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# International Trade and Endogenous Standards: the Case of GMO Regulations[*]

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## Abstract

This paper quantifies the effect of GMO regulation on bilateral trade flows of agricultural products. We develop a composite index of GMO regulations and using a gravity model we show that bilateral differences in GMO regulation negatively affect trade flows. This effect is especially driven by labeling, approval process and traceability. Our results are robust to the endogeneity of GMO standards to trade flows.

**JEL**: F13, F14, Q13, Q18, Q17
**Keywords**: GMO Standards, Harmonization, Trade Flows, Gravity Model, Endogeneity

## 1. Introduction

Public policies on genetically modified organisms (GMO) differ strongly across countries and regions, resulting in a market fragmentation that currently challenges the international trading regime (Isaac *et al.*, 2004). Several authors have pointed out that the stringency of GMO regulations of important agri-food importers like the European Union (EU) and

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Japan, in contraposition with the ‘soft’ GMO regulations of exporters like the US and Argentina, can represent a serious problem for developing countries’ strategies in deciding GMO production and regulation (e.g. Tothova and Oehmke, 2004; Anderson and Jackson, 2004; Anderson, 2010). Indeed, while the potential gains from GMO adoption appear particularly high for several Asian and African countries (Huang *et al.* 2004; Anderson, 2005; Smale *et al.*, 2009; Gruère *et al.*, 2009a), developing countries also face the potential loss of access to rich markets with strong consumer opposition to GMOs.

Formal evidence on the trade effects of GMO regulations is rare and often inconclusive. Empirically investigating this issue is difficult, because there are no comparable measures of GMO standards. Thus, the first aim of this paper is to create such a measure. Specifically, the paper develops a composite index on the stringency of GMO regulations for a sample of sixty countries. We use this index to study how similarity/dissimilarity in GMO regulations affects bilateral trade flows. The composite nature of our index allow us to analyze both the overall trade effect of the GMO regulation, as well as the partial effects induced by each component of the GMO regulation, like the approval process, labeling and so on.

The paper adds to the existing literature in three ways. First, we study the trade effect of GMO regulations using an ‘objective’ multidimensional index of GMO standards and its components, in order to shed light on the regulatory dimensions that matter most for trade flows. Thus, we depart from the standard approach of using simple dummy variables to capture the trade effect of GMO regulation as, for example, in Disdier and Fontagnè (2010).[1] Second, we focus on harmonization or differences in standards instead of on the more traditional question of the trade reduction effect induced by the stringency in GMO regulations. Indeed, we try to answer a slightly different question: how much does similarity/dissimilarity in GMO regulation between exporting and importing countries affect bilateral trade in GMO related products? This question appears to be more relevant in understanding the actual effect of GMO regulations or standards in general.

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[1] Obviously, this does not mean that using a dummy for capturing the trade effect of GMO is *a priori* less interesting. Indeed, the last approach has the advantage of exploiting the time dimension, strengthening econometric identification. Of course, the best strategy also depends on the research question and/or data availability. However, it is clear that if we want to understand which GMO regulatory dimension matters the most for trade flows, then one needs to go beyond a simple categorization based on dummy variables. Gruère *et al.* (2009a) represent an example in that direction; however they limited the investigation to GMO labeling policies.

Our final contribution is the attempt to account for potential bias induced by the endogeneity of GMO standards to trade flows, an issue mostly ignored in existing empirical studies.[2] Indeed, political economy studies (see Anderson and Jackson, 2004; Gruère *et al*. 2009a; Swinnen and Vandemoortele, 2011) suggest that GMO regulations are endogenous to trade flows.

This paper is related to several other studies. Particularly relevant for our analysis are the studies of Cadot *et al*. (2001), Parcell and Kalaitzandonakes (2004), Disdier and Fontagné (2010), Tothova and Oehmke (2004), Veyssiere (2007), and Gruère *et al.* (2009a).[3] Cadot *et al*. (2001) find that the 'regulatory protectionism' aspect of the EU GMO regulation has no repercussions on US export of corn seeds, but has a negative effect on other forms of corn. Downstream traders' and food retailers' private decisions not to purchase GM products were more important than cultivation bans. Parcell and Kalaitzandonakes (2004) did not find any relevant effect on future prices after major food companies announced a voluntary ban on purchasing GM crops. More recently, Disdier and Fontagné (2010) used a gravity equation to estimate the effects of the EU *de facto* moratorium on GMOs. They show that the EU moratorium, as well as other European GMO standards, has negative trade effects on the exporting countries.

Tothova and Oehmke (2004) develop a Krugman-style trade model to study the endogenous choice of different countries in setting GMO standards, showing the formation of 'clubs' of countries that share similar GMO regulations. These 'clubs' act as sub-global preferential trading agreements. Their model suggests the formation of two trading blocs, one in favor, the other against GMOs. In between, there emerges a third group of countries that face a choice between lower production costs (through the adoption of GM crops) and the maintenance of an export market by restricting GMO production. Veyssiere (2007), also studied the dilemma faced by exporting countries whether or not to approve GM products, finding that GM product approval is optimal under a labeling regime, whereas non-approval is optimal in the absence of mandatory

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[2] To date, in the gravity literature concerning the trade effect of non-tariff barriers (NTBs), the problem of endogeneity of NTBs to trade flows has rarely been taken into account. Exceptions can be found in Shepherd (2007), Olper and Raimondi (2008) and Djankov *et al.* (2010).

[3] Others related important studies are the ones from Lapan and Moschini (2004) and Smyth *et al.* (2006). The former shows that GMO labeling can redistribute income among trading nations, and can benefit the importing country. Differently Smyth *et al.* (2006) show that trade patterns of GMO products displayed changes after the introduction of GMO regulations. See also Runge and Jackson (2000), Fulton and Giannakas (2004) for GMO labeling issues, and Gruère (2006) for an overview of worldwide GMO regulatory systems.

labeling. Finally, Gruère *et al.* (2009a) adopt a political economy approach to evaluate the importance of socio-economic factors in the selection of GM labeling regulations. They show, both theoretically and empirically, that production and trade interests play an important role in GM labeling choices. In particular, in developing countries, regional influences and trade factors may be more important than domestic consumer preferences or anti-GMO campaigns. Clearly, these studies suggest that GMO regulations are potentially endogenous to trade flows.

Our paper is also related to an emerging literature showing that harmonization of standards is important for international trade. For example, de Frahan and Vancauteren (2006), Moenius (2006), Czubala *et al.* (2009) and Shepherd (2007), find that international standards have a smaller impact on trade than unilateral standards. Indeed, harmonization may limit costs thanks to the substitution of multiple national or regional standards with a single unified international standard. Moreover, if the domestic standard is similar to the foreign one, producers have already coped with the cost of compliance and export costs are lower.

The organization of the paper is as follows. Section (2) explains how we constructed the GMO regulatory index. Section (3) presents the empirical model and discusses the data and the countries used in the empirical exercise. Section (4) presents and discusses the econometric results. Finally, section (5) provides conclusions and implications.

## 2. An index of GMO regulation

### *2.1 Sample, data and computational strategy*[4]

We create a GMO regulation index for 60 countries for which it was possible to collect information on laws and acts regulating GMO cultivation and commercialization. We collected information on GMO regulations until June 2008. The index thus reflects GMO regulations in place in 2007, or before. However, it is important to keep in mind that, especially for developing countries, there could be significant delays in the enforcement of the regulations, due to political and technical reasons. This may cause a slightly upward bias of the index for some developing countries.

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[4] An online Appendix provides an in-depth description and justification of the characteristics and economic impact of each regulatory dimension, composing the GMO index described in the text.

The criteria for the countries selection was the availability of information on laws and acts on GMO cultivation and commercialization. Figure 1 gives the full list of the considered countries. The main information source used to classify the GMO regulations are the Global Agriculture Information Network (GAIN) reports on biotechnology provided by the Foreign Agricultural Service (FAS) of the United States Department of Agriculture (USDA). For missing information we referred to official national acts and reports.

The country sample includes most of the OECD members and non-OECD important exporters of agricultural products The countries in the sample produce more than the 80%, 95%, 60% and 66% of global maize, soybean, rapeseed and cotton, respectively.[5] Six different components of the GMO regulation were considered, namely approval process, risk assessment, labeling, traceability, coexistence and membership in international GMO agreements. Each component was scored with values ranging from 0 (first condition) to the total number of sub-components identified for each category (see Table 1). Higher scores correspond to more restrictive regulations. For those countries that declare themselves 'GM-free' (e.g. Zambia and Zimbabwe), meaning that no GM products can be domestically cultivated or introduced, we assigned the highest score. On the contrary, the lower score is assigned where no rules have been adopted. For the approval process, the restrictiveness increases with the adoption of the precautionary principle rather than the principle of substantial equivalence. For example, the approval process of the US follows the principle of substantial equivalence, while the EU Members adopt the precautionary principle. The restrictiveness of the risk assessment has been evaluated on the degree of its implementation. Only a few countries do not have rules for risk assessment (e.g. Bangladesh and Ukraine), while the countries with risk assessment rules, but not yet enforced, are mainly developing countries (e.g. Kenya, Peru and Sri Lanka). The labeling restrictiveness captures voluntary *versus* mandatory, as well as the threshold level. For example, labeling restrictiveness increases from countries as India and Bangladesh, where there are no enforced GMO labels, over countries with voluntary labeling (Argentina, Canada and US), to countries with mandatory labeling with a threshold higher than 1% (e.g. Japan, Korea and Russia ) or equal or lower than 1% (EU Members). With respect to traceability, the score increases from identity preservation (IP)

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[5] Authors' computation based on FAOSTAT data: http://faostat.fao.org/site/567/default.aspx#ancor

to traceability, given the greater complexity and the higher compliance costs of the latter. Many exporter countries do not have any GMO traceability requirements (e.g. Argentina, China, Hong Kong, and India) or only IP (e.g. Australia and US). In contrast, GMO traceability is compulsory in many importers (e.g. EU Members and Japan). In our scoring method, the coexistence burden increases with the complexity of the requirements in national guidelines. Most of the countries in the sample do not have coexistence rules (e.g. Brazil, Canada, China), others have partial (Argentina, Finland, New Zealand) or comprehensive (Japan and EU) coexistence guidelines.

The international regulatory framework starts at World Trade Organization (WTO) level, where GMO standards fall under the Sanitary and Phytosanitary (SPS) agreement that aims to reduce the protectionist bias of food standards in general. Given the specificity of GMO products, two more GMO specific international agreements are considered in the category ‘membership in international GMO agreements’, namely the Cartagena Protocol and the Codex Alimentarius (see the Web-appendix for details). In this category the score increases with the number of agreements to which the country subscribed. Note that only Hong Kong and Taiwan are not members of either of the agreements, while all the other countries are members of at least one agreement.

Some categories are strongly related to each other. For example, in many regulations an approval process cannot be conducted without a product risk assessment. However, this logic does not systematically apply to the GMO standards context. An analysis of the regulation of the 60 countries suggests many unexpected and ambiguous stages of implementation. For example, there are countries with a voluntary labeling regime but with no required traceability or segregation system (e.g. Canada).

The final GMO index is obtained by the summation of scores of each category and, after normalization, has a value between 0 and 1, where higher values indicate a more restrictive regulation on GMO production, commercialization and trade.[6]

An overview of the GMO index ranking and score is given in Figure 1. Several interesting patterns emerge. First, as expected, the index documents the well known polarization between the US and the EU. The former has a GMO regulatory index of 0.35, which contrasts with the EU average of 0.69. Secondly, with the exception of GM-free

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[6] Our GMO index is built on the overall regulation without distinctions among products. However, a national GMO regulation may require different measures for different products. For example, in the EU coexistence is related to the cultivation of maize, given that it is the only GM crop approved.

countries, developing countries tend to be in the low part of the ranking. All the considered EU countries, as well as Asian food importers like Japan (but not South Korea), display a high GMO index. However, it is interesting to note that also within the EU there exist some differences in the GMO rules.[7] For example, the highest score of 0.75 was found in Austria and Italy that have imposed a ban on the cultivation of EU approved GMO maize. Spain and Germany have significantly lower scores, equal to 0.60 and 0.65, respectively.

Stringent regulations generally require more costly procedures for exporters, and comprehensive policies can have a greater trade effect. It is assumed that approval procedures are fixed costs, while traceability and labeling are variable costs, influencing present and future GM and non-GM crop exports (see Gruère, 2006).

## 3. GMO standards and international trade

### 3.1 Empirical model and estimation strategy

In this section we present our strategy in assessing the potential trade effect of GMO regulations. The bilateral trade equation is derived from the standard constant elasticity of substitution (CES) monopolistic competition trade model, with increasing returns to scale and iceberg trade costs, introduced by Krugman (1980). In the empirical version of the model the bilateral trade flow from *j* to *i* in product *k* ($M_{ijk}$) can be summarized by the following log-linear bilateral trade equation:

$$\ln M_{ijk} = \beta_0 + \lambda_j + \chi_i + \beta_1 \ln D_{ij} + \beta_2 \ln(1+\tau_{ijk}) + \Omega \mathbf{Z}_{ij} + u_{ijk} \qquad (1)$$

where $\lambda_j$ and $\chi_i$ are the exporter and importer fixed effects controlling for the size terms as well as for unobserved number of varieties (firms) and price terms of the exporter, and for expenditure and unobserved price terms of the importer, respectively. $D_{ij}$ is the transport cost proxied by distance between *i* and *j*, while $\tau_{ijk}$ is the *ad valorem* bilateral

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[7] The EU produced four main acts to regulate plant biotechnology and its products: Dir. 2001/18/EC on the deliberate release into the environment of GMO; Reg. 1829/2003/EC and 1830/2003/EC on the traceability and labeling of GM products, and Recommendation 2003/556/EC on coexistence. The source of different levels of stringency across Member States is mainly in the coexistence regulation. Given the not-binding force of the Recommendation, compared with the compulsory nature of Regulations and Directives, each Member State has greater freedom in deciding coexistence requirements. Moreover, delays in the transposition of the EU acts in domestic laws, may induce further differences in the effective restrictiveness of GMO regulations.

tariff on product *k*. $\mathbf{Z}_{ij}$ is a vector of any other bilateral trade cost different from distance and tariffs and, finally, $u_{ijk}$ is an error term. The parameters $\beta_1$, $\beta_2$, and $\Omega$ are the coefficients to be estimated.

We augment this basic gravity equation by introducing a variable measuring bilateral differences in GMO regulatory indexes in the vector of other trade costs, $\mathbf{Z}_{ij}$. We computed two different GMO bilateral variables. The first is obtained by taking the absolute deviation of the GMO index across country pairs, namely $GMO_{ij} = \left| GMO_i - GMO_j \right|$. An advantage of this bilateral measure, other than its simplicity and its transparency, is that it is easily computable for each regulatory component. The $GMO_{ij}$ bilateral index increases in the level of dissimilarity (or distance) in GMO regulations across country pairs or, put differently, it represents an inverse index of 'harmonization' in GMO regulations.

In order to test the robustness of our findings, we also used a second index called $GMOw_{ij}$, following Anderson (2009) and Jaffe (1986). This second index can be defined as follows:

$$GMOw_{ij} = \frac{\sum_{m=1}^{M} f_{im} f_{jm}}{\left(\sum_{m=1}^{M} f_{im}^2\right)^{1/2} \left(\sum_{m=1}^{M} f_{jm}^2\right)^{1/2}}$$

Where $f_{im}$ ($f_{jm}$) is the ratio between the regulatory component score attributed to country *i* (*j*) on the highest score assigned to the component *m*. This allows a degree of bilateral regulatory 'closeness' between two countries, ranging between 0 (completely different) and 1 (identical regulation). Jaffe (1989) indicates that the proximity measure is 0 for countries whose vectors are orthogonal and 1 for countries whose position vectors are identical.[8] Finally, note that, given the definition of our bilateral variables, they should display opposite coefficient signs in the regression results, $GMOw_{ij}$ being a similarity index, while $GMO_{ij}$ is a dissimilarity index. Indeed, the correlation coefficient between them is negative and equal to –0.60.

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[8] In practice, this index defines vectors of national rationed scores, named $f_i = (f_{i1}, \ldots, f_{iM})$ with $M = 6$, which locates country *i* in the *M*-dimensional space. Similarity of the regulation can be computed through the proximity of the *f*-vectors, defined by the *cosine* of the angle between them.

With regard to the estimation method, as equation (1) is applied to disaggregated trade data (our regressions are always run at the HS 6-digit level) the first problem is the large number of zero bilateral trade flows. One of the most common methods to deal with zero trade is the Heckman (1979) two stage selection correction: *i*) a Probit equation where all trade flows determinants are regressed on the indicator variable, $T_{ij}$, equal to 1 when $j$ exports to $i$ and 0 otherwise; *ii*) an OLS second-stage with the same regressors as the Probit equation, plus the inverse Mills ratio from the first stage, correcting for the bias generated by the sample selection problem. Following the modification suggested in Helpman *et al.* (2008) and supported by Martin and Pham (2008), we omitted an independent variable associated with the fixed trade costs in the second OLS stage.[9] Furthermore, to check for robustness of the Heckman selection procedure, we used a modified Poisson fixed-effects estimation, namely the zero-inflated negative binomial model (ZINB), which accounts for the possible bias created by the logarithmic transformation (Jensen's inequality) and the failure of the homoskedasticity assumption.[10]

Moreover, as in previous studies (i.e. Disdier and Fontagné, 2010), we face an identification problem, because it is not possible to distinguish between GMO and non-GMO traded products. As a consequence, a reduction in trade flows can only partially be attributed to GMO regulations. In order to deal with this issue, in the specification of the gravity equation we consider also other potential determinants of trade flows different from GMO standards, like tariffs. The inclusion of bilateral tariffs in the trade cost function is important because if our bilateral GMO index is positively correlated to bilateral tariffs, then omitting tariffs can result in an overestimation of the GMO effect on trade flows.[11]

Finally, as discussed in the introduction, a relevant concern about the estimation strategy of the gravity equation (1) is related to the possibility that GMO regulations are endogenous to trade flows. For this reason, in the empirical analysis we also check the

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[9] The underlying idea is that fixed trade costs, here proxied by the language dummy, affect the probability to export. Thus, the language dummy is included only in the (first stage) selection equation, but not in the OLS equation (see Martin and Pham, 2008).

[10] As pointed out by Burger *et al*. (2009), the ZINB considers the existence of two latent groups within the population: the first with strictly zero counts, the second with a non-zero probability of observing positive trade flows. The ZINB model is estimated in two steps: first a Probit regression of the probability that there is no bilateral trade; a second (Negative Binomial) Poisson regression of the probability of each count for the group that has a non-zero probability (see Burger *et al*. 2009).

[11] The correlation between tariffs and NTBs is an empirical question. To date, considerable evidence of a positive correlation for agri-food products can be found in Kee *et al*. (2009). In our sample, running a fixed effect regression of tariffs on the GMO index, the coefficient of tariffs is positive and strongly significant.

robustness of our main findings for possible bias due to the endogeneity of GMO standards.

### *3.2 Data*

To study the effect of GMO standards on trade flows we consider the trade data of three major potential GM products: maize, soybean and rapeseed, for both human and animal consumption. We also include cotton products related to the agri-food channel, in particular seeds, oils and cake for animal fodder or as feed ingredients. Trade data come from the Commodity Trade database of the United Nations Statistical Division (UN-COMTRADE). We work at the 6-digit level of the 2002 Harmonized System (HS 2002) classification. Because it is not possible to distinguish between GMO and non-GMO products, we consider those products recognized in the literature as potentially genetically modified.

In the empirical analysis, we start considering all the HS 6-digit headings related to the four potential GMO products taken together, in order to assess the overall impact of the GMO standards on trade. Second, we also consider each group of products separately, in order to distinguish specific regulatory effects on maize, soybean, rapeseed and cotton. The four groups of HS 6-digit headings are called, for simplicity, *Maize*, *Soybean*, *Rapeseed*, and *Cotton*.[12]

The country sample is selected using the following rules. First, we considered importing and exporting countries covered by our GMO index. Next, in order to ensure the presence of bilateral trade flow, we checked that all the exporting countries are exporters and/or producers of at least one of the four products considered. Production data comes from FAOSTAT.

The time period considered covers the average trade flows over three years: 2005, 2006 and 2007.[13] Despite the GMO adoption started in the late nineties, it is only in recent years that we have witnessed an acceleration of the diffusion of GMO regulation. This can be attributed not only to the growing amount of GMOs traded, but also to the

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[12] The HS 2002 (6-digit) headings used are as follow. *Maize*: 071040, 100510, 100590, 110220, 110313, 110320, 110423, 110812, 151521, 151529, 190410, 190420, 200580, 230210, 230310; *Soybean*: 120100, 120810, 150710, 150790, 210310, 210610, 230400; *Rapeseed*: 120510, 120590, 151411, 151419, 151491, 151499, 230649; *Cotton*: 120720, 151221, 151229, 230610.

[13] For practical reasons, we do not extend the sample period to 2008, to eliminate the possible confounding effect due to the financial crisis export slow down.

international trade controversy that has led to the definition of GMO import and export rules.

Finally, regarding the other standard covariates used in the gravity equation, like distance, and dummies for other trade costs (contiguity, language, and colony) they are taken from CEPII (Centre d'Etudes Prospectives et d'Informations Internationales). Differently, bilateral tariffs are obtained from the MAcMap database (Bouët *et al.*, 2008) jointly developed by ITC (UNCTAD and WTO, Geneva) and CEPII (Paris). MAcMap includes *ad-valorem*, as well as specific components of each bilateral tariff line at the HS 6-digit level. Thus no tariff aggregation was needed in the empirical model. Moreover, the original methodology used by the MAcMap database to aggregate tariffs (a weighting scheme based on reference group of countries) limits the extent of the endogeneity bias of tariffs.

Table 2 provides summary statistics of variables used in the empirical model.

## 4. Results

In this section the results of the econometric estimation of equation (1) are reported and discussed. First we focus on the assumption that the two bilateral measures of the GMO index are exogenous variables. Then we check the robustness of the results by considering the potential endogeneity.[14]

Table 3 reports results pooling the data across the four groups of products and considering four different estimators: a simple OLS on positive trade, the first stage Probit of the Heckman selection procedure and its second OLS stage and, finally, the ZINB estimator. Starting from standard gravity covariates, the distance coefficient is always negative and significant. The common border and colony dummies are positive and significant, with the exception of colony in the OLS specification where it has a negative, but not significant, effect. As expected, bilateral tariffs have a negative and significant effect on bilateral trade flows. If we give a structural interpretation to the tariff coefficient, equal to $(1-\sigma)$ with $\sigma > 1$ representing the elasticity of substitution between varieties,

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[14] We follow this strategy for both comparability and practical reasons. Indeed, almost all previous papers have considered GMO regulations as an exogenous variable. Moreover, it is well known that finding good instruments of such a variable is quite a difficult task in a gravity environment (more on this below).

then we have an estimate of such elasticity. Its average value, around 3, is of the same order of magnitude as recent estimates reported by Raimondi and Olper (2011).

Moving to the variable of interest, columns 1 to 4 consider the dissimilarity index, $GMO_{ij}$. Across all estimators, it has a negative and strongly significant coefficient ($p$-value < 0.01).[15] Because the index measures the distance in GMO regulations across countries, a negative coefficient means that bilateral trade flow is increasing in the similarity of GMO regulation. The (absolute) magnitude of the estimated effect increases from 1.18 to 1.65 on passing from the OLS to the II stage Heckman, suggesting that selection bias can be a problem, a conclusion confirmed by the high significant level of the Mills ratio. It is interesting to note that also the $GMO_{ij}$ coefficient of the first stage Probit regression is significantly negative (see Column 2), suggesting that distance in the GMO regulation negatively affects also the probability of positive trade, namely its extensive margin.

In order to check for robustness in the Heckman procedure for the treatment of zeros, column (4) reports the ZINB estimator, validated by the over-dispersion and Vuong tests.[16] Once again the effect is negative and strongly significant. However, the estimated coefficient is lower in magnitude.

Columns 5 to 8 run the same specifications but using the similarity index, $GMOw_{ij}$. The results are very similar, suggesting that the findings are robust to the choice of the bilateral index. The difference, as expected, is the opposite (positive) sign of the estimated coefficient, as now we are measuring similarity in GMO regulation. Yet, it is also worth noting that by using $GMOw_{ij}$ the first stage Probit effect is, as expected, positive, but not significant.

To put the estimates into perspective, and using our preferred specification (Column 3 of Table 3), the magnitude of the estimated coefficient implies that a one standard deviation decrease in the GMO dissimilarity index (=0.188), which means an increase in regulatory closeness, increases exports of about 33%, all else remaining equal. This effect approximately corresponds to a change in $GMO_{ij}$ from the value of France-Chile (=0.40) to that of France-Switzerland (=0.20). Thus the effect is not only statistically significant but appears also relevant from an economic point of view.

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[15] In order to verify if the inclusion of intra-EU trade flow is driving the results, we also run regressions omitting them. Results are both qualitatively and quantitatively similar, confirming the robustness of our findings.

[16] The over-dispersion test checks whether the negative binomial specification or the Poisson specification is preferred. The Vuong statistic tests if the zero-inflated model is favored rather the non-zero inflated one.

Table 4 investigates which GMO regulatory component matters the most considering both the probability of positive trade (extensive margin) and the volume of trade (intensive margin). In line with the results of Table 3, all GMO components exert a negative effect on the volume of trade, and most of them are statistically significant at 1% level, with the exclusion of international agreements that are barely significant, and the risk assessment that is not significant. Interestingly, considering the first stage Probit, and thus the probability to trade, only labeling and traceability significantly affect the extensive trade margin. This result may suggests that these components also act by raising fixed trade costs.

Because regulatory components tend to be positively correlated, we also ran a specification that considers them simultaneously, in order to better disentangle their effect. Results are reported at the bottom of Table 4. Not surprisingly, their estimated coefficients decrease in absolute magnitude. However, the (theoretically) most important dimensions, namely labeling, approval process, and traceability, remain strongly significant. Because each component is normalized to vary from 0 to 1, the results suggest that labeling is the dimension most detrimental to trade, followed by the approval process and traceability. Given this ranking, it is not surprising that GMO labeling has been the major field of conflict across countries in terms of trade policies (Carrau, 2009).

Table 5 investigates the sensitivity of different product groups to the $GMO_{ij}$ index, running regressions for each group separately. The estimated coefficients on the $GMO_{ij}$ are negative for all the groups, but are statistically significant only for corn, soybean and rapeseed, suggesting that these agricultural commodities are those most affected by GMO regulations. The importance of labeling, approval process and traceability are also confirmed for these three crops. Coexistence affects only maize and soybean, which are the two most cultivated GM crops worldwide and also the main imported GM products in the EU. Differently, we do not detect significant effects for cotton, possibly because only part of cotton products are considered. Probit regressions at the product level confirm that labeling and traceability are the most important regulatory components affecting the extensive margin of trade.

Finally, Table 6 investigates the effects of the GMO regulations for different levels of development, interacting the $GMO_{ij}$ index with three (exporting) dummies for developing, emerging and developed countries. Results show that the GMO regulations affect especially trade flows from developed countries and, to a lesser extent, from emerging countries. The effect on developing countries' trade is insignificant. Of course, this is not surprising given the structure of our dataset, where 94% of the exports come from emerging and developed countries.[17]

In summary, our analysis suggests that cross-country differences in GMO standards significantly affect trade flows. These effects appear largely attributable to labeling, approval, and traceability standards, and are particularly relevant for corn and soybean products. Yet, the trade effect of GMO standards is especially relevant for trade flows from developed and emerging countries, but not from developing countries. The last result, however, should not be interpreted as a general indication that developing countries exports are not affected by GMO regulations. Indeed, developing countries are minor producers and exporters of the main GMO crops considered.

### *4.1. Are GMO regulations endogenous to trade flows ?*

There are different potential sources of endogeneity in our model. We are especially concerned with endogeneity due to the potential simultaneity bias between GMO regulations and bilateral trade flows, for at least two reasons. First, a growing political economy literature on GMO regulation suggests that GMO standards are affected by the country's trade position and comparative advantage (see Anderson and Jackson, 2004; Gruère *et al.* 2009a; Swinnen and Vandemoortele, 2011; Vigani and Olper, 2012). Thus, if import and regulation are not modeled to be simultaneously determined, the estimated impact of regulation on imports can be biased downward (see Trefler, 1993). Second, empirical evidence and conceptual models suggest that developing countries have set GMO standards taking into account the trade-off between agronomic advantage and loss of market access, in countries where consumers have strong concerns on GMOs (Tothova and Oehmke, 2004; Veyssiere, 2007; Gruère *et al*. 2009a).

Addressing simultaneity in the gravity model is difficult because of the lack of good instruments. In fact, almost all the potential determinants of GMO regulations exert an effect on bilateral trade flows, thus they tend to be weak instruments (see Baier and Bergstrand, 2007). Previous attempts to deal with this kind of endogeneity in gravity

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[17] Specifically, exports from developed countries represent 63% of observations and 54% of the total exports value. Exports from emerging countries are 31% of observations and 45% of exports value. Exports from developing countries are only 6% of the observations, and around 1% of the total value of the exports in the sample.

models have followed the approach of Lee and Swagel (1997) and Trefler (1993), who used industrial conditions as an instrument for trade policy (see Shepherd, 2007; Olper and Raimondi, 2008). However, when working at the HS 6-digit level, it is impossible to adopt this strategy due to data constraints. An alternative strategy, followed in this paper, is the one proposed by Djankov *et al.* (2010), who deals with the potential endogeneity of the time to ship goods in a gravity model, using the trade times of neighboring countries as instrument. The intuition is that while trade flows may affect domestic trade times, they are less likely to affect times abroad. Following a similar logic, we instrument the GMO index by using the weighted average GMO indices of the five closest neighbors, using the distance between capitals as a weight.

The results of this exercise are shown in Table 7. Columns (1) and (2) report a benchmark OLS and the corresponding IV regression, respectively. We start from these regressions because, as it is well known, an instrumental variable approach can also be used to deal with selection bias problems (see Wooldridge 2002). Interestingly, passing from the OLS to the IV estimator, the coefficient of the $GMO_{ij}$ increases in magnitude from -1.18 to -2.26, and remains strongly significant.[18] This result means that when the distance in GMO regulations is modeled endogenously, its estimated coefficient is approximately two times larger the size obtained from treating it exogenously, as the theory of endogenous trade policy predicts.

A formal test for this conclusion is reported at the bottom of the table. The Hausman endogeneity test rejects at the 1% level the hypothesis that the $GMO_{ij}$ index can be treated as exogenous. Moreover, the Cragg-Donald under-identification test is also strongly significant, rejecting the hypothesis of weak identification in the first stage regression (not shown).

Columns 3 and 4 give further support to these results. Indeed, by running a IV second stage Heckman regression, the coefficient of $GMO_{ij}$ once again significantly increases and, as expected, it has an order of magnitude similar to the one obtained without the Heckman selection correction.[19]

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[18] Using the $GMOw_{ij}$ instead of $GMO_{ij}$, the results are qualitatively similar, although the magnitude of the increase in the IV regression is higher.

[19] See Wooldridge (2002) and Baier and Bergstrand (2007) for a similar estimator. Basically it represents a three step estimator. The first stage is the estimation of the predicted probabilities of trade, through a Probit equation. The second stage is a linear regression of $GMO_{ij}$ on a constant, the Mills ratio from the first stage, including all the covariates of the first stage plus the instrument. The third stage is the estimation of the gravity equation substituting the predicted values from the second-stage regression for $GMO_{ij}$.

Keeping in mind the usual caveats about instruments, these results appear interesting for several reasons. First, they strongly confirm the results of the previous section on the positive effect of GMO standards harmonization on international trade. Second, they confirm that the GMO regulation is endogenous to trade flows, and this is in line with the idea that governments take into account the country trade position in deciding on GMO regulation. Finally, using regression from Column 4 of Table 7, the magnitude of the estimated IV coefficient implies that a one standard deviation decrease in the GMO dissimilarity index (=0.161), increases exports of about 53%, *ceteris paribus*. This means that, using the effect of the GMO regulation when treated exogenously as a lower bound, the increase of trade due to the harmonization ranges between 33% to 53%. It is worth noting that this effect is of the same order of magnitude of a full liberalization trade effect in the agro-food sector.[20]

## 5. Summary and Conclusion

Motivated by the complex pattern and evolution of GMO regulations in the last decade, this paper quantifies the effect of GMO regulations on bilateral trade flows at the global level. A composite index of such regulations, as well as a score for six GMO regulatory dimensions, was developed for sixty countries. In a second step, we use a gravity model to analyze how bilateral similarity/dissimilarity in GMO regulations affects trade flows for the composite index and its components. There are three main results.

First, countries that have strong differences in their GMO regulations trade significantly less. Thus, what matter for trade flows is the level of harmonization in GMO standards between countries, a result in line with the recent evidence related to other industries (see Czubala *et al.* 2009; Shepherd, 2007). Second, the regulatory dimension that matters the most is labeling, followed by the approval process and traceability. Not surprisingly, coexistence appears less important from the point of view of trade as it is more related to the field production stage. Third, all these effects are particularly strong for developed and emerging countries. Finally, we found that the endogeneity of GMO regulation to trade flows is potentially important. Taking into account endogeneity, the magnitude of the estimated GMO regulatory effect increases by a factor of 2.

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[20] Hertel and Keeney (2006) using GTAP, found that agricultural and food trade increased of 21% when all tariffs and agricultural subsidies were removed. Similarly, Raimondi and Olper (2011), using a gravity model showed that current trade barriers (tariffs) reduce food industry global trade of 33%.

The main policy implication of this study is that a process of global harmonization of GMO standards would have a large positive trade effect, and this is especially true with regard to labeling policies.

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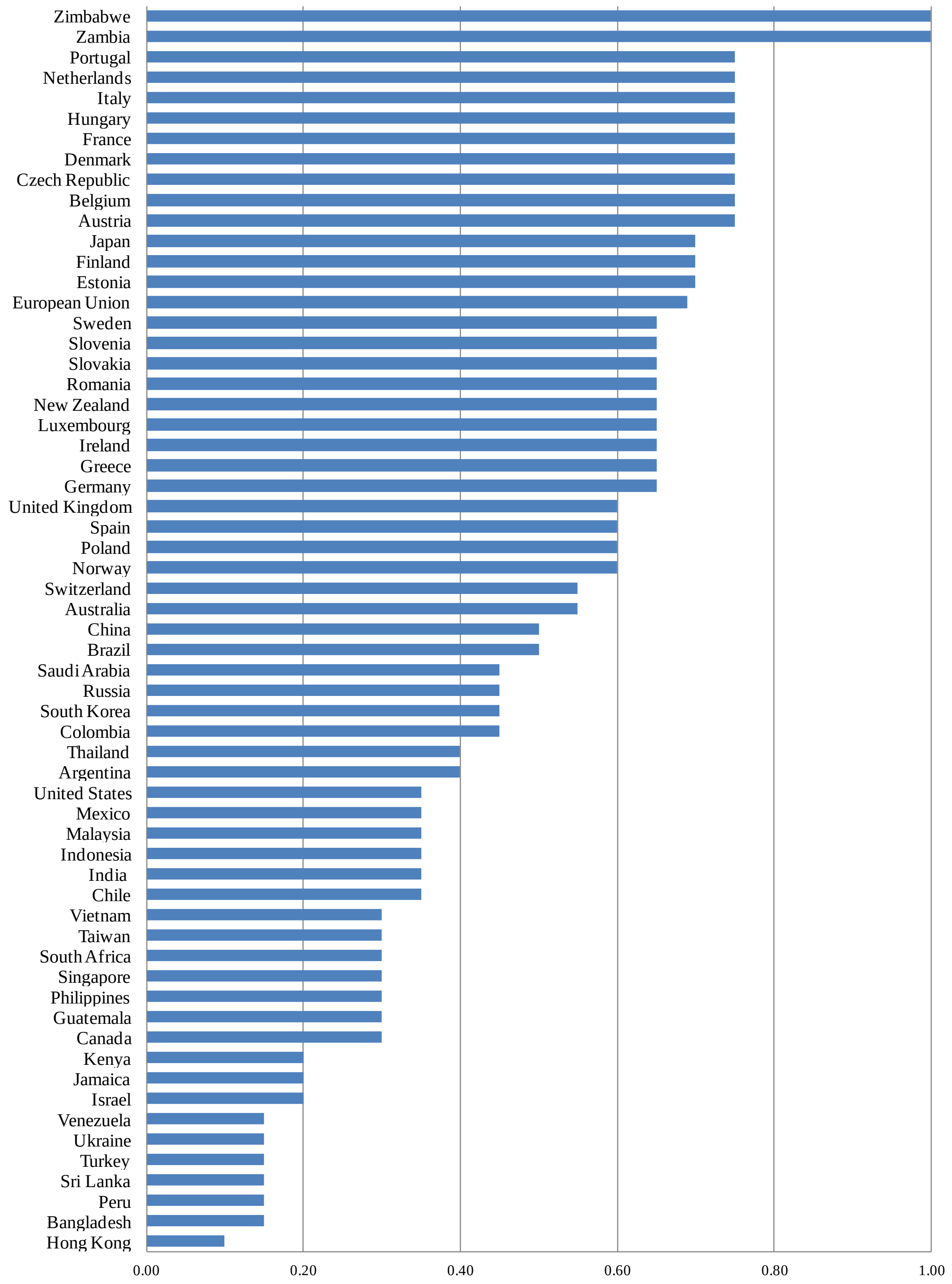
**Figure 1.** GMO regulatory index score and ranking



*Notes*: Mean = 0.50; Standard Deviation = 0.226

**Table 1**. Categories, conditions and scores of the GMO regulatory index

| | | |
|---|---|---|
| **1.** | **Approval process** | **Score** |
| | Absence of GMO approval procedures | 0 |
| | Mandatory approval process but far from enforcement | 1 |
| | Mandatory approval process adopting the principle of substantial equivalence | 2 |
| | Mandatory approval process adopting the precautionary principle | 3 |
| | GM-free country | 4 |
| **2.** | **Risk assessment** | **Score** |
| | Absence of GMO risk analysis | 0 |
| | Proposed risk assessment but far from enforcement | 1 |
| | Mandatory risk assessment | 2 |
| | GM-free country | 3 |
| **3.** | **Labeling policies** | **Score** |
| | Absence of labeling policies | 0 |
| | Voluntary GMO labeling | 1 |
| | Mandatory GMO label with threshold >1% | 2 |
| | Mandatory GMO label with threshold <= 1% | 3 |
| | GM-free country | 4 |
| **4.** | **Traceability requirements** | **Score** |
| | Absence of GMO traceability or an IP | 0 |
| | GMO traceability far from enforcement or is in place IP | 1 |
| | Mandatory GMO traceability | 2 |
| | GM-free country | 3 |
| **5.** | **Coexistence guidelines** | **Score** |
| | Absence of coexistence rules | 0 |
| | GMO coexistence policies far from enforcement | 1 |
| | Partial guidelines on coexistence | 2 |
| | Exhaustive guidelines on coexistence | 3 |
| | GM-free country | 4 |
| **6.** | **Membership in international agreements** | **Score** |
| | No adherence to international agreements | 0 |
| | Adherence to a single international agreement | 1 |
| | Adherence to both international agreements | 2 |

*Note*: see text.

**Table 2**. Summary statistics of variables used in the gravity equation

| Variables | No. of Obs. | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| $GMOw_{ij}$ *Similarity Index* | 3540 | 0.815 | 0.148 | 0 | 1 |
| $GMO_{ij}$ *Dissimilarity Index* | 3540 | 0.258 | 0.188 | 0 | 0.90 |
| $GMO_{ij}$ *Diss. Components* | 3540 | | | 0 | 1.00 |
| *Labeling* | 3540 | 0.327 | 0.287 | 0 | 1 |
| *Approval* | 3540 | 0.291 | 0.283 | 0 | 1 |
| *Traceability* | 3540 | 0.352 | 0.321 | 0 | 1 |
| *Risk assessment* | 3540 | 0.141 | 0.209 | 0 | 1 |
| *Coexistence* | 3540 | 0.319 | 0.313 | 0 | 1 |
| *Agreements* | 3540 | 0.223 | 0.302 | 0 | 1 |
| $GMO_{ij}$ *5 closest neighbours* | 3540 | 0.213 | 0.161 | 0 | 1 |
| $Ln\ Import_{ijk}$ | 17112 | 3.208 | 3.392 | -6.91 | 15.031 |
| $Ln\ Distance_{ij}$ | 91253 | 8.659 | 0.938 | 5.08 | 9.880 |
| *Contiguity* | 91253 | 0.042 | 0.200 | 0 | 1 |
| *Language* | 91253 | 0.105 | 0.306 | 0 | 1 |
| *Colony* | 91253 | 0.026 | 0.159 | 0 | 1 |
| $Ln\ (1 + tariff_{ijk})$ | 91253 | 0.057 | 0.163 | 0 | 1.950 |

*Notes*: because the GMO regulatory index does not vary across products, the number of observations refer only to 60*59 = 3540 bilateral countries observations. Observations related to *Ln Import* refer only to positive trade. See text for variables explanation.

**Table 3**. GMO regulation and trade: regression results.

| | *OLS* | *Heckman procedure* | | *ZINB* | *OLS* | *Heckman procedure* | | *ZINB* |
|---|---|---|---|---|---|---|---|---|
| | | Probit | II stage OLS | | | Probit | II stage OLS | |
| Variables | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| *$GMO_{ij}$ Index* | -1.18*** | -0.24*** | -1.53*** | -0.94*** | | | | |
| | *(0.19)* | *(0.07)* | *(0.19)* | *(0.26)* | | | | |
| *$GMOw_{ij}$ Index* | | | | | 1.65*** | 0.11 | 1.93*** | 1.21** |
| | | | | | *(0.36)* | *(0.13)* | *(0.35)* | *(0.50)* |
| *Ln Distance $_{ij}$* | -0.80*** | -0.65*** | -1.65*** | -2.10*** | -0.85*** | -0.67*** | -1.73*** | -2.14*** |
| | *(0.04)* | *(0.02)* | *(0.06)* | *(0.07)* | *(0.03)* | *(0.02)* | *(0.06)* | *(0.07)* |
| *Contiguity* | 0.98*** | 0.47*** | 1.30*** | 1.15*** | 0.96*** | 0.46*** | 1.27*** | 1.13*** |
| | *(0.09)* | *(0.07)* | *(0.09)* | *(0.19)* | *(0.09)* | *(0.07)* | *(0.09)* | *(0.19)* |
| *Language* | 0.11 | 0.22*** | | 0.19 | 0.11 | 0.23*** | | 0.16 |
| | *(0.08)* | *(0.04)* | | *(0.15)* | *(0.08)* | *(0.04)* | | *(0.15)* |
| *Colony* | -0.11 | 0.22*** | 0.36*** | 0.36** | -0.15 | 0.21*** | 0.30*** | 0.38** |
| | *(0.10)* | *(0.06)* | *(0.10)* | *(0.18)* | *(0.10)* | *(0.06)* | *(0.10)* | *(0.18)* |
| *Ln (1 + tariff $_{ij}$)* | -1.57*** | -0.33*** | -1.88*** | -1.05*** | -1.61*** | -0.35*** | -1.95*** | -1.05*** |
| | *(0.20)* | *(0.06)* | *(0.20)* | *(0.39)* | *(0.20)* | *(0.06)* | *(0.20)* | *(0.39)* |
| *Mills ratio* | | | 2.19*** | | | | 2.20*** | |
| | | | *(0.14)* | | | | *(0.14)* | |
| *Constant* | 5.85*** | 4.18*** | 10.40*** | 20.38*** | 4.64*** | 4.84*** | 5.95*** | -8.01*** |
| | *(0.62)* | *(0.19)* | *(0.79)* | *(0.83)* | *(0.70)* | *(0.24)* | *(0.67)* | *(0.37)* |
| Observations | 17112 | 91253 | 17112 | 91253 | 17112 | 91253 | 17112 | 91253 |
| FE Importer, exporter and HS2 | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

*Notes*: In parentheses robust standard errors clustered within importing-exporting countries. ***, ** and * indicate significance level at 1%, 5% and 10%, respectively. Each regression includes fixed effects for importers, exporters and HS 2-digit products. In the ZINB regressions of column (4) and (8), the over-dispersion test (*alpha* value) is 18.36 and 18.33 respectively, both significant at 1%; differently, for the Vuong Test the *z*-score is 32.23 and 32.42, respectively.

## **Table 4**. GMO regulation and trade: regressions at regulatory components level

| | | *$GMO_{ij}$ Dissimilarity Index Components* | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | *Labeling* | *Approval* | *Traceability* | *Risk* | *Coexistence* | *Agreements* | *Mills ratio* |
| Probit | (1) | -0.16*** *(0.05)* | | | | | | |
| II st.OLS | (2) | -0.80*** *(0.13)* | | | | | | 2.19*** *(0.14)* |
| Probit | (3) | | -0.05 *(0.05)* | | | | | |
| II st.OLS | (4) | | -0.76*** *(0.16)* | | | | | 2.20*** *(0.14)* |
| Probit | (5) | | | -0.12*** *(0.04)* | | | | |
| II st.OLS | (6) | | | -0.52*** *(0.10)* | | | | 2.17*** *(0.14)* |
| Probit | (7) | | | | 0.08 *(0.17)* | | | |
| II st.OLS | (8) | | | | -0.50 *(0.49)* | | | 2.18*** *(0.14)* |
| Probit | (9) | | | | | -0.04 *(0.04)* | | |
| II st.OLS | (10) | | | | | -0.31*** *(0.08)* | | 2.19*** *(0.14)* |
| Probit | (11) | | | | | | 0.01 *(0.05)* | |
| II st.OLS | (12) | | | | | | -0.21* *(0.12)* | 2.18*** *(0.14)* |
| Probit | (13) | -0.13** *(0.05)* | 0.03 *(0.06)* | -0.10** *(0.04)* | 0.13 *(0.17)* | 0.01 *(0.04)* | 0.04 *(0.05)* | |
| II st.OLS | (14) | -0.54*** *(0.14)* | -0.36** *(0.17)* | -0.29*** *(0.11)* | -0.02 *(0.49)* | -0.14 *(0.09)* | -0.05 *(0.12)* | 2.18*** *(0.14)* |

*Notes*: In parentheses robust standard errors clustered within importing-exporting country. ***, ** and * indicate significance level at 1%, 5% and 10%, respectively. Figures refer to the first (Probit) and second (OLS) stage of the Heckman regression. Each regression includes all the controls of Table 3, plus country fixed effects for importers, exporters, and HS 2-digit products. The total number of observations does not add up to 17,112 (as Column 1 of Table 3) because in the estimation of the first stage Probit equation for each product group, we lose observations due to zero imports of some products for some countries (i.e. Indonesia and Ukraine and corn imports).

**Table 5**. GMO regulation and trade: regressions at regulatory components and product group level

| | **Maize** | | **Soybean** | | **Rapeseed** | | **Cotton** | |
|---|---|---|---|---|---|---|---|---|
| $GMO_{ij}$ Index | Probit | II st.OLS | Probit | II st.OLS | Probit | II st.OLS | Probit | II st.OLS |
| *Labeling* | -0.10* | -0.66*** | -0.26*** | -1.19*** | -0.31*** | -1.41*** | -0.27* | -0.23 |
| | *(0.06)* | *(0.16)* | *(0.08)* | *(0.26)* | *(0.10)* | *(0.41)* | *(0.15)* | *(0.90)* |
| *Approval* | *0.07* | *-0.66**** | *-0.14* | *-1.16**** | *-0.22* | *-1.46*** | *-0.40*** | *-1.45* |
| | (0.06) | (0.20) | (0.09) | (0.33) | (0.15) | (0.68) | (0.20) | (1.14) |
| *Traceability* | -0.13*** | -0.49*** | -0.12** | -0.79*** | -0.27*** | -1.08*** | -0.07 | -0.21 |
| | *(0.04)* | *(0.13)* | *(0.06)* | *(0.18)* | *(0.08)* | *(0.33)* | *(0.14)* | *(0.81)* |
| *Risk* | *0.35** | *0.04* | *-0.11* | *0.27* | *-0.51* | *-2.75** | *-0.16* | *-1.15* |
| | (0.20) | (0.58) | (0.24) | (1.04) | (0.45) | (1.56) | (0.53) | (3.22) |
| *Coexistence* | -0.03 | -0.32*** | -0.08 | -0.46*** | -0.02 | -0.09 | 0.09 | 1.08 |
| | *(0.05)* | *(0.11)* | *(0.07)* | *(0.18)* | *(0.07)* | *(0.23)* | *(0.17)* | *(1.06)* |
| *Agreements* | *-0.05* | *-0.47**** | *0.08* | *-0.34* | *-0.11* | *0.14* | *0.08* | *0.70* |
| | (0.06) | (0.15) | (0.09) | (0.24) | (0.10) | (0.40) | (0.15) | (0.76) |
| Observations | 45345 | 8236 | 17759 | 3983 | 17164 | 2119 | 5508 | 316 |

*Notes*: In parentheses robust standard errors clustered within importing-exporting country. ***, ** and * indicate significance level at 1%, 5% and 10%, respectively. Figures refer to the first (Probit) and second (OLS) stage of the Heckman regression. Each regression includes all the controls of Table 3, plus country fixed effects for importer, exporter, and HS 2-digit products.

**Table 6**. GMO regulation and trade: different levels of development

| Variables | OLS | *Heckman procedure* | |
|---|---|---|---|
| | | Probit | II stage OLS |
| $GMO_{ij}$ * *Developing* | 0.85<br>*(0.57)* | 0.07<br>*(0.20)* | 0.56<br>*(0.57)* |
| $GMO_{ij}$ * *Emerging* | -0.61*<br>*(0.36)* | -0.02<br>*(0.12)* | -0.88**<br>*(0.36)* |
| $GMO_{ij}$ * *Developed* | -1.71***<br>*(0.22)* | -0.45***<br>*(0.08)* | -2.13***<br>*(0.22)* |
| $Ln\ Distance_{ij}$ | -0.79***<br>*(0.04)* | -0.65***<br>*(0.02)* | -1.63***<br>*(0.06)* |
| *Contiguity* | 0.98***<br>*(0.09)* | 0.47***<br>*(0.07)* | 1.29***<br>*(0.09)* |
| *Language* | 0.09<br>*(0.08)* | 0.22***<br>*(0.04)* | |
| *Colony* | -0.09<br>*(0.10)* | 0.23***<br>*(0.06)* | 0.37***<br>*(0.10)* |
| $Ln\ (1 + tariff_{ij})$ | -1.56***<br>*(0.20)* | -0.33***<br>*(0.06)* | -1.86***<br>*(0.20)* |
| *Mills ratio* | | | 2.15***<br>*(0.14)* |
| Constant | 7.83***<br>*(0.80)* | 4.58***<br>*(0.18)* | 9.48***<br>*(0.82)* |
| Observations | 17112 | 91253 | 17112 |
| FE Importer, exporter and HS 2-digit | Yes | Yes | Yes |

*Notes*: In parentheses robust standard errors clustered within importing-exporting country. ***, ** and * indicate significance level at 1%, 5% and 10%, respectively. Figures refer to the first (Probit) and second (OLS) stage of the Heckman regression. Each regression includes country fixed effects for importer, exporter, and HS 2-digit products.

**Table 7**. GMO regulation and trade: IV regressions

| Variables | OLS | IV | *Heckman procedure* | |
|---|---|---|---|---|
| | | | II stage OLS | II stage IV |
| *GMOij Index* | -1.18*** | -2.26*** | -1.53*** | -2.63*** |
| | *(0.19)* | *(0.38)* | *(0.19)* | *(0.38)* |
| *Ln Distance* $_{ij}$ | -0.80*** | -0.71*** | -1.65*** | -1.56*** |
| | *(0.04)* | *(0.05)* | *(0.06)* | *(0.07)* |
| *Contiguity* | 0.98*** | 1.02*** | 1.30*** | 1.33*** |
| | *(0.09)* | *(0.09)* | *(0.09)* | *(0.09)* |
| *Language* | 0.11 | 0.08 | | |
| | *(0.08)* | *(0.08)* | | |
| *Colony* | -0.11 | -0.03 | 0.36*** | 0.43*** |
| | *(0.10)* | *(0.10)* | *(0.10)* | *(0.10)* |
| *Ln (1 + tariff* $_{ij}$ *)* | -1.57*** | -1.46*** | -1.88*** | -1.78*** |
| | *(0.20)* | *(0.20)* | *(0.20)* | *(0.20)* |
| *Mills ratio* | | | 2.19*** | 2.18*** |
| | | | *(0.14)* | *(0.14)* |
| Constant | 8.64*** | 8.71*** | 10.40*** | 10.59*** |
| | *(0.77)* | *(0.78)* | *(0.79)* | *(0.80)* |
| Observations | 17112 | 17112 | 17112 | 17113 |
| FE Impoerter, exporter and HS2 | Yes | Yes | Yes | Yes |
| Cragg-Donald underid. test | | 5145.08 | | |
| *p-value* | | *0.000* | | |
| Hausman endogeneity test | | 9.91 | | |
| *p-value* | | *0.002* | | |

*Notes*: In parentheses robust standard error clustered within importing-exporting country. ***, ** and * indicate significance level at 1%, 5% and 10%, respectively. In the IV regressions the *GMO*$_{ij}$ index is instrumented with the weighted average index of the five closer neighbor countries (see text). The Cragg-Donald under-identification test tests the null hypothesis that the first stage is weakly identified. The critical value for rejection of the hypothesis of weak identification is 16.38 (10% level) as reported in Stock and Yogo (2002). The Hausman endogeneity test tests the null hypothesis that the endogenous variable can be treated as exogenous. Each regression includes fixed effects for importers, exporters, and HS 2-digit products.

## Web-appendix A.1. GMO index regulatory components

In this online appendix, we provide a full description of the characteristics and economic impact of each regulatory dimension composing the GMO index used in the empirical analysis.
As a general rule, a more restrictive regulatory component would increase production and compliance costs due to comprehensive requirements, and would consequently have a greater effect on trade. We assigned higher scores to more restrictive requirements. Table 1 shows the list of regulatory components and sub-dimensions.

### *Approval process*

The first condition that allows any possible handling of a GMO product in a country is its approval status. GM ingredients or foods need specific approval procedures for import and cultivation. These procedures test the safety of GM products. In contrast with other requirements (e.g. traceability and labeling), which act similarly to other trade standards, approval is a measure that directly affects market access: if a GM event is not approved it is not possible to introduce it into the country.

Approval process requirements vary significantly across countries. There are two main groups of countries that share similar approaches. One group follows the EU regulation based on the 'precautionary principle'. It means that any product produced with, or derived from, transgenic crops is subject to GM regulation and the consumer 'right to know'. The second group follows the US 'substantial equivalence' approach, that exempts essentially equivalent products from any specific requirement (Gruère, 2006). Between the two there are other different approaches to the approval process.

We defined five levels of restrictiveness (from 0 to 4) for an approval process. The levels are based on the degree of domestic implementation of the regulation. A score of 0 is assigned if there are no constraints on GMO cultivation and marketing; 1 if there exists a mandatory approval process established at legislative level, but not yet implemented; 2 if the mandatory approval process follows the principle of substantial equivalence; 3 if the mandatory approval process follows the precautionary principle; and finally, 4 for GM-free countries (prohibition of cultivation and marketing).

Most EU members, Japan and fast-growing income countries like China and India are scored in the third condition, which is the most comprehensive. The zero or first condition includes developing or emerging countries that take the so called 'wait and see' position.

### *Risk assessment*

Assessments are based on the biological characteristics of the new organism, and test the safety of food and feed containing GMOs and the effects on the environment. The typology of the testing depends on the country's approach, whether based on substantial equivalent or precautionary principle. In many cases the exporter is the legal subject responsible for the assessment.

Risk assessment is the target for international harmonization efforts for shared methodologies, though still at discussion stage. The scheduling and realization of programs for field trials is expensive and some countries (e.g. developing countries) are not able to deal with these costs.

We identified four levels (range 0-3) for risk assessment regulation. The two extreme conditions, scored 0 and 3, indicate a lack in the risk assessment framework, but the difference is substantial: a score of 0 (e.g. Ukraine) indicates a normative void that does not affect trade or cultivation as there are no standards; score 3, on the contrary, applies to GM-free countries, hence totally opposed to the importation (and cultivation) of GMOs and imposing the strongest degree of restrictiveness. Between these two scores, we assign 1 if the risk assessment is at proposal stage, and 2 if risk assessment is compulsory.

### *Labeling policies*

In 1997, the EU introduced GMO labeling with the purpose of guaranteeing the consumer's 'right to know'. Labels carry indications of the presence of GM ingredients, but also of health safety and product diversification. Labeling has also met environmental issues, playing a major role in consumption decisions of consumers concerned with environmental pollution associated with GM products (Appleton, 2000). A label can act as an hazard warning, affecting the demand for GM and non-GM products (Gruère, 2006).

A labeling regime is expected to affect trade flows, in particular the trade of the biggest suppliers of GM crops (Gruère and Rao, 2007; Gruère *et al.* 2009b). Costs caused by a label depend on: the threshold level, the capacity of the public authorities to enforce labeling requirements, and the capacity of industry to comply with labeling rules. GM labels have effects on the whole agri-food chain. Actors have to collect and handle information concerning the presence of GM ingredients until the final consumer. The transfer of this information adds onerous management costs. Ultimately, labeling indirectly affects trade through the imposition of implementation costs, carried by exporters.

Among countries we registered two main approaches: voluntary and mandatory labeling. Mandatory labeling requirements are divided into further two groups: label on the finished product (Australia and Japan), and on GM technology as a production process (EU and China). In the former case, the quantification of GM ingredients is required to be labeled, and, usually, the threshold is higher. In the latter case any product derived from GM crops has to be reported. In this case, thresholds are more restrictive.

We have identified five categories of labeling, based on threshold. Compliance with a restrictive threshold implies an increase in production and commercialization costs. We assigned a 0 score in absence of labeling requirements; 1 with voluntary regime; 2 in the presence of a mandatory regime with a threshold higher than 1%; 3 with mandatory regime with a threshold equal or lower than 1%; finally, 4 in GM-free countries.

### *Traceability requirements*

Traceability is an instrument to create a network to 'retrace history, use or location of an entity by means of recorded identification', and to guarantee efficient withdrawal from the food and feed market if any unexpected effect occurs to health and environment. In the case of GMO products, the traceability system is based on identity preservation (IP) for the diversification between different productions, ensuring to the consumer the origin and the characteristics of the product. Moreover, producers, processors and retailers have to collect, retain and transmit information at each stage of the agri-food chain (Bailey, 2002).

Countries with a comprehensive traceability regulation must create procedures for the identification of industry chain participants who supply and demand products. Agents of the food chain must transmit information on the identity of the product and whether it contains GMOs, and must retain the information for a period of time (post-market monitoring), i.e. 5 years. Moreover they must guarantee information availability for applicants (Wilson *et al.*, 2008).

At the producer level, farmers have to be certain of the absence of cross-pollination between neighboring crops, and must comply with certified storage and harvesting. Elevators, processors and retailers must keep information on product identity and transmit this information by lot numbers and test results.

All these requirements induce increasing costs, but also benefit the market niche gains. Cost increase is difficult to establish because traceability is an issue with long term implications, whereas variable costs depend on crops e.g. soybean and maize provide a great number of byproducts in different agri-food industries. Moreover, liability and compensation schemes are crucial. The main costs are due to certification, record collection and information keeping, and are carried by GMO producers and supplier countries, with a potentially higher final market price for both GMO and GM-free products.

For the traceability category we defined the following scores: 0 if the regulation does not require traceability or IP; 1 if traceability is at proposal stage or if IP is enforced; 2 if traceability is mandatory; and 3 if the country is GM-free.

### *Coexistence guidelines*

The purpose of coexistence is to guarantee consumers and farmers the possibility of choosing what to consume or produce among GM, traditional and organic products. This is feasible only if there is IP among crops, which must be segregated in space and time. Coexistence procedures require mechanisms preventing pollen flows (such as distances or pollen barriers between fields of GM, traditional and organic products), refuge areas and dedicated machineries, but also compensation and liability systems. It also requires strong cooperation between farmers in close proximity.

Production costs rise due to isolation, monitoring, purity testing, dedicated equipment and/or its cleaning. Costs may vary at different purity levels, taking into account that zero threshold of transgene in GM-free crops is not feasible in some agricultural systems. Some policy makers in developing countries assume that coexistence is not feasible or can be done only by facing prohibitive costs.

Because of the difficulties in establishing coexistence strategies, the level of implementation of coexistence policies varies widely across countries, and in several cases requirements are not stated clearly. For this reason we decided to score 0 those countries without any coexistence rule; 1 if coexistence policies are still far from enforcement; 2 if there are partial guidelines; 3 if exhaustive coexistence guidelines are adopted; and 4 if the country is GM-free.

### *Membership in international GMO related agreements*

The purpose of the Codex Alimentarius is to define standards for consumer protection, and to promote fair relationship in international trade practices. It successfully reached an agreement on safety assessment procedures for GMOs, but no formal labeling standards were adopted.

The aim of the Cartagena Protocol on Biosafety (BSP), which is part of the United Nations Convention on Biodiversity, is to introduce a shared procedure for risk assessment, risk management and trans-boundary movements of Living Modified Organisms (LMOs). The BSP acts between importer and exporter, introducing an Advanced Informed Agreement (AIA) for the intentional introduction of LMOs into the environment. In particular, it requires a comprehensive risk assessment and risk management framework provided by the exporter before the first introduction of a LMO into the importer territory. Rules from the BSP are on bundling, transport, packaging and identification during any LMO trans-boundary movement.

The compliance with the BSP can impose higher production and marketing costs, on both GM and non-GM products, because of the creation of domestic structures for annual testing.

If the country does not adhere to either one of the two international agreements, the score is 0; otherwise the score is 1 or 2 when the country subscribes to one or both agreements.

It is important to note that, until the Codex Alimentarius reaches agreement on GMO labeling, and the BSP comes actively into force in all member countries, neither international institution will influence trade flows. However, we decided to consider also this category on the grounds that the expected future enforcement will have a trade effect.