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EU Inspections of GM Content in Food and Feed: Are They Effective?

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Abstract: We investigate the effectiveness of inspecting regimes in controlling food and feed products containing genetically modified organisms (GMOs) non-compliant with European Commission (EC) regulations (i.e., a food/feed import containing above the 0.9% GM content threshold for food and at or above 0.1% for feed allowed by the EC regulations but not (or incorrectly) labelled or food/feed imports containing unauthorized GMOs). We collate information at the country level from EC official reports on the number of samples and cases of non-compliance identified by official controls conducted by European Member States (MS). We analyze the probability of finding non-compliant food/feed imports for a number of MS countries between 2000 and 2013, by using a hierarchical model, which interlinks the number of samples taken (i.e., inspections) with interceptions of non-compliant products. Results show that the probability of finding imported products non-compliant with EC's GMO regulations in food and feed varies among MS countries but, in most cases, is relatively high. For instance, for imported food products in 2004, the probability of the rate of intercepting non-compliant food products being above 5% and 10% in France was 99% and 70%, respectively. However, whereas countries such as Sweden, Portugal, and Austria also show a high rate of intercepting non-compliant food, other countries such as Germany and Spain show a very low probability of finding imported food products being non-compliant. For imported feed products, the overall probability of rate of intercepting non-compliant feed products being above 5% and 10% per country and year was even higher than for imported food products (e.g., 100% in the case of Hungary in 2005). The European Union regulation needs to guide MS adequately in order to establish the optimal level of inspections, guaranteeing consumers' freedom of choice.

Keywords: genetically modified food; genetically modified feed; European Union; imports; inspections

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1. Introduction

The regulatory framework on genetically modified (GM) food and feed in the European Union (EU) is established as objective to ensure a high level of protection of human life and health, welfare, environment and consumer interests (Regulation European Commission (EC) 1829/2003). According to this regulatory framework, one basic interest for consumers is to have freedom of choice of foodstuff. This essentially means that consumers shall be provided with information, usually through product labelling, on whether a product contains ingredients derived from genetic engineering.

The last Eurobarometer Survey from the European Food Safety Authority (EFSA) shows that European consumers are less concerned about the use of GMOs in food or drinks than a decade ago [1,2]. Nevertheless, food labelling and prior information about whether GM technology has been used in food products have an impact on consumers' willingness to buy GM food. Nam et al. [3] analyzed the value of providing information on GM raw materials in cooking oil to consumers, concluding that a policy on GMO

labelling would lead to an increase in consumers' preference for non-GM. This would be more noticeable for consumers with low GM awareness. In addition, the lower the prior information consumers have on GM raw materials in food products, the higher the value of such information. Zhu and Xie [4] showed that consumers' willingness to pay (WTP) for GM food is affected by their previous knowledge on GMO and new (positive/negative) information on GMOs. Giordano et al. [5] and Zhan et al. [6] examined that such negative perceptions on GMO food are not easily changed, even when consumers are given new information. Thus, consumers with prior negative information on GMOs will not be comfortable eating GM food [7–9].

The need to establish a European Community-wide framework for official controls of feed and foodstuffs at the borders was firstly identified in the EU white paper on Food safety [10]. As a result, the Regulation (EC) 882/2004 on "official controls performed to ensure the verification of compliance with feed and food law, animal health and animal welfare rules" sets out the general control systems that the responsible authorities for enforcement for feed and food law and animal health and animal welfare legislation. In this regard, article 30 of Regulation (EC) 882/2004 states that "in order to ensure a more efficient organization of the official controls on feed and food from third countries and in order to facilitate commercial flows, it may be necessary to designate specific points of entry for feed and food from third countries into the territory of the Community".

Member States (MS) are also required to present an annual report to the European Commission (EC) with information on the implementation of the multiannual control plans. The report should provide results of the official controls and audits carried out during the previous year and, where necessary, an update of the initial control plan in response to these results. It also should provide the type and number of cases of non-compliance identified as well as any actions to ensure the effective operation of multi-annual national control plans, including enforcement action and its results. Once each of the reports from MS is received by the EC, an annual report is elaborated on the overall operation of official controls in MS [11].

Regulation (EC) 882/2004 also states that guidelines to develop national control plans at the Community level "should promote coherent national strategies and identify risk-based priorities and the most effective control procedures", adding that "multiannual control plans should establish a solid basis for the Commission inspection services to carry out controls in the Member States" [11]. Hence, MS are required to carry out inspections and other control measures, including sample checks and testing, to ensure compliance with this Regulation. In cases where imported products are found to contain an authorized GMO within the EC, withdrawal/recall of the commodity and possibly change of labelling are applied. In cases where an unauthorized GM is concerned, the product is rejected (i.e., redispatched to the country of origin or destroyed). Through the Regulation (EC) 619/2011, feed containing GM material authorized for commercialization in a third country and for which a valid application has been submitted to the European Food Safety Authority (EFSA), may be accepted and labelled, provided a number of conditions are fulfilled.

One controversial aspect in this policy is the threshold level of GM material content, above which a product is required to be labelled as a GM product. Currently, food products containing authorized GM material above 0.9% have to be classified and labelled as GMOs, whereas the entrance in the EU market of products containing unauthorized GM material is forbidden. For feed commodities, the presence of unauthorized GM material with certain characteristics (authorized in a third country and already under validation in the EU, etc.) is considered compliant below 0.1%. The reason behind why 0.9% for food and 0.1% for feed were selected is not too clear and it is often argued that there is no scientific justification for tolerance thresholds [12]. A plausible explanation is that such threshold level ensures consumer choice while still ensuring practicability, since testing a zero-tolerance threshold level for GM traces would not be possible [13].

A significant part of the food products consumed in the EU relies not only on domestically produced food and feed but also on food and feed produced elsewhere (food (or

'foodstuff') means any substance or product, whether processed, partially processed or unprocessed, intended to be, or reasonably expected to be ingested by humans (Regulation (EC) 178/2002), and feed (feed (or 'feedingstuff') means any substance or product, including additives, whether processed, partially processed or unprocessed, intended to be used for oral feeding to animals (Regulation (EC) 178/2002)). As of June 2021, a total of 109 GM crop events were approved/renewed in the EU, most of them for imports and processing and/or for food and feed. More than half of GM crops approved in the EU are types of GM maize (52 events), soybeans (20 events), cotton (14 events) and rapeseed (13 events). Importing products from third countries, where regulatory procedures regarding GMO levels and detection differ from those in the EU, may lead to a non-compliant presence level of GMOs in imported cargos that can enter the EU food/feed chain if undetected.

In particular, GM soybean is a crop that could potentially pass undetected due to its relative high level of imports. There is a large vegetal protein deficit in the EU and, in particular, for soy products [14]. A total of 17 million tons of soybeans were imported by the EU in 2019 [15]. Out of the 17 million tons of soybean, 11.0 million tons were imported from two major GM soybean producers: Brazil (5.2 million tons) and the US (5.7 million tons) [15].

In order to achieve the objectives set up by the regulatory framework on GM food and feed in the EU, inspections and sampling in EU countries are conducted to ensure that food/feed products non-compliant with GM regulation are identified.

Quantitative and qualitative information from MS annual reports presented to the EC on the implementation of control plans for GMOs was used. More specifically, information on the number of samples carried out and interceptions of non-compliant food/feed products was collected for the analysis.

Using such information, this paper aims at assessing the probability of finding imported food and feed products non-compliant with EC regulation, by country. By considering such probability, we try to elucidate whether increasing the number of inspections may result in a higher number of detections. Results allow us to discuss whether public money allocated to the control of GMOs is likely to ensure that European consumers have freedom of choice in food products.

This paper is structured as follows. The next section presents data collected on GMO sampling and detections by country, and the methodology to estimate the probability of finding non-compliant food/feed products. Section 3 shows the analysis by food and feed products. The results from the analysis are discussed in Section 4. Finally, Section 5 presents the main conclusions.

2. Materials and Methods

We collated information on both GMO detection numbers at the EU borders and the detection effort provided in the mission reports of 17 MS (Austria, Belgium, Czech Republic, France, Germany, Greece, Hungary, Italy, The Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden and the United Kingdom) for the period 2000–2014 conducted by the Health and Consumer Protection Directorate General of the EC to evaluate the efficacy of official control systems on foods consisting of or produced from GMOs.

Table 1 provides information on the country reports used as well as the period covered and information on the type of crop use (for food and/or feed). Further information on the samples and the number of detections of non-compliant food/feed products per year and country can be found in Tables A1 and A2 in Appendix A.

Table 1. Country reports by year, period covered and crop use.

Country	Food	Feed	Year of Report	Period Covered
Austria	✓		2003; 2007	2000–2002; 2004–2005
Austria		✓	2003; 2007	2000–2005; 2013
Belgium	✓		2006	2004–2005
Belgium		✓	2006	2004–2005
Czech Republic	✓		2006; 2012	2005; 2010–2011
Czech Republic		✓	2006	2004–2005
France	✓		2006	2004–2005
France		✓	2006	2004–2005
Germany	✓		2001; 2006	2000; 2004–2005
Germany		✓	2006	2004–2005
Greece	✓		2006	2004–2005
Greece		✓	2006; 2007	2004–2006
Hungary	✓		2006; 2012	2004–2005; 2011
Hungary		✓	2006	2004–2005
Italy	✓		2005	2004
Italy		✓	2005	2004
The Netherlands	✓		2005; 2012	2004; 2010–2012
The Netherlands		✓	2005; 2012	2004–2005; 2010–2012
Poland	✓		2006; 2013	2004–2005; 2010–2011
Poland		✓	2006	2004–2005
Portugal	✓		2005; 2011	2000–2004; 2009–2010
Portugal		✓	2011	2008
Romania	✓		2012	2011–2012
Romania		✓	2012	2011–2012
Slovak Republic	✓		2006	2004–2005
Slovak Republic		✓	2006	2004–2005
Slovenia	✓		2006	2004–2005
Slovenia		✓	2006	2004–2005
Spain	✓		2003	2000–2002
Spain		✓	2003	2002
Sweden	✓		2002; 2011	2000; 2002; 2009–2010
UK	✓		2003; 2014	2000–2002; 2012–2013
UK		✓	2003; 2014	2000–2001; 2012

Using a hierarchical model, we estimate the interception rates from inspections carried out by EU countries regarding GM presence in food and feed. We assume that the likelihood of detections of uncompliant GM material depends on the number of inspections (i.e., samples) as shown by Areal et al. [16] and McAusland and Costello [17]. The literature on inspection regimes is mainly focused on phytosanitary controls associated with plant health including alien diseases and pests [18–20], with more limited research being conducted on GM controls to our knowledge [21,22]. Interception measure for our analysis is defined as the number of samples within a year where non-compliance is present.

The model is specified as follows:

$$\begin{aligned} y_i &\sim \text{Binomial}(\theta_i, \text{samples}_i) \\ \text{logit}\theta_i &\sim N(\mu_i, \tau^2) \\ \mu_i &= \alpha + \beta \times \log(\text{samples}_i) \\ \alpha &\sim \text{Normal}(0,\ 0.0001) \\ \beta &\sim \text{Normal}(0,\ 0.0001) \\ \tau &\sim \text{Gamma}(0.001,\ 0.001) \end{aligned}$$

We denote θ_i, $i = 1, \ldots, n$ as the interception rates of non-compliant food/feed products. We use a link function in combination with a normal distribution. Within the Bayesian framework, we also need to specify the prior distribution for the unknown parameters in the model (α, β, τ).We use diffuse priors (i.e., proper priors with large variance) for these parameters. The units of analysis are the number of interception rates

of non-compliant food/feed products (θ_i) and number of samples ($samples_i$) conducted in each MS during the period 2000–2014. Hence, the model estimates the probability of sampled food/feed products being non-compliant with EC GMOs regulation. The model treats the observations as independent (i.e., ignoring the year-by-year structure of the data) and assumes no potential dependent variability in across MS, which implies that an increase in interception rate in one country is assumed to be unrelated to an interception rate in another country. While country reports inform about next years' sampling plans, there is no reference to results from other MS as the basis for future plans. Hence, we assumed the level of inspection effort for GMO detection in food and feed to be related to the level of interceptions. We also expect that the same effort level in inspections would have had the same effect independently of the MS in which the inspections are carried out.

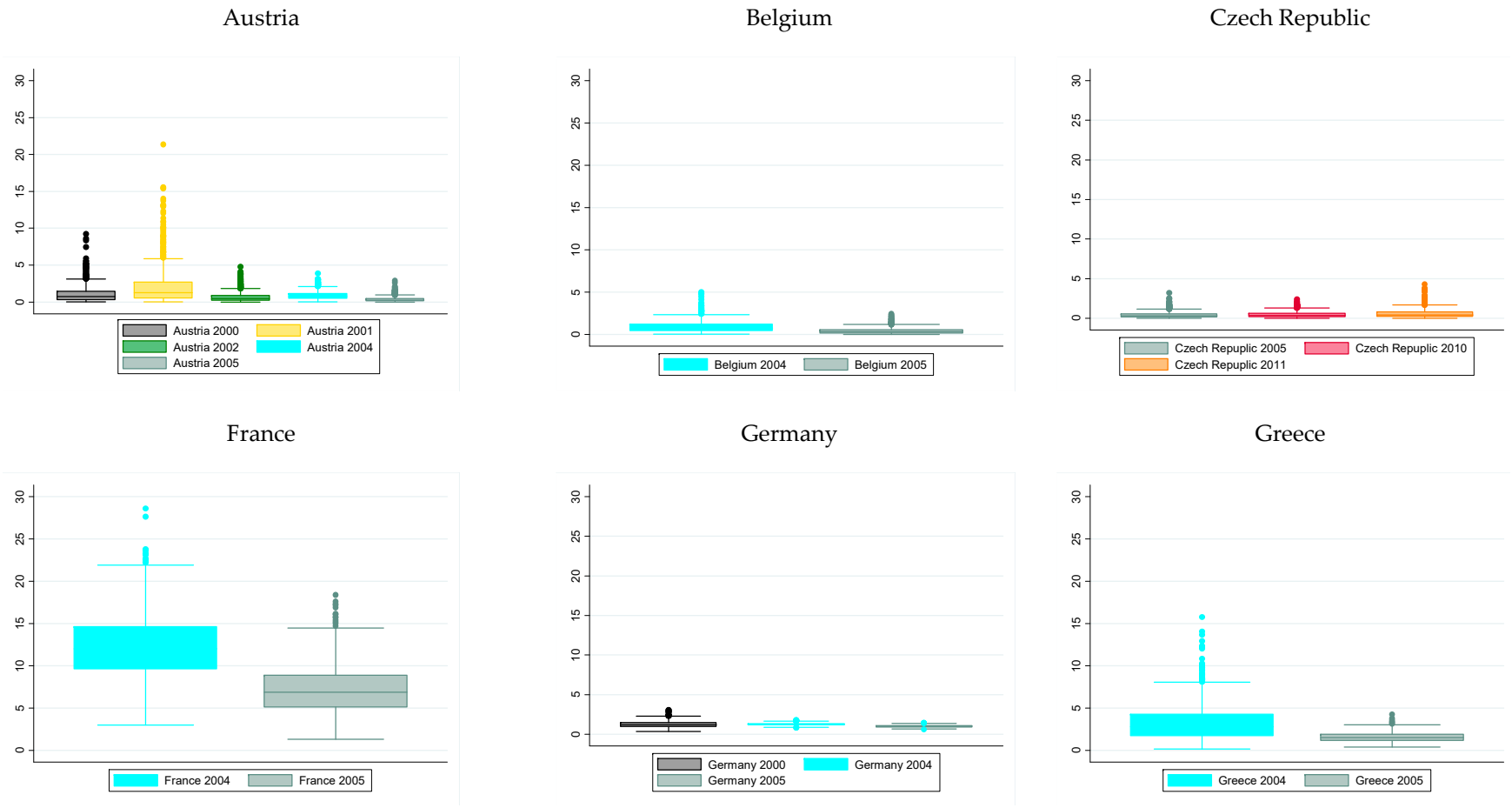
The model accounts for uncertainty on the estimated parameter based on the number of samples conducted. The estimation consisted of Monte Carlo Markov Chain (MCMC) with 1100 iterations and 100 burn-in (i.e., we retained 1000 iterations). To check the model parameter estimates' convergence, we analyzed the MCMC output. We found all parameter values of the MCMC output were stable, indicating they have converged.

3. Results

3.1. Food

We found that the probability of finding food products non-compliant with EC GMO regulation varies between EU countries and years. In some cases, the probabilities of intercepting food products with GMO levels above the allowed threshold or unauthorized GM products are relatively high. Hence, and contrary to what was expected, our results suggest that the potential impact of the unknown presence of GMOs is not independent of the country where inspections are carried out. Figure 1 shows box-plots of the probability of finding non-compliant food products per country and year. Generally, results suggest that this probability tends to be lower on average in later years. However, this is not the case for The Netherlands, Poland, Portugal, Romania, Slovenia and Sweden. The level of certainty on the probabilities for this latter group of MS also varies between countries with relatively large percentages for some countries and years.

Table 2 shows the probability of the rate of intercepting non-compliant food products being above 5% and 10% per country and year. This rate has been relatively high in France, Portugal and Sweden for every single year of analysis. As an example, Portugal showed a probability of 10% (5% threshold) and 67.6% (10% threshold) in 2001. Other countries such as Austria, Greece, and Sweden also show a high rate of intercepting non-compliant food products but only in some years.



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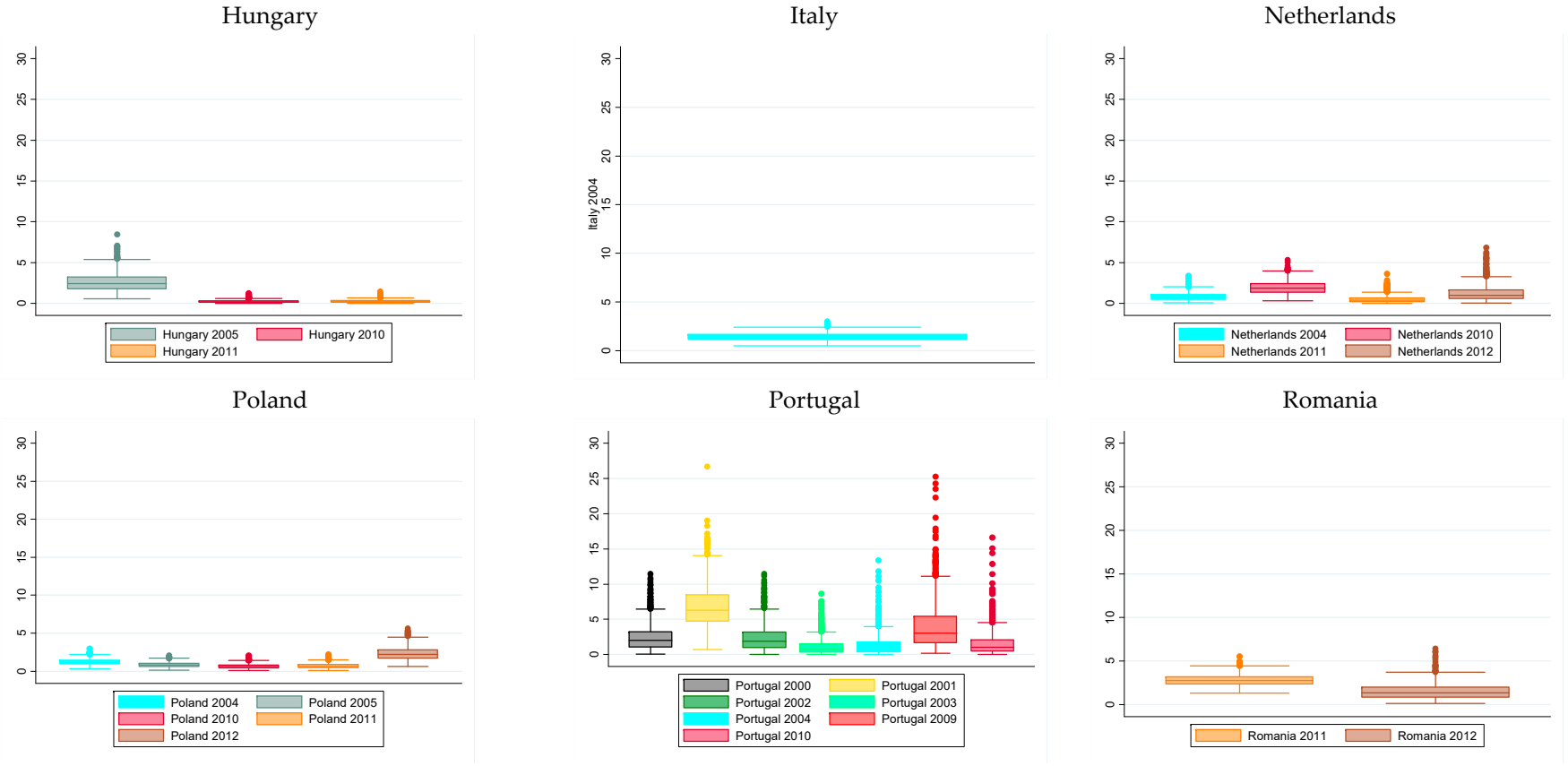

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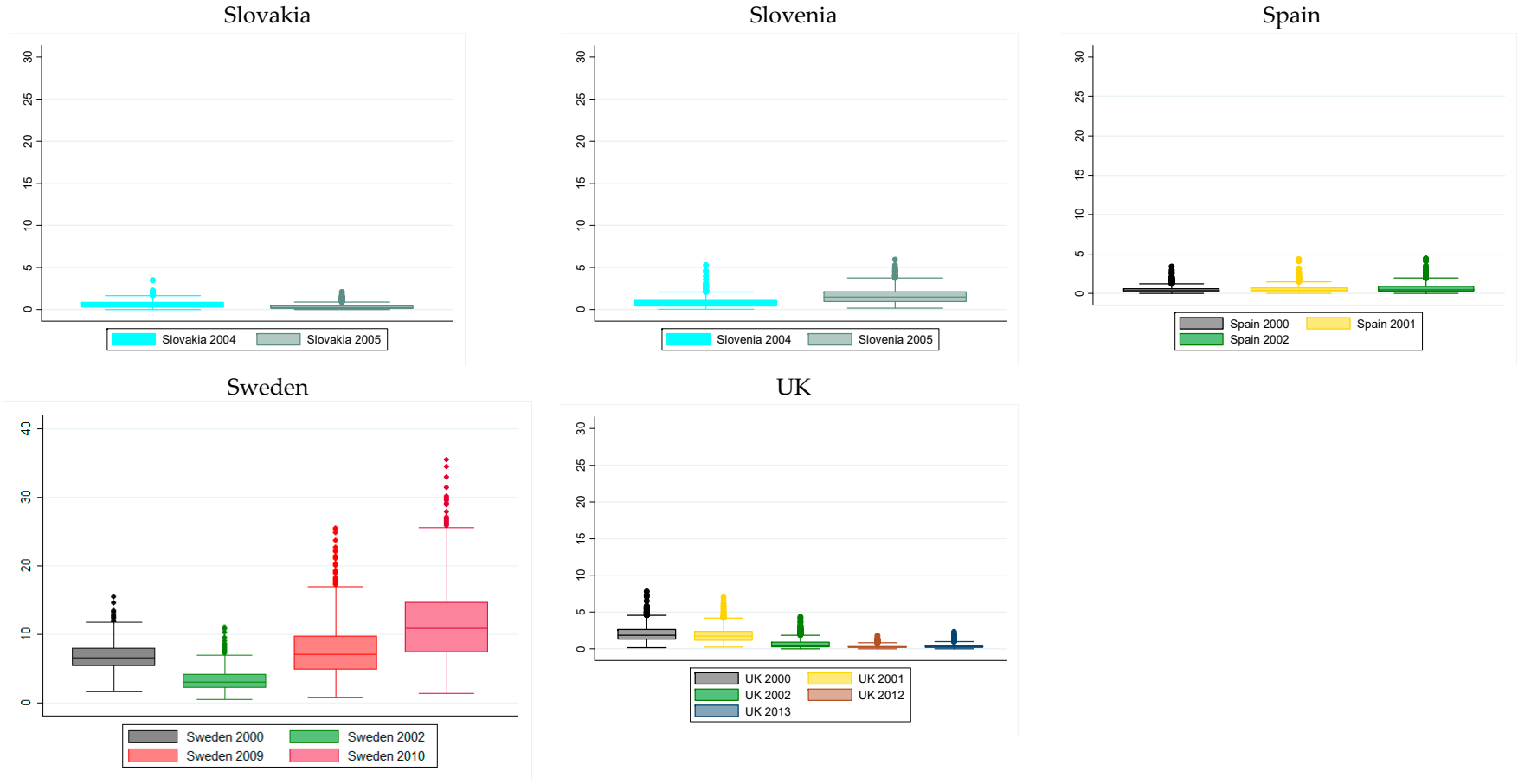


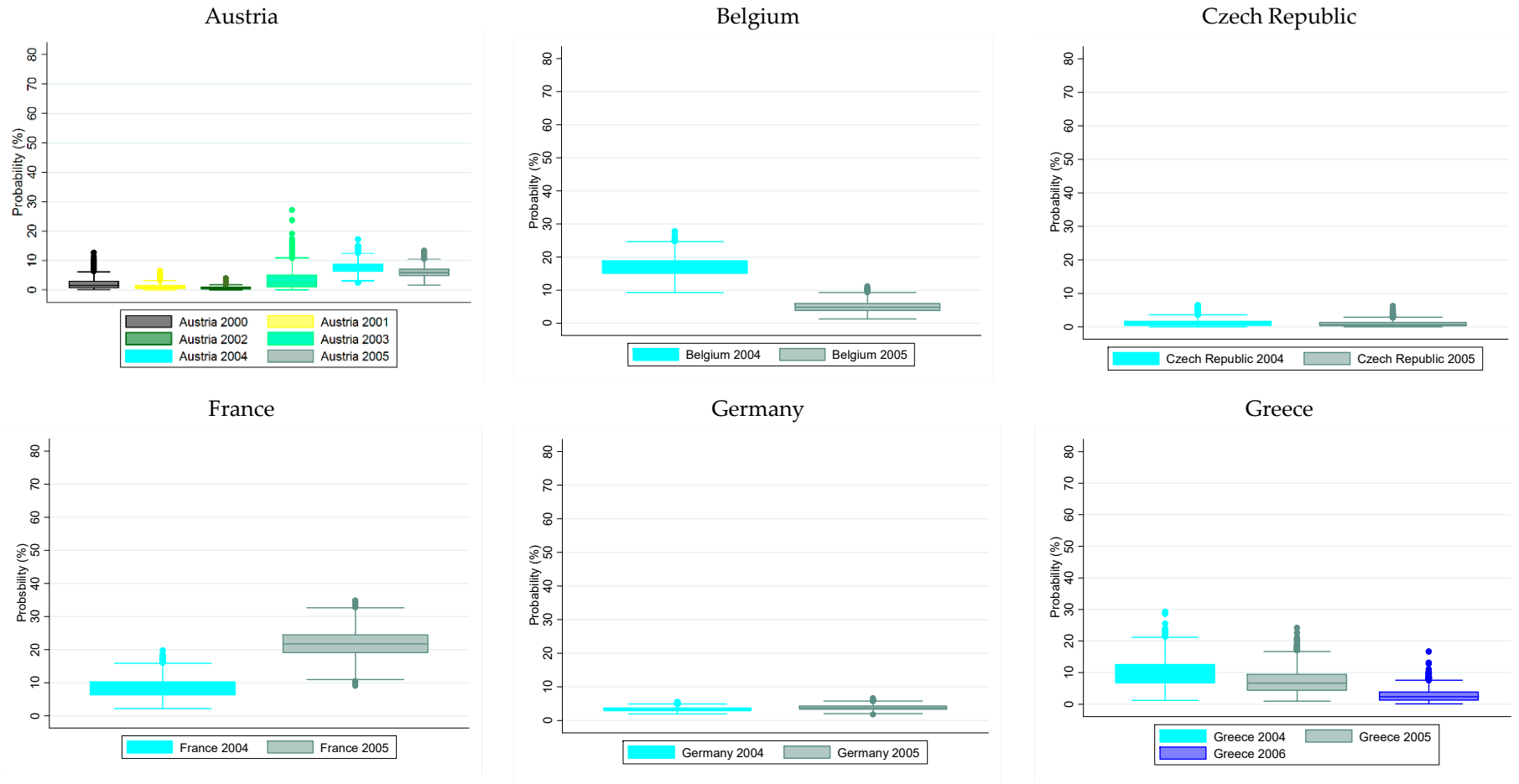
Figure 1. Box-plot of probability of finding non-compliant food products per country and year.

Table 2. Probability of rate of intercepting non-compliant food products being above 5% and 10% per country and year.

Country (Year)	Prob. >5%	Prob. >10%	Country (Year)	Prob. >5%	Prob. >10%
Austria 2000	0.90	0.10	Portugal 2000	8.10	0.40
Austria 2001	8.70	1.60	Portugal 2001	67.60	13.90
Austria 2002	0.00	0.00	Portugal 2002	9.20	0.50
Austria 2004	0.00	0.00	Portugal 2003	2.70	0.10
Austria 2005	0.00	0.00	Portugal 2004	2.90	0.20
Belgium 2004	0.10	0.00	Portugal 2009	28.30	6.20
Belgium 2005	0.00	0.00	Portugal 2010	5.50	0.70
Czech Republic 2004	1.50	0.00	Romania 2011	0.20	0.00
Czech Republic 2005	0.00	0.00	Romania 2012	0.50	0.00
Czech Republic 2010	0.00	0.00	Slovakia 2004	0.00	0.00
Czech Republic 2011	0.00	0.00	Slovakia 2005	0.00	0.00
France 2004	99.10	69.80	Slovenia 2004	0.00	0.00
France 2005	78.20	14.20	Slovenia 2005	0.20	0.00
Germany 2000	0.00	0.00	Spain 2000	0.00	0.00
Germany 2004	0.00	0.00	Spain 2001	0.00	0.00
Germany 2005	0.00	0.00	Spain 2002	0.00	0.00
Greece 2004	16.50	1.90	Sweden 2000	77.50	5.40
Greece 2005	0.00	0.00	Sweden 2002	12.60	0.10
Hungary 2005	2.40	0.00	Sweden 2009	72.30	24.00
Hungary 2010	0.00	0.00	Sweden 2010	88.20	54.70
Hungary 2011	0.00	0.00	UK 2000	1.90	0.00
Italy 2004	0.00	0.00	UK 2001	1.40	0.00
The Netherlands 2004	0.00	0.00	UK 2002	0.00	0.00
The Netherlands 2010	0.30	0.00	UK 2012	0.00	0.00
The Netherlands 2011	0.00	0.00	UK 2013	0.00	0.00
The Netherlands 2012	0.50	0.00			
Poland 2004	0.00	0.00			
Poland 2005	0.00	0.00			
Poland 2010	0.00	0.00			
Poland 2011	0.00	0.00			
Poland 2012	0.20	0.00			

3.2. Feed

We found a higher risk of non-compliance with GMO regulations for the case of feed products compared with food products. Similarly to the food products, the probability of finding non-compliant feed products varies between EU countries and years analyzed. Figure 2 shows box-plots of the probability of finding non-compliant feed products per country and year. The rate of intercepting non-compliant feed products has been as high as 40% on average for Slovenia in 2005. Contrary to what happened in the case of food products, results suggest that the probability of finding non-compliant feed products does not tend to be lower, on average, in later years. Hence, the probability of finding non-compliant feed products was not the lowest in the last year studied for countries such as Austria, France, Germany, Hungary, Poland, Romania, Slovakia and the UK. As in the food products analysis, the level of certainty on these probabilities varies between countries and years with relatively large percentages for some countries and years.



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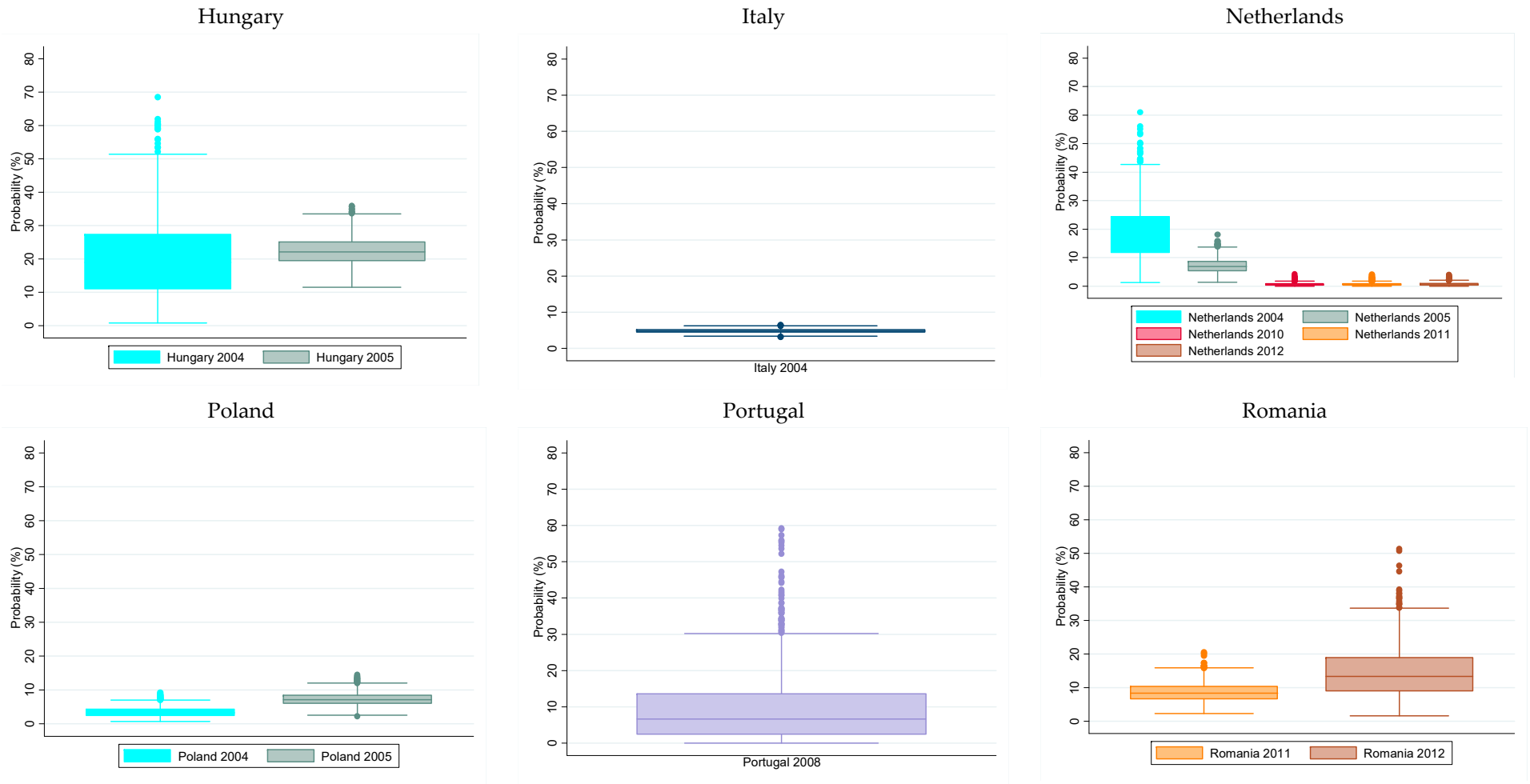

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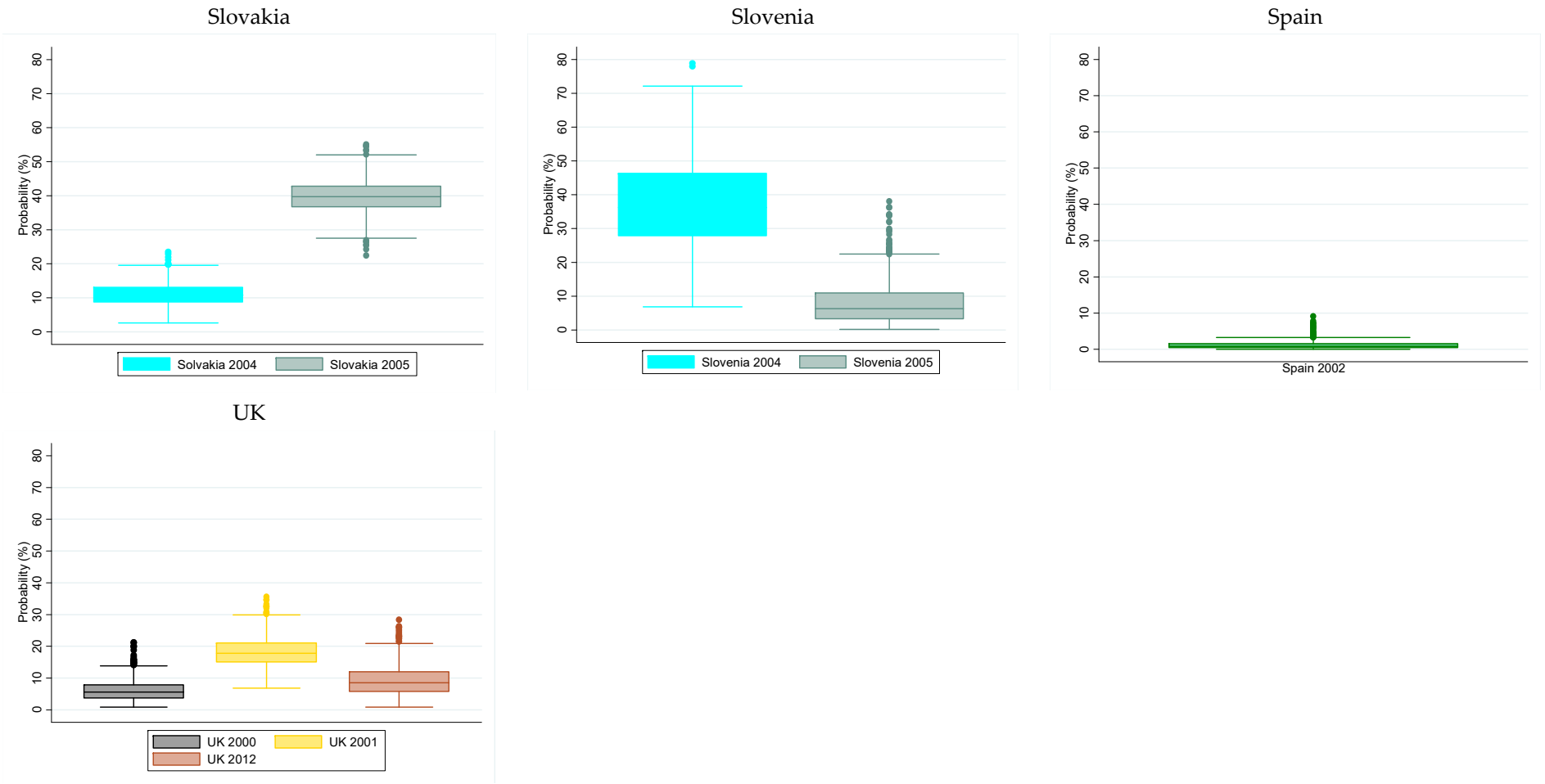

Figure 2. Probability of finding non-compliant feed products per country and year.

Table 3 shows the probability of rate of intercepting non-compliant feed products being above 5% and 10% per country and year. The rate of intercepting non-compliant feed products is relatively high in most of the countries and years studied, with the probability of intercepting GM feed products being above 5%, reaching over 85% for some years in Austria, Belgium, France, Greece, Hungary, The Netherlands, Poland, Portugal, Romania, Slovakia and the UK. Significant improvements seem to have happened in The Netherlands in recent years, where the probability of intercepting non-compliant GM feed products is below 5%.

Table 3. Probability of rate of intercepting non-compliant feed products being above 5% and 10% per country and year.

Country (Year)	Prob. >5%	Prob. >10%	Country (Year)	Prob. >5%	Prob. >10%
Austria 2000	7.60	0.40	Italy 2004	32.20	0.00
Austria 2001	0.80	0.00	The Netherlands 2004	96.70	83.00
Austria 2002	0.00	0.00	The Netherlands 2005	80.40	13.00
Austria 2003	24.60	5.60	The Netherlands 2010	0.00	0.00
Austria 2004	93.40	11.10	The Netherlands 2011	0.00	0.00
Austria 2005	67.40	1.90	The Netherlands 2012	0.00	0.00
Austria 2013	55.90	4.00	Poland 2004	15.10	0.00
Belgium 2004	100.00	99.90	Poland 2005	89.20	8.60
Belgium 2005	45.20	0.70	Portugal 2008	58.00	36.00
Czech Republic 2004	1.30	0.00	Romania 2011	92.80	28.20
Czech Republic 2005	0.40	0.00	Romania 2012	93.90	68.40
France 2004	90.70	27.60	Slovakia 2004	98.40	58.60
France 2005	100.00	99.80	Slovakia 2005	100.0	100.0
Germany 2004	0.60	0.00	Slovenia 2004	100.0	99.40
Germany 2005	6.30	0.00	Slovenia 2005	60.50	29.80
Greece 2004	88.10	45.30	Spain 2002	1.20	0.00
Greece 2005	68.60	21.60	UK 2000	57.50	10.40
Greece 2006	10.70	0.60	UK 2001	100.0	97.80
Hungary 2004	95.70	79.60	UK 2012	81.00	38.10
Hungary 2005	100.00	100.00			

4. Discussion

The findings suggest that increasing the level of inspections and other control measures may lead to an increase in detections of non-compliant GMO presence in both food and feed products in the EU.

The differences found between food and feed products in the probability of intercepting non-compliant GMO presence in a product may be because food derived from animals fed with GM crops is not required to be labelled as GMOs. Hence, there is no incentive for farmers to buy GM-free feed. It is worth noting that the EU is highly dependent on imports of soybeans and soybean meal for feed production. Soybean and soya cake imports by the EU were 17 and 25.3 million tons in 2019, the EU being the second and the first importer worldwide [15]. Considering that approximately 80% of the soya produced worldwide is grown in countries which are major adopters of GM soya—the US, Brazil and Argentina (adoption rates close to 95%) [23]—it is very likely that most of the soybean EU imports are GM. Additionally, food products derived from animals fed with GM feed cannot be detected in the inspections (the DNA of the GM feed is no longer present).

From an economic perspective, the number of inspections carried out to intercept non-compliant GMO presence in food and feed products should increase up to the point where the marginal costs of inspections equal their marginal benefit (i.e., ensuring consumers have freedom of choice of foodstuff with reliable product labelling on the product production process). Marginal benefit (MB) decreases with additional inspections due to the lower additional satisfaction citizenship receives for each new inspection. Marginal costs (MC) rise with additional inspections, since increasing inspections results in more staff conducting such activities and higher management complexity (Figure 3). In order to set risk-based priorities at the policy level, the identification of the optimal level of

inspections to be carried out seems to be an adequate step to implement (i.e., set a number of inspections where resources are neither wasted nor insufficient).

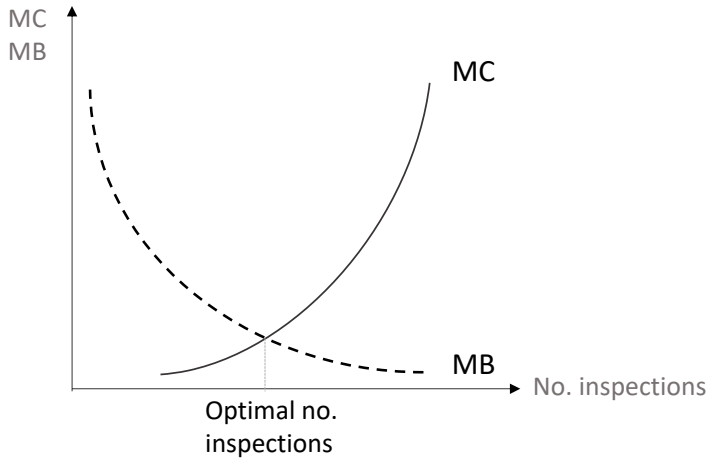

Figure 3. Relationship between marginal benefit and marginal costs of inspections.

Hence, this optimal level of inspections would be the level at which the marginal cost of an extra inspection (including sampling costs) equals the marginal benefit associated with the inspection. If the marginal cost of inspecting and sampling, at a given number of inspections carried out, is relatively high compared to the marginal benefits to consumers of being informed about the presence of GMOs in products, the number of inspections and samples should be reduced (i.e., there is an overuse of resources). By contrast, in case the marginal cost of inspecting and sampling was relatively lower than the marginal benefit, the number of inspections and samples should be increased (i.e., a case when not enough resources are used). The latter case represents a situation where the social value associated with increasing the number of inspections is relatively high compared to the costs associated with such increase.

In other words, under this situation, non-compliant food imports are likely to enter the EU without noticing, and consumers may be consuming food products that contain GMOs without knowing due to the underutilization of control resources. Regarding feed products, this is less of a problem under the current regulation. Since there is no legislation to label products from animals fed with GMOs, the benefits associated with conducting the inspections are zero.

However, neither the regulations on official controls nor regulation on traceability and labelling (Regulation (EC) 1830/2003 and 619/2011) refer specifically to an economic optimal level of inspections. Instead, article 26 of the Regulation (EC) 882/2004 establishes that adequate financial resources (not specifying what adequate actually means) should be available through general taxation, fees or charges established by the competent MS authorities for organizing official controls. The regulation establishes that general taxation, fees and charges should be based on the costs incurred and are to be paid by the operator or their representative to the competent authority in charge of import controls. However, there is no mention about what the level of this control effort must be or what elements/aspects should be considered to achieve it. Finally, the regulation points out that it is appropriate to directly establish the rates for main import items with a view to ensuring the uniform application and to avoid trade distortions; the EU has been challenged on trade distortion grounds by the World Trade Organization (WTO).

Additionally, there are signs in the reports that specify inadequate financial resources may be allocated, at least in some countries, to ensuring EU consumers have freedom of choice of foodstuff. Thus, the official report from Portugal in 2005 pointed out that "the number of inspections planned and carried out for traceability and sampling for the analyses of GMO in food and feed, is very limited due to lack of human resources ...

the allocation of limited human and financial resources only allows a very small amount of inspections and analysis of samples to be planned and carried out resulting in limited implementation of EU legislation". In the 2003 UK report, it is stated that: "Due to high analysis costs and budgetary constraints on Local Authorities, there is a tendency to focus primarily on documentary checks. The number of samples taken annually both of domestic and imported foodstuffs is very limited". Results for the UK for the most recent years suggest that no more inspections are needed for food products but more are still needed for feed products. It seems clear that no economic perspective is taken when conducting analysis and recommendations on the level of inspections. For instance, in the 2006 Hungarian report, it is detailed that "The ratio of sampling for soya and maize products is adequate given the import ration of the two". The ratio of sampling should be linked to the marginal costs and benefits associated with carrying out inspections. The probability of finding non-authorized presence of GMOs in food and feed in 2005 in Hungary—2.5% and 22%, respectively—suggests that benefits could be gained from increased detection efforts. With regard to the sampling of feed products, the Hungarian report points out that "The plan sufficiently covers the main products potentially containing GMO and directs sampling towards products on the market and products to be imported" but concludes that "Overall, in Hungary there is an acceptable system in place for the implementation of Regulations (EC) 1829/2003 and 1830/2003. However, deficiencies were noted in particular with regard controls on import of GMO product, and the adventitious presence of GMO in food and feed and seed". Other countries such as Belgium in their 2006 report did not raise any concerns despite the probability of intercepting GM feed products being relatively high (>10% in 2004): "Overall, there is a good system in place for official controls within the scope of Regulation (EC) 1829/2003 and 1830/2003. Controls were well planned and executed, inspectors were aware of the applicable legislation concerning labelling and traceability of GMO in food and feed. Where non-compliances were found appropriate follow-up measures were taken."

Outside the EU, similar results to the ones obtained here have been found. In South Africa, according to a study conducted to determine the extent of products that would be impacted by mandatory GMO labelling, a total of 23 out of 46 off-the-shelf food products tested positive, with a GM content ranging from 0.02% to 97% [22]. In Turkey, it was found that GM soya is present in the Turkish food and feed industry and there is non-compliance with current labelling requirements (in Turkey, approved GM items are allowed to be imported requiring labelling of food products containing >0.9% GM ingredients, as in the EU) [21].

Since GM crop production is expected to keep growing due to the adoption of GM crops by more countries and new GM traits [24,25], optimal levels of resources allocated to inspections become even more important.

5. Conclusions

Although having a 100% certainty that there is not non-labelled GM food and feed products in the EU market may be an unrealistic aim, some of the probabilities shown here seem to be beyond what European consumers may believe to be an acceptable probability of products containing above the authorized GM content.

The uncertainty about products being correctly labelled raises two interlinked questions: (1) *Do European consumers have freedom of choice in food products?* and (2) *Is public money allocated to this policy well spent?* We found that the implementation of the regulatory framework on genetically modified (GM) food and feed in the European Union (EU) did not ensure the basic interest for consumers of having freedom of choice of foodstuff. Consumers are likely to be provided with misleading information, since it is possible that they are purchasing products containing ingredients derived from GMOs and not being labelled accordingly to the regulatory framework. We conclude that (a) it was likely that EU consumers have been misinformed about whether food and feed products contain any GMOs and (b) the lack of incentives for achieving an optimal level of control inspections

is probably partially down. This latter issue is a consequence that consumers, the main benefiters of the policy, are unaware of whether the optimal number of controls is in place or whether there is a probability that what they are consuming contains GMOs and has not been labelled accordingly.

Results shown here bring into question the effectiveness of the implementation of the European regulation on GMOs up to now. We acknowledge that the new Regulation (Regulation (EC) 2017/625) on official controls and other official activities, performed to ensure the application of food and feed law, rules on animal health and welfare, plant health and plant protection products, most of which came into force on 14 December 2019, establishes that the EC needs to ensure a minimum level of official controls to prevent the presence in the agro-food chain of GMOs for food and feed production and of GM food and feed, which have not been authorized.

According to the results shown in this paper, the implementation of the regulation must be focused not only on the minimum but on the optimal number of controls per country, considering the probability of finding non-compliant products. Determining the optimal number of controls requires detailed information by EU country on (i) the benefit of consumers for reducing the risk of consuming non-compliant products on GMO regulation and (ii) the costs of increasing inspections (i.e., public money allocated for such task). Unfortunately, such information is not currently available by country.

Finally, regarding the practical implementation of the optimal level of control, it is worth mentioning that the criteria to determine the optimal number of inspections may not only be based on the average marginal benefits and costs per country but include information on the level of certainty about these. Hence, we would obtain not just a curve as shown in Figure 3, but an area of the optimal number of inspections from which decision makers would have to select the optimum level of inspections.

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Appendix A

Table A1. Sample and number of detections per country and year for feed *.

	2000	2001	2002	2003	2004	2005	2006	2008	2010	2011	2012	2013
Austria	35 (0)	73 (0)	155 (0)	16 (0)	196 (15)	164 (10)						89 (5)
Belgium					183 (32)	160 (8)						
Czech Republic					62 (0)	92 (0)						
France					79 (7)	99 (22)						
Germany					983 (33)	630 (24)						
Greece					38 (4)	40 (3)	53 (1)					
Hungary					8 (2)	20 (86)						
Italy					79 (1652)							
The Netherlands					14 (3)	94 (7)			143 (0)	160 (0)	137 (0)	
Poland					5 (146)	13 (176)						
Portugal								0 (3)				
Romania										8 (90)	3 (18)	
Slovakia					86 (10)	93 (38)						
Slovenia					11 (5)	14 (1)						
Spain				79 (0)								
UK	50 (3)	69 (13)									31 (3)	

* Detections of non-compliant feed products are shown in brackets.

Table A2. Sample and number of detections per country and year for food *.

	2000	2001	2002	2003	2004	2005	2009	2010	2011	2012	2013
Austria	41 (0)	12 (0)	88 (0)		241 (2)	242 (0)					
Belgium					132 (1)	171 (0)					
Czech Republic					133 (3)	173 (0)		163 (0)	97 (0)		
France					69 (10)	82 (7)					
Germany	612 (8)				5265 (67)	5887 (60)					
Greece					47 (2)	477 (8)					
Hungary						169 (5)		437 (0)	402 (0)		
Italy					891 (13)						
The Netherlands					258 (2)			237 (5)	137 (0)	90 (1)	
Poland					734 (9)	709 (6)		633 (4)	597 (4)	283 (7)	
Portugal	38 (1)	60 (5)	38 (1)	33 (0)	30 (0)		16 (1)	19 (0)			
Romania									636 (19)	126 (2)	
Slovakia					225 (1)	257 (0)					
Slovenia					165 (1)	172 (3)					
Spain	145 (0)	125 (0)	84 (0)								
Sweden					149 (11)	106 (4)	39 (4)	24 (4)			
UK	130 (3)	142 (3)	87 (0)							301 (0)	216 (0)

* Detections of non-compliant food products are shown in brackets.

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