460   | 471       | 2       | 2,480   |
| Destination GDP (Billion US$)| 1,070| 1,700    | 0.4    | 11,000  |
| Domestic Price            | 358.05| 99.36     | 191.05  | 540.08  |
| Bilateral                 | 0.11  | 0.31      | 0       | 1       |
| Multilateral              | 0.12  | 0.33      | 0       | 1       |

### TABLE 4 Descriptive statistics of variables
The coefficient of GMORI for corn is $-0.775$. This implies that a 1% increase in the regulatory index of a destination on GM foods will lead to a 0.78% decline in corn exports to the destination. A 1% increase in the index will lead to a 0.87% decrease in soybean exports to the destination. The estimate for corn is significant at 1% while that of soybean is significant at 5%. The direction of the coefficients for corn and soybean is expected to be negative. This is consistent with the “a priori” expectation because about 90% of the corn and soybean produced in the United States is genetically modified. The average yearly exports of corn and soybean by the United States were US$9 billion and US$16.5 billion, respectively, from 2004 to 2017.

Based on the average export values and coefficients obtained, a 1% increase in the GMORI will lead to about US$71.8 million and US$144 million losses in corn and soybean export revenue, respectively. These values are around those obtained by Weverbrock and Xia (2000). Using an average inflation of about 2.13% from FRED St. Louis fed, the current value of their US$4.97 billion estimate is about US$8 billion. Considering that their estimate was based on regulations for only EU countries at that time, it is rational to hypothesize that their estimate is similar to those obtained for this study given that the present study encompasses 120 countries (more countries) but only two commodities (corn and soybean) for a subset of the regulations and standards (GMORI). This is presented in Table 8.

The possible losses from an increase in the GMORI of the major U.S. destinations are presented in Table 9. Over the period, the top 10 export destinations for U.S. corn were Japan, Mexico, South Korea, Taiwan, Egypt, Colombia, China, Canada, Venezuela, and Dominican Republic. The expected losses from a 1% increase in the GMORI for these countries were computed based on U.S. average exports to these destinations. From Table 9, Japan has been the major destination of U.S. corn with an average export of about US$2.5 billion. Based on the coefficient obtained for corn for the GMORI variable, a 1% increase in Japan's GMORI will lead to about US$20 million loss in corn export revenue by the United States. Similarly, a 1% increase in Mexico's GMORI will lead to about US$13 million loss in corn export revenue by the United States.

### Table 5: Average yearly US exports in dollars

| Product | Soybeans | Corn |
|---------|----------|------|
| 2004    | 6,667,516,000 | 5,875,414,000 |
| 2005    | 6,273,643,000 | 4,788,825,000 |
| 2006    | 6,935,556,000 | 6,991,702,000 |
| 2007    | 9,992,106,000 | 9,762,572,000 |
| 2008    | 15,430,894,000 | 13,431,013,000 |
| 2009    | 16,423,200,000 | 8,745,959,000 |
| 2010    | 18,610,815,000 | 9,791,987,000 |
| 2011    | 17,590,943,000 | 13,652,198,000 |
| 2012    | 24,770,918,000 | 9,313,057,000 |
| 2013    | 21,570,162,000 | 6,385,673,000 |
| 2014    | 23,866,105,000 | 10,581,900,000 |
| 2015    | 18,861,872,000 | 8,270,992,000 |
| 2016    | 22,839,176,000 | 9,878,581,000 |
| 2017    | 21,455,886,000 | 9,112,465,000 |
| 2018    | 17,063,101,000 | 12,466,848,000 |
| Average | 16,556,793,000 | 9,269,946,000 |
| Standard Deviation | 6,114,732,000 | 2,526,625,000 |

### Table 6: Multilevel mixed-effects random effects estimation for corn. The significance value is 5% for ‘*’ and 1% for ‘***’

| Variables | Model 1 | Model 2 | Model 3 |
|-----------|---------|---------|---------|
| lnGDP_{it} | $-0.172^{***}$ | $-0.170^{***}$ | $-0.173^{***}$ |
|           | (0.040) | (0.041) | (0.041) |
| lnGDP_{jt} | $0.372^{***}$ | $0.460^{***}$ | $0.440^{***}$ |
|           | (0.059) | (0.062) | (0.064) |
| lnDist_{ij} | $-1.503^{***}$ | $-1.414^{***}$ | $-1.267^{***}$ |
|           | (0.273) | (0.259) | (0.278) |
| lnExcrate_{it} | $0.210^{***}$ | $0.170^{***}$ | $0.168^{***}$ |
|           | (0.046) | (0.046) | (0.046) |
| lnPratio_{it} | $0.511^{**}$ | $0.491^{**}$ | $0.516^{**}$ |
|           | (0.230) | (0.233) | (0.234) |
| lnGMORI_{j} | $-0.827^{***}$ | $-0.775^{***}$ |
|           | (0.231) | (0.235) |
| Bilateral_{it} | 0.138 |
| Multilateral_{it} | 0.392 |
| Constant | 13.123^{***} | 13.694^{***} | 12.551^{***} |
|           | (2.688) | (2.584) | (2.732) |

### Table 7: Multilevel mixed-effects random effects estimation for soybean

| Variables | Model 1 | Model 2 | Model 3 |
|-----------|---------|---------|---------|
| lnGDP_{it} | $-0.180^{***}$ | $-0.173^{***}$ | $-0.176^{***}$ |
|           | (0.040) | (0.041) | (0.041) |
| lnGDP_{jt} | $0.364^{***}$ | $0.450^{***}$ | $0.428^{***}$ |
|           | (0.058) | (0.061) | (0.063) |
| lnDist_{ij} | $-1.427^{***}$ | $-1.344^{***}$ | $-1.207^{***}$ |
|           | (0.270) | (0.258) | (0.276) |
| lnExcrate_{it} | $0.199^{***}$ | $0.160^{***}$ | $0.158^{***}$ |
|           | (0.045) | (0.045) | (0.045) |
| lnPratio_{it} | $0.506^{**}$ | $0.480^{**}$ | $0.501^{**}$ |
|           | (0.229) | (0.232) | (0.234) |
| lnGMORI_{j} | $-0.796^{***}$ | $-0.755^{***}$ |
|           | (0.230) | (0.234) |
| Bilateral_{it} | 0.138 |
| Multilateral_{it} | 0.392 |
| Constant | 13.184^{***} | 13.756^{***} | 12.613^{***} |
|           | (2.688) | (2.584) | (2.732) |
Table 9. The major export destinations for U.S. soybeans are China, Mexico, Japan, Indonesia, Taiwan, Germany, Egypt, Spain, South Korea, and the Netherlands. A 1% increase in the GMORI of China will lead to about US$ 74 million loss in U.S. soybean export revenue from China. Likewise, a 1% increase in the GMORI of Mexico will lead to about US$12 million loss in soybean export revenue by the United States.

### 3.2.3 Free trade agreements

The two free trade agreements considered in the study are as follows: (1) The existence of bilateral FTA between United States and the destination; (2) the existence of a multilateral trade agreement between United States and the destination. The results reveal that having a bilateral trade agreement with the United States did not significantly affect the exports for any of the crops. Likewise, the membership of a multilateral trade agreement did not affect the exports of corn or soybean to the destination. It is interesting but not surprising that the FTAs do not have an effect on U.S. corn and soybean exports. This may be attributed to the fact that the United States has FTAs with only 20 out of the 120 trade partners considered in this study. Given this small proportion and the fact that most of the trade partners are members of the WTO, the effects of the FTAs on corn and soybean are justifiably insignificant.

### 4 Conclusion and Policy Recommendations

This study examined the cost implications of GMORI of U.S. trade partners on its corn and soybean exports using a multilevel mixed-effects model. The results indicate that increases in the restrictions to genetically modified foods by countries will lead to export revenue losses to the United States. It was found that a 1% increase in the GMORI of a country decreases U.S. corn export by 0.78% while it leads to 0.87% decline in soybean exports. Over the study period, this implies that a 1% increase in this index causes a US$71.8 million and US$144 million loss in export revenues for corn and soybean, respectively. Among the major export destinations, the highest losses in revenue are seen from exports to China, Mexico, Japan, and Taiwan, respectively.

Despite this prognosis, previous studies have shown that global adoption of GMOs continue to grow (Brookes & Barfoot, 2014; Smyth et al., 2015). Hence, it is recommended that the United States continues with the information dissemination effort to enhance the adoption rate. It is also recommended that labeling policies on GM should be synchronized to match the requirements of the destination countries. Furthermore, information on GM foods should be persistently transparent along the international trade supply chain. Finally, an enhanced dissemination of information on its advantages must be actively pursued to change destination countries’ negative perception of this technology. It will also be beneficial to have a consistent
evaluation measure for the rate of adoption among trade partners.

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ENDNOTES
1https://www.ers.usda.gov/data-products/ adoption-of-genetically-engineered-crops-in-the-us/recent-trends-in-ge-adoption/
2To remedy this decline, the United States has been in a number of trade agreement negotiations in recent years to obtain favorable conditions in trade engagements. This yielded positive returns. For instance, the EU eliminated grain import duties on certain U.S. grain imports in 2020 (see details on the USDA FAS website - https://www.fas.usda.gov/data/europ e-union-eu-eliminates-grain-import-duties).
3All the disputes discussed in this section can be found on the WTO website https://www.wto.org/english/tratop_e/dispu_e/dispu_subjects_index_e.htm
4The technique of the production of GM foods is also referred to as biotechnology in some literature.
5The EU imposed duty on wheat imports from Canada based on reference prices rather than transaction values leading to a 55% higher duty-paid import price in the early 1990s. In response to this, Canada requested for consultations with EU. Following this, a panel was established but panelists have not been selected. Another dispute that emerged was between the United States and Brazil. The latter raised concerns that the United States had legislation, regulations, statutory instruments, and amendments that aided U.S. producers and exporters of upland cotton, giving them advantage in the Brazil cotton market.
6https://www.wto.org/english/tratop_e/dispu_e/cases_e/ds291_e.htm
7http://www.fao.org/3/i2490e/i2490e04d.pdf or http://www.fao.org/3/i2490e/i2490e00.htm
8https://ec.europa.eu/environment/europagreencapital/countriesruleoutgmos/
9Name kept in French as shown on their website http://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele.asp
10https://ustr.gov/trade-agreements/free-trade-agreements
11https://www.stlouisfed.org/
12https://apps.fas.usda.gov/gats/default.aspx.

| Partner | GMORI | Average Export value (Dollars) | Expected Loss for 1% increase in GMORI (Dollars) |
|---------|-------|-------------------------------|-----------------------------------------------|
| Corn    |       |                               |                                               |
| Japan   | 0.7   | 2,583,175,477                 | 20,019,610                                     |
| Mexico  | 0.35  | 1,716,427,189                 | 13,302,310                                     |
| South Korea | 0.45 | 946,437,192                  | 7,334,888                                      |
| Taiwan  | 0.5   | 552,960,230                   | 4,285,441                                      |
| Egypt   | 0.3   | 416,263,159                   | 3,226,040                                      |
| Colombia| 0.45  | 363,573,452                   | 2,817,694                                      |
| China   | 0.5   | 309,622,905                   | 2,399,578                                      |
| Canada  | 0.3   | 241,589,740                   | 1,872,320                                      |
| Venezuela| 0.15 | 185,942,322                  | 1,441,053                                      |
| Dominican Republic | 0.3 | 135,183,648 | 1,047,673                                      |
| Soybean |       |                               |                                               |
| China   | 0.5   | 8,516,192,789                 | 74,090,877                                     |
| Mexico  | 0.35  | 1,385,135,790                 | 12,050,681                                     |
| Japan   | 0.7   | 1,038,462,397                 | 9,034,623                                      |
| Indonesia| 0.35 | 659,401,488                  | 5,736,793                                      |
| Taiwan  | 0.5   | 632,202,520                   | 5,500,162                                      |
| Germany | 0.65  | 491,622,201                   | 4,277,113                                      |
| Egypt   | 0.3   | 289,764,016                   | 2,520,947                                      |
| Spain   | 0.65  | 257,258,152                   | 2,238,146                                      |
| South Korea | 0.45 | 254,421,788                  | 2,213,470                                      |
| Netherlands | 0.75 | 216,491,016 | 1,883,472                                      |

TABLE 9 Average U.S corn and soybean exports to top 10 destinations from 2004 to 2015
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