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International evidence

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Are veterinary drug maximum residue limits protectionist? International evidence

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Highlights

- Codex covers a small fraction of MRLs for veterinary drug-commodity-product pairs.
- Countries tend to converge to Codex MRLs and regulatory variation is lower for veterinary drugs when an international standard exists.
- Increasing the institutional capacity of Codex Alimentarius for establishing a larger set of MRLs could reduce the heterogeneity of MRLs across countries.

Abstract: We analyze the distribution of maximum residue limits (MRLs) on veterinary drugs used in animal production and aquaculture in a global context of food consumption and trade. We compare MRLs by drug–commodity pairs for a large set of countries, commodities, and drugs. We find that international standards by Codex Alimentarius only cover a small fraction of the drug-commodity pairs. We compare countries' MRLs to Codex MRLs when they exist and look at potential deviations from the science-based MRLs in either direction (more or less stringent than Codex). For drugs without Codex standard, we look at deviation from median values. When Codex MRLs exist, variation and stringency above codex MRLs are minimal, a somewhat surprising and hopeful finding. Little protectionism prevails when a Codex standard exists. We find higher variation when Codex standards do not exist. We test for significant differences in MRL variation for cases with and without a Codex MRL and find robust evidence of higher variation for the latter. Increasing the institutional capacity of Codex for establishing a larger set of MRLs would reduce the heterogeneity of MRLs across countries.

Keywords: Maximum Residue Limits (MRLs), Livestock, Meat, Veterinary Drugs, Trade, Protectionism, Codex

JEL Codes: Q17, F13, I18

Introduction

Member countries of the World Trade Organization (WTO) are expected to abide by its Sanitary and Phytosanitary Standards (SPS) Agreement. The Agreement requires SPS policies to be science-based with an underlying scientific risk assessment. If the science is not established, countries can invoke the precautionary principle which allows for temporary limits or ban while the science is underway. The SPS agreement encourages (but does not require) countries to follow international standards such as those established by the Codex Alimentarius Commission (Codex hereafter).[1] Further, policies addressing SPS risks must be least-trade restrictive, that is, not impede trade unnecessarily to prevent protectionism (World Trade Organization 2023).

Maximum Residue Limits (MRLs) for pesticides, contaminants, and veterinary drugs are important SPS measures that set the maximum amount of a residue that is allowable in any edible food item. Veterinary drugs, on which we focus here, are particularly important for meat, poultry, and aquaculture product markets and international trade. The scientific health risk assessments are reviewed by regulatory bodies within each country to determine a country-specific MRL for drug-food item pairs that would not cause harm to human, animal and/or environmental health. Each established MRL is specific to a drug-commodity-product pair (e.g., amoxicillin-beef-liver).

Some countries, lacking the expertise, defer to other countries or Codex to set MRLs. Establishing MRLs for each drug in all edible animal tissues is economically burdensome for many countries, particularly for developing nations (Handford et al. 2015). Additionally, differences in regulations between countries lead to trade frictions among trading partners

[1]The Codex Alimentarius Commission is a Joint commission of the Food Agriculture Organization and World Health Organization that establishes the scientific standards for veterinary drugs, pesticides and contaminants used in food animal and plant production.

(Thilmany and Barrett 1997; Disdier et al. 2008; Disdier and van Tongeren 2010). This regulatory heterogeneity requires producers in exporting countries to bear the additional costs of complying with regulations that vary from one origin country to another (Beghin and Schweizer 2020). International entities like Codex formulate global scientific standards for drug residues in livestock, poultry, and aquaculture, as well as for pesticides and contaminants in food crops (USITC, 2020).

The objective of this paper is to characterize and quantify the prevalence of veterinary-drug MRLs for livestock, poultry, and aquaculture products for a large set of countries with respect to each drug-commodity-product pairing using a large MRL database maintained for USDA–FAS. We distinguish between cases where 1) both countries MRLs and international standard are established and 2) when only the countries MRLs are established. When both a country and international MRL exist, we assess the relative stringency, laxity, and alignment of a country's MRL with the international standard. When no international MRL exists, we use the median of countries' MRLs as a pseudo standard. The median MRL is a resistant central drug-commodity-product MRL value which allows us to gauge stringency, laxity, and alignment to the pseudo-world standard. We then develop a singular MRL-factor $(1 + MRL)$ based index that aggregates proportional differences in MRL factors and examine their distribution. We undertake robustness checks by considering a larger range of values for the pseudo-standards, beyond the median.

The literature has characterized the stringency of regulations for food crops. Several stringency indices have been constructed to aggregate food regulation of different nature (Kox and Lejour 2005; Berden et al. 2009; Rau et al. 2010; Burnquist et al. 2011; Winchester et al. 2012). Others have used a single index focused on quantitative food regulation such as the MRLs

(Achterbosch et al. 2009; Drogué and DeMaria 2012; Li and Beghin 2014; Xiong and Beghin, 2014; Hejazi et al. 2022). Some previous studies have focused on a single drug/pesticide using the importers' MRL (Otsuki, et al. 2001; Wilson, et al. 2003; Wilson and Otsuki; 2004).

Our index builds upon the single-index approach, providing a measure of stringency that accommodates all drugs including drugs classified as banned or undetectable by Codex or individual countries implying a zero MRL tolerance. It also accommodates drug-commodity-product pairs for which drugs have been exempted from MRLs by Codex but are still regulated by countries. [2] Finally, we consider drug-commodity-product pairs for which international standards do not exist. Our index is unitless and decreasing in stringency.

We find that New Zealand, South Africa, and Japan have the largest coverage, regulating the most drug-commodity-product pairs. Cattle, swine, chicken, and sheep are the most regulated production systems with the largest set of MRLs. Milk from cattle and edible tissues from cattle have the highest coverage (22%) relative to the potential maximum pairs for each commodity. Muscle, liver, and kidney are edible tissues with the largest set of MRLs. Codex MRLs cover 3.8% of the full set of existing and potential drug-commodity-product pairs, and 27% of existing MRLs, a relatively small fraction of the pairs.

The stringency estimation shows that when Codex MRLs exist, 88% of drug-commodity-product pair MRLs comply with Codex. Eight percent of pairs are more stringent than Codex and three percent are laxer than Codex. The drug-commodity-product pairs with missing MRLs whose stringency cannot be established (i.e., "unknown") is one percent.[3] Conversely, when

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[2]Exempt drug-commodity-product pairs are pairs in which residues in edible animal tissues from the use of the drugs combined with good production management are not likely to pose a health risk to human health. Animal farm management practices include the provision of clean water, cleanliness of the farm environment and tools, and good animal stress management (Singh 2014).

[3]See the Empirical Method section for these cases of missing numerical values.

international standards do not exist, country-level "compliance" with the median MRL is 65% with nine percent of the pair MRLs being more stringent than the median MRLs and 19% being laxer. The drug-commodity-product pairs with MRL missing numerical values whose stringency cannot be established (i.e., "unknown") is seven percent.

Three stylized facts emerge. First, when international standards exist, countries tend to align with Codex. Second, the dispersion of MRLs for which the Codex MRL exists is narrower than that of MRLs without a Codex MRL. Tails around the Codex standard are smaller than those for pairs without a Codex standard. Last, drug-commodity-product pairs whose MRLs are missing is lower when international standards exist compared to when they do not exist.[4]

The alignment to Codex is in contrast to findings on pesticide and contaminant MRLs for which stringency is often higher than Codex, especially among high-income countries (Li and Beghin 2014; Otsuki et al., 2001). The alignment To Codex MRLs when they exist suggests that Codex can facilitate, if not provide, harmonization for food regulation related to drug residues in the meat, poultry, and aquaculture markets. The compliance with Codex MRLs across countries also implies that in these markets, exporters do not face heterogeneous production costs varying by destination markets related to these MRLs. The wider dispersion of MRLs without Codex standards implies trade frictions. Enabling Codex to establish a larger set of international MRLs for veterinary drugs for more products would likely reduce the current heterogeneity across countries when international standards do not exist and consequently reduce trade frictions.

Empirical Method

To examine the stringency of regulations of veterinary drugs across countries, we construct an MRL-based index that measures stringency in proportional deviation from a central value, the

[4]Missing pair MRLs as per USITC (2020) refer to when a drug–commodity–product pair MRL for a country is not in the database, and the MRL type is not categorized as Exempt.

codex value of the MRL, or in its absence, a median value across countries serving as a pseudo-standard. The index is quantitative and has desired properties allowing for comparison of stringency across countries, commodity groups, commodities, and drugs. Our indices, under different aggregations, allow for characterizing a country's policy as protectionist if systematic and stricter deviations from the international standards are observed and reflected in the index' values.

A veterinary drug MRL index

The index is a single–policy instrument (i.e., MRL) incorporates two supplemental considerations. Several vet drugs are categorized by Codex under risk management recommendation (RMR) and in many countries constrained to be "not detectable" or banned outrightly, implying a zero MRL. In this case, one cannot take a proportional deviation from the Codex MRL (division by zero or ratios of zeros). We use a factor of the MRL, $(1 + MRL)$, which allows us to compute proportional deviations (in factors) albeit with a small bias. Second, some safe drugs are exempted by Codex to have an MRL (an implicit unbounded MRL). In the latter case, any set MRL on such drug would be protectionist. To accommodate this case, we take a supremum, larger (by 10%) than the maximum observed values across countries for the exempted drug-commodity-product pairs and use that as the "most lenient" MRL. This implies a small bias as well since it is still an MRL when none is required, but this approach allows a comparison and ranking of countries' stringency and protectionism in these safe drugs. The computed index under exempted drugs still provides a useful characterization and ordering of countries when they deviate from lenient MRLs for exempted drugs.

Our index is unitless, but it is influenced by scale because we use factors $(1 + MRL)$ rather than MRLs. Hence, there is a tradeoff in which we increase the MRL coverage of important drugs with health significance given the toxicity of their residues, at the cost of not being scale-independent. The use of proportional deviations in MRL factors rather than proportional differences in MRL implies that the aggregation of deviations puts more weight on drugs with higher reference MRL levels. Finally, we account for MRLs for which international standards do not exist using a robust central value of observed drug-commodity-product pair MRLs as a pseudo reference standard.

The index leads to different aggregations across drug-commodity-product pairs to compare the stringency between commodities, across drugs, commodity groups, and countries. The reference MRL factor uses the science-based MRL when Codex MRL exists and the pair's median MRL across countries when Codex MRL does not exist. The MRL-factor-based proportional variation, PV, is defined as:

$$PV_{cdxp} = \frac{(1 + MRL_{ref_{cdxp}}) - (1 + MRL_{cdxp})}{(1 + MRL_{ref_{cdxp}})} \tag{1}$$

where $c = 1, \dots, C$ countries, $d = 1, \dots, D$ drugs, $x = 1, \dots, X$ commodities, and $p = 1, \dots, P$ products.[5] $(1 + MRL_{ref_{cdxp}})$ is the reference MRL against which a country pair stringency is measured. It is $(1 + MRL_{codex_{cdxp}})$ when Codex MRL exists, and $(1 + MRL_{median_{cdxp}})$ otherwise.

When the $\left\{(1 + MRL_{ref_{cdxp}}) - (1 + MRL_{cdxp})\right\} = 0$, the country is compliant; when $\left\{(1 + MRL_{ref_{cdxp}}) - (1 + MRL_{cdxp})\right\} > 0$, the country is more stringent; and when $\left\{(1 + MRL_{ref_{cdxp}}) - (1 + MRL_{cdxp})\right\} < 0$, the country is laxer in regulating the drug-commodity-product pair.

[5]Products and drugs are country specific. Not all countries regulate the full set of drug-commodity pairs.

There are three cases for which Codex and country–level pairs MRLs are not directly characterized by a numerical value: RMR/banned/undetectable drugs implying a zero MRL, drug-commodity-product pairs categorized as Exempt implying an unbounded MRL, and missing MRLs for some other pairs not included in the RMR or Exempt sets. For RMR drugs, we replace the missing MRLs with zero to be consistent with their undetectable residue status. For countries that defer to other countries or Codex in this case (e.g., Cameroon deferring to Codex), we also replace the missing MRLs with zero. Countries whose pair MRLs are zero are considered to be compliant with Codex and countries with MRLs higher than zero are laxer than Codex.

For Exempt drugs, we replace the missing MRLs in both countries and Codex with a supremum exceeding the maximum MRL observed of each drug–commodity–product pair across all countries. To set an MRL for an exempt drug implies being more stringent than Codex. Hence, we establish a supremum by choosing the largest observed MRL for that particular drug–commodity–product pair and scaled by 10% to reflect the highest level of laxity in a case when setting an MRL is unnecessary.[6] For these exempted drugs, missing MRLs in the dataset are set to the supremum and are considered compliant. Pairs whose MRLs are lower than the MRL-factor supremum are considered more stringent.

For drug–commodity–product pairs whose MRLs are truly missing and not involving RMR or Exempt drugs or deferrals, are assumed not to be defined by the countries. Several reasons could lead to such missing MRLs: country's production systems may not use the drug, or

[6]Suppose the maximum of an exempt pair is 100ppb and a country has an existing MRL of 100ppb, the country pair would be considered as compliant. Hence, by adjusting the supremum MRL by 10%, we are able to maintain the more stringent status of such country pair relative to exempted drug under Codex.

there is lack of expertise for setting a science-based MRL. In this case, stringency of the drug–commodity–product pairs cannot be ascertained. We categorize such pairs as “unknown.”

<u>Aggregation of proportional variation estimation</u>

To examine the overall stringency of MRL regulation, we aggregate the proportional variations of MRL factors into indices. To estimate aggregate proportional variations in MRL factors by country, commodity, product, and drug, we propose the following sub-level aggregation indices:

$$M_c = \frac{1}{N_c}\sum_{d=1}^{D}\sum_{x=1}^{X}\sum_{p=1}^{P} PV_{cdxp}, \tag{2}$$

$$M_x = \frac{1}{N_x}\sum_{c=1}^{C}\sum_{d=1}^{D}\sum_{p=1}^{P} PV_{cdxp}, \tag{3}$$

$$M_p = \frac{1}{N_p}\sum_{c=1}^{C}\sum_{d=1}^{D} PV_{cdxp}, \tag{4}$$

$$M_d = \frac{1}{N_d}\sum_{c=1}^{C}\sum_{x=1}^{X}\sum_{p=1}^{P} PV_{cdxp}, \tag{5}$$

where N_i is the number of observations across countries $(i = c)$, commodity $(i = x)$, product $(i = p)$ and drugs $(i = d)$. M_c, M_x, M_p, M_d are sub-level aggregation for each country, commodity, product, and drug respectively. Other variables remain as defined in equation (1). For instance, when a country is compliant with the reference MRL across all its drug-commodity-product pairs, its aggregate stringency variation $M_c = 0$. When all countries align with reference MRLs across all commodities, $M_d = 0$.

We compute the aggregation for the two subsets of $(1 + MRL_{ref_{cdxp}})$: the general case of when Codex MRL exists (explained later in the data section), and when Codex MRL does not exist. This allows us to compare the distribution of variations under these two regulatory regimes.

Statistical test and robustness checks

In the absence of Codex standards, it is important to understand patterns of MRL setting by policymakers and regulatory institutions in various countries. A greater heterogeneity of MRLs in the absence of Codex MRLs would have implications for the cost of meat, poultry, and aquaculture production and trade. The absence of international standards could be detrimental to economic exchange and human welfare through over- or under-protecting drugs that pose a potential health risk.

To identify differences in MRL setting when international standards exist and otherwise, we compute separate indices for these two subsets of MRLs. We then test for statistical differences between the frequencies of stringency categories (compliant, stringent, or lax) when Codex MRLs do and do not exist, using a chi-square test. We also test statistical differences between the proportional variation in MRL factors by aggregation (country, commodity, product, and drug) for each stringency category when MRLs do and do not exist, using a student t-test.

We conduct several robustness checks to determine how sensitive our results are to the assumptions made. In our first robustness check, we allow for a wider range of reference MRLs (pseudo standard) in absence of Codex. For this robustness check, we test the sensitivity of our results to a wider range of central values (Median MRL value ±5%, ±10%, and ±25%).

In our second robustness check, we compare the proportional variation in the MRL factor when we do and do not include countries that defer their drug-commodity-product MRL to the European Union (EU) or the United States (US) drug-commodity-product MRL. Not accounting for deferral countries could bias results or their presence could inflate the influence of EU or US standards. We compare the results for the case when Codex MRLs exist and otherwise.

In our third robustness check, we use higher-order distributional moments to compare the stringency variation obtained with our MRL–factor–based index to the variation obtained with a proportional-deviations index that is scale-independent. The latter implies that the pairs whose reference MRLs are zeros and ratios of zeros are excluded from the dataset. This excludes RMR/banned/undetectable drugs and pairs with zero ($MRL_{ref_{cdxp}}$) but allows us to explore the possible implications of the scale dependence using MRL factors rather than the MRLs.

Data

The veterinary drug MRLs database for the year 2020 was purchased from the FoodChain ID Group, Inc and generated 9/11/2020. It includes Codex MRLs as the international science–based standards. The database for our investigation covers MRLs for 406 veterinary drugs, 60 commodities, 164 products for 88 countries and Codex.

The MRL type is categorized as Default, Exempt, and General. The database has 452,859 records with 66,584 drug-commodity-product pairs.[7] There are international standards established by Codex for 3,341 drug-commodity-product pairs. However, there are duplicates of pairs in country and Codex. For instance, for cattle fat, Codex has two MRLs for carbadox both with the general MRL and MRL value of zero (Carbadox is an RMR drug). Removing these duplicate pairs in Codex leaves 2,513 unique Codex drug-commodity-product pairs. Similarly, New Zealand has 20 duplicate pairs which are removed.[8]

[7]Not all drugs are used in every production system. This implies that the feasible dataset has a unique combination of drug and product.
[8]For duplicate pairs we take the minimum of the two pairs.

The European Union (EU), the Gulf Cooperation Council (GGC), and the Eurasian Economic Union (EEAU) are treated as independent countries. We adjust the dataset for countries whose deferral information are available. Forty-one countries fully defer to Codex, five countries fully/partially defer to the US, and six fully/partially defer to the EU.[9] Primarily, Panama and Uruguay defer to Codex MRLs. However, when the MRL for a drug–commodity–product pair is not set by Codex, Panama defers to the lowest pair MRL between the US and the EU. In this case, Uruguay defers to the EU first and then to the US for MRL pairs not regulated by the EU. The drug–commodity–product pair MRLs of the Codex, EU and US are replicated for their deferral countries.

Based on the drug–commodity-products dimension across all countries (88x406x164), the potential global pair record would be 5,859,392 pairs. Codex has set MRLs for about 27% of the total drug-commodity-product pairs across countries. However, many drug-commodity pairs do not exist.[10]

Data treatment

There are drug–commodity–product pairs whose MRLs are missing either by country, Codex, or both. The three cases of missing MRLs were discussed extensively earlier in the method section. Based on available information, we account for some of the missing pair MRLs as explained above for exempt and RMR drugs.[11] Japan and China have "not detectable" policy on 20 and 7 drugs, respectively. Drug–commodity–product pairs are not available in the database for many countries. Thus, 5,409,874 pairs are dropped. The final database has 676,798 pairs. We do not

[9]See Table A1 in Appendix A for list of full deferral countries.
[10]Feasible dataset contains unique combination of commodity and product. For instance, cattle have five products (i.e., cattle edible offal, cattle fat, cattle kidney, cattle liver, and cattle muscle). Whereas there are commodities with one product (e.g., Barramundi).
[11]See Table A2 in Appendix A for list of Codex exempt drug–commodity–product pairs. And Table A3 for list of RMR and banned drugs.

account for non-approved and/or banned drugs where information is not available. We summarize the data processing flow in a chart presented in Figure 1.

<Figure 1 here>

Stringency estimation of country-level MRLs

Based on the setup of the database (see Figure 1), the MRLs are separated into two categories. The first category “Codex MRL exist” is when a Codex MRL exists for country pairs and the second category “No Codex MRL” is when Codex MRLs do not exist for country pairs which we also refer to as “non-specified” pairs. The “non-specified” set contains 491,631 drug–commodity–product pairs. Of these, there are 25,976 pairs with missing MRLs and are categorized as “unknown”. Hence, we have 465,655 drug–commodity–product country-level pairs with numerical MRLs that we compare with the median pair MRLs.

When Codex MRL exists, we further divide this into two sub-categories: special cases (104,875 pairs) and general cases (80,292 pairs). These are drug–commodity–product pairs for which both country and Codex MRLs exist. The general case contains drug–commodity–product pairs for which there are no exclusive considerations. The special cases are the RMR and Exempt drugs previously mentioned. The special cases have truncated distributions since they are set at the two bounds of the range of possible MRLs (zero for RMR, and supremum for exempted drugs).

Exempting tolerance residue level of a veterinary drug in a food animal product strongly suggests the regulation of such drug for use in animal health should not lead to any friction in international trade of the concerned food animal product(s). At the opposite end of the spectrum however, residues of RMR/banned/undetectable drugs should not be found in livestock, poultry, and aquaculture products. A detectable level would legitimately hinder trade. The special–case

MRLs, because of their truncated distributions, are not included beyond the analysis comparing the frequencies of MRL stringency. These comparisons are based on general cases when Codex MRLs exist and "non–specified" when they do not exist.

Summary statistics

Based on BACI data, in 2020, 84 out of 88 countries in the MRL database traded at least one of the 164 commodities and accounted for about 90.6% of the total trade value.[12] The EU–27 ($69.0bn), the United States ($19.1bn), and China ($16.2bn) account for about 60% of the total trade. For exports, the EU–27 ($33.8bn), Brazil ($7.0bn), and the United States ($6.8bn) are the top three countries. India ranks 4th ($4.95bn), New Zealand ranks 12th ($2.04bn) and South Africa ($0.22bn) is the African country with the highest export from the continent. For imports, the EU–27 ($35.2bn), China ($13.4bn), and the United States ($12.3bn) are the top three markets. Following are Japan ($4.84bn), the Gulf Cooperation Council ($4.82bn), the United Kingdom ($3.9bn), Hong Kong ($3.3bn) and South Korea (2.7bn).

A high volume of exports and/or imports could incentivize countries to set regulations to ensure a similar quality of products crossing their borders as that produced domestically. For example, New Zealand, South Africa, and Japan rank highest by the number of drug–commodity–product pairs regulated and percentage coverage of drug–commodity–product pairs (see Appendix B Figure B1 for details) and are major exporters of meat and dairy products (Vinci 2022). For meat and dairy products, there is a high volume of trade despite a high number of official SPS notifications and trade frictions reflected in SPS concerns at the WTO (Disdier and van Tongeren 2010).

[12] 2020 BACI data for HS 07 trade values for commodities in the MRL database.

Cattle (edible offal, tissues, and organs), swine, and chicken commodities are the most regulated in the global meat market in terms of number of drug–commodity–product MRL pairs. (see Appendix B Figure B2). Meat and dairy products account for 52% and 32% of international trade in food animal products, respectively (Chatellier 2021). Milk products from cattle, buffalo, and sheep account for 97% of milk produced globally, suggesting why they are highly regulated (FAO 2023). In terms of coverage, milk from cattle has the highest coverage of country–drug–commodity pairs of 22%.

Muscle, kidney, and liver have the largest set of drug–commodity–product MRLs (see Appendix B Figure B3 for details). Fat and muscle have the highest coverage across all countries, drugs and commodities. Their coverage is approximately 14% of potential maximum pairs.[13] The level of MRL coverage for muscle, kidney, and liver is not surprising. Intramuscular is a major route of administration of drugs in animal production and the liver is the organ that is responsible for body detoxification. Thus, there is a high potential for drug residue accumulation in these products.

Results on Stringency

When an international standard exists

Table 1 summarizes the number of drug–commodity–product pair MRLs across all countries by their alignment with Codex. We examine whether the pair MRLs are compliant with, more stringent, or laxer than Codex MRLs. When a Codex MRL exists, approximately 57% of the drug–commodity–product MRLs are special–case pairs, and 43% are categorized as general case. Exempt and RMR are two special cases under Codex.

<Table 1 here>

[13]Note that all drugs do not apply to all commodity-product pairs.

RMR

Drugs categorized as RMR by Codex should have zero drug residue detectable in animal edible tissues. Approximately 85% of drug–commodity-product MRLs are compliant (i.e., country pair MRL = 0 and Codex RMR = 0). Surprisingly, approximately 6% of the country–level MRLs for RMR drugs are laxer than Codex (MRL > 0 and Codex RMR = 0). This implies that some countries choose to allow a detectable level of residue for drugs that have been shown to be carcinogenic and present a possibility of dangerous food safety issues within the context of “One Health”. The drug–commodity–product pairs with missing MRLs whose stringency cannot be established (i.e., “unknown”) in the RMR special case are 9%.

Exempt

For Exempt drug–commodity, approximately 81% of drug–commodity–product MRLs are compliant (i.e., country pair MRL = Codex Exempt). Surprisingly, 19% of drug–commodity–product pairs are more stringent than the international standard. This implies that a country has chosen to place an MRL on a drug–commodity–product pair deemed “non-harmful”. This imposes additional production costs on the producers of an exporting country whose MRL aligns with Codex in these drug–commodity–product pairs and trades with a destination country where such pairs have established MRLs.

General case

Beyond the two special cases, approximately 88% of all drug–commodity–product pairs are compliant with Codex (country MRL = Codex General MRL); 8% are more stringent than Codex (country MRL < Codex General MRL); and 3% are laxer than Codex (country MRL > Codex General MRL). The pairs with missing MRLs whose stringency cannot be established (i.e., “unknown”) are 1%. This high level of compliance with Codex across countries in veterinary drug regulation is contrary to what was found with pesticide and contaminant MRLs in food items. The latter tend to be more stringent than Codex and heterogeneous among countries (Li and Beghin 2014; Handford et al. 2015, Otsuki et al. 2001). This compliance finding for veterinary drugs MRLs is surprising and unexpected as departing from Codex can procure some strategic advantages and/or protect domestic industries.

Food trade and market competitiveness are impacted when MRLs are heterogenous across trading partners (USITC 2020). Cost of production is increasing in stringency and heterogenous standards across destinations could compromise scale economies. Conversely, domestic stringency beyond Codex presents the market with perceived higher quality and safer food animal products, and a strategic exporter advantage to have a larger market share among the exporting countries. The potential loss of profit from lowering the domestic standard incentivizes non-alignment with international standards (Barrett and Yang 2001). Nevertheless, these cases of excess stringency seem to be few with drug residues.

When international standards do not exist

Almost 73% of the drug–commodity–product MRLs across all countries lack an international standard. Further, approximately 5% of these drug–commodity–product pairs are categorized as "unknown" (i.e., their MRLs are missing and the nature of stringency of the pairs cannot be established). These "unknown" pairs are excluded from further analysis.

We compare the country-level drug–commodity–product MRL to the pseudo standard of the median MRL of each drug–commodity–product combination. Country "compliance" with the pseudo-standard is 68% (i.e., country MRL = median MRL). Approximately 12% percent of drug–commodity–product pair MRLs are stringent (i.e., country MRL < median MRL), and 15% drug–commodity–product pairs are laxer (i.e., country MRL > median MRL) (see Table 1).

Comparing the MRL statistics with and without Codex, the percentage of drug–commodity–product pairs that are compliant is higher when Codex MRLs exist (88%) than when Codex MRLs do not exist (68%). Fewer drug–commodity–product pairs are laxer when Codex MRL exists (3%) than when they do not exist (15%). Fewer pair MRLs are missing when Codex MRLs exist (1%) than when they do not exist (5%). There are two possible and non-exhaustive conjectures from these findings. First, countries tend to set their MRLs when Codex has an established MRL for a drug–commodity–product pair. Second, Codex tries to set MRLs for pairs being regulated the most across countries. Either or both can potentially reduce trade frictions among trading partners in the food animal market.

<u>Frequency significant difference tests</u>

We carry out two tests to formally examine the effect of international standards set by Codex on country-level MRLs and their distribution. Firstly, we test for significant difference between the frequencies of stringency categories with and without Codex. The tests are carried out under the null hypothesis that frequency of compliance, more stringent pair or laxer pairs are not different whether or not Codex MRLs exist.

There are significant differences between the frequencies at all levels of stringency (i.e., compliant, more stringent, and laxer MRLs) when international standards do and do not exist (see Table 2). We test the three levels of stringency for completeness. Since the frequencies are different at compliant and more stringent levels, it follows that the frequency of MRLs that are laxer than the reference MRLs will be different. This is because the frequencies sum to 100%. These results show that Codex as an international science-based Commission indeed plays a significant role in veterinary drug regulation in livestock, poultry and aquaculture production globally. The results suggest that when Codex exists, countries are more likely to set a standard and tend to converge to Codex.

The SPS agreement of the World Trade Organization (WTO) seeks to promote harmonized global regulatory measures by encouraging WTO Members to adopt international SPS standards. This seems to be the case for veterinary drug residue limits. Increasing the capacity of Codex Alimentarius to set MRLs across more drug–commodity–product pairs could facilitate harmonizing country MRLs with Codex MRLs.

Secondly, we aggregate proportional stringency variation of MRLs by country, commodity, products, and drugs for each stringency category using our MRL-factor-based indices (equations (2) – (5)). Note that when MRLs are compliant with reference MRLs, aggregate proportional stringency variation (M_i) will be zero. We aggregate for when international standards exist and otherwise at each stringency level (i.e., when laxer and more stringent than reference standards) and test for significant differences in aggregate proportional variation in MRL factors between when Codex MRLs exist and otherwise. The results are reported in Table 3a.

All differences are significant with the exception for Country when MRLs are more stringent and for Drugs when they are laxer than the reference MRLs. When MRLs are more stringent than the reference MRLs, the t-statistics are negative. This implies for each aggregate proportional stringency variation, when drug–commodity–product pairs are more stringent, the degree of stringency is higher when international standards do not exist. Similarly, when MRLs are laxer than the reference MRLs, the t–statistics are positive suggesting at each aggregate proportional variation when compared to the reference MRLs, laxity is higher when international standards do not exist.

This is also the case when we obtain the mean of aggregate proportional stringency variation of MRLs when international standards exist and otherwise (see Table 3b). As a context for these estimates, the mean aggregate proportional variation when MRLs are at reference MRLs, is zero. Hence, these estimates indicate how each aggregate proportional stringency variation in MRL factors is close to zero. When MRLs are more stringent or laxer, aggregate proportional variation is closer to zero when international standards exist.

<Tables 3a and 3b here>

<u>Summary of aggregate stringency</u>

We provide a summary of the aggregate stringency at country, commodity, and product levels (see Table 4a). The average proportional variation for each country, commodity, and product are reported in Tables C 1–3 in Appendix C. When international standards exist, country aggregate over all commodities, drugs and products shows that 53% of the countries are compliant (i.e., aggregate stringency value is zero), 15% are more stringent (i.e., aggregate stringency value is > 0) and 32% are laxer than Codex (i.e., aggregate stringency value is < 0). Few countries exhibit systematic protectionist behavior in both categories (i.e., when Codex MRLs exist and otherwise), except India and South Africa. Most countries in the dataset exhibit negative aggregate proportional stringency variation for MRLs without an international standard, which is anti-protectionist.

The commodity aggregate shows that none is exactly at Codex (i.e., no commodity has MRLs across its products, drugs, and countries whose MRLs are the same as Codex MRLs), 43% of the commodities have more stringent aggregate values (i.e., aggregate stringency is > 0) and 57% are laxer than Codex (i.e., aggregate stringency is < 0), including all the major meats, a surprising finding. All dairy commodities are mostly stringent when Codex MRLs exist and mostly laxer otherwise. For product aggregate, no product is at Codex (i.e., no product has MRLs across all countries and drugs whose MRLs are the same as Codex MRLs), 44% are more stringent than Codex and 56% are laxer than Codex. All product exhibit aggregate laxity when Codex MRLs do not exist.

<Table 4a here>

Ranking of aggregate stringency

We examine the country aggregate by income and continent. We present the results in Tables 4b and 4c respectively. We then rank the stringency or laxity. When international standards exist, High-income countries are the most stringent and lax countries. When international standards do not exist, lower middle-income countries are the most stringent and the high-income countries are the laxest. By continent, when international standards exist, Europe is the most stringent continent and Oceania is the laxest continent. When international standards do not exist, Asia is the most stringent and Oceania is the laxest continent.

We categorize the commodities into livestock, poultry and aquaculture. In Table 4d are the average aggregate proportional variation by these categories. From the results, when international standards exist and commodities have more stringent aggregate values, (i.e., aggregate stringency is > 0), poultry is the most stringent category. The result is the same when aggregate values are laxer (i.e., aggregate stringency is < 0). When international standards do not exist, all commodity categories are laxer (i.e., aggregate stringency is < 0). In this case, poultry category is also the laxest commodity. At the product level, major edible tissues such as the muscle, liver, kidney and fat exhibit aggregate laxity whether or not international standards exist.

Distribution of stringency variation of pair MRLs

We now characterize the distribution of the proportional stringency variation when an international standard does and does not exist. We characterize the distribution for the three major meat markets (see Figures D1 a–c in Appendix D). For a clearer understanding of the density plots of the distribution, we use the higher order moments to characterize proportional stringency variation across the major meat markets for both when international standards exist and otherwise (see Table D1 in Appendix D).

From the results, the distribution of the proportional stringency variation across all markets and stringency levels show that at when pair MRLs are more stringent and laxer than reference MRLs, on the average, a proportional stringency variation is closer to the mean when international standards exist. The exception is in the chicken market where on average, a proportional stringency variation is closer to the mean when international standards do not exist.

It appears that whether Codex MRLs exist or not, a substantial portion of the regulatory variation occurs when country MRLs are laxer than the reference MRLs in the three major meat markets. This is somewhat not surprising since an MRL laxer than the reference standard can take any value between the reference standard and positive infinity. The proportional stringency variation PV_{cpd} of a laxer drug–commodity–product pair lies to the left of zero and to negative infinity (i.e., $PV_{cpd} \in (-\infty, 0)$). MRL pairs that are more stringent than their reference MRL lie to the right of zero and reach 1 if they require zero MRLs, $PV_{cpd} \in (0, 1]$. Hence, the higher variances in country MRLs when they are laxer than the reference MRLs.

When international standards exist, variances are relatively lower. This suggests that the existence of international standards anchors MRLs in a closer range of values, even when they are more stringent or laxer than Codex. The skewness of all the distributions is negative. This implies that in all three major markets and at both stringency levels (i.e., when pair MRLs are more stringent and laxer than reference MRLs), the distribution is left-tailed. In the cattle and chicken markets, for both when pair MRLs are more stringent and laxer, the tails when international standards do not exist are longer than when they do exist. This suggests that when international standards do not exist, both proportional stringency and laxity are higher across all the drug-commodity-product pairs.

These results suggest that expanding the coverage of Codex MRLs for veterinary drugs could help reduce food regulatory variations among countries across all the drug–commodity–product pairs and consequently reduce MRL-related trade frictions in the global market. The lower food regulatory variation and higher compliance with international standards when they exist suggest that the countries are willing to align with Codex MRLs. Firms and/or national governments do not seem to resist the move towards harmonization of MRLs. This could be that the cost of alignment is bearable, especially if the expectation is that other countries will align with the international standards and facilitate trade.

Robustness Checks

Median as the reference MRL when international standards do not exist

Firstly, we examine the level of potential bias using the median MRL as the central value for reference MRL when international standards do not exist (see RC1 in Appendix D). We expand the notion of median value by considering a range around the median MRL and then examine the frequency of categorization (i.e., lax, compliant, stringent). We consider ±5%, ±10%, and ±25% ranges of the median MRL values (see RC1 in Appendix D). The expansion of the median MRL does not significantly change our results at all levels of stringency (i.e., "compliant", "lax" and "stringent") as reported in Table 1. This provides the basis for using the median MRL as the reference MRL when international standards do not exist.

Inclusion of deferral markets

Secondly, we examine how including countries that defer to the MRLs of the EU or the US potentially change the results (see RC2 in Appendix D). We exclude the US and the EU full deferral countries and re-examine the frequencies of stringency and the distribution of proportional variation. We compare these distributions with the distribution of the proportional variation using the full dataset. We then statistically test for differences in frequencies of each stringency level with and without the full deferral countries (See Table D3b in Appendix D).

Comparison of stringency frequencies with and without deferral countries

The exclusion of the deferral countries (see RC2a) somewhat changed the frequencies of stringency (see Table D3a in Appendix C). Given this result, we provide a formal test to examine the statistical differences of the frequencies in Table 1 and Table D3a for both when international standards exist and otherwise (see RC2b). The results are reported in Table D3b in Appendix D. We find that whether or not international standards exist, the frequencies of stringency are significantly different when EU and US deferral countries are not accounted for. Thus, exclusion of full deferral countries could potentially change the distribution of proportional stringency variation.

Comparison of proportional variation distributions

We check for potential changes in proportional stringency variation when we exclude the deferral countries (see RC2c in Appendix D for details). The exclusion of the EU and the US full deferral countries does not change our conclusion on the distributions of the proportional stringency variation (see Table D3c in Appendix D). When international standards exist, variances are relatively lower, skewness of all the distributions is negative. The tails when international standards do not exist are longer than when they do exist.

Also, we formally test for differences in the variances of the distribution of the proportional stringency variation with and without the full deferral countries (see RC2d). We report the results in Table D3d in Appendix D. We test at each level of stringency (i.e., when MRLs are more stringent and laxer). We find that whether or not international standards exist, the variances of proportional stringency variation using full dataset and excluding deferral countries are not different when pair MRLs are more stringent. However, when pair MRLs are laxer, the variances are significantly different (except in the case of the chicken market).

Comparison between MRL-factor-based index and MRL-based index

Thirdly, we examine the effect of the trade-off in using our MRL-factor-based index compared to using an MRL-based index (i.e., using the index without the factors). As mentioned earlier, our MRL–factor–based index is not scale–independent (see RC3 for details). The MRL-based index is scale independent but requires that we exclude pair MRLs with reference MRL of zero and ratios of zeroes. We compare the results from our MRL–factor–based index with the MRL–based index in the following estimations:

Frequency of stringency categories

We examine the frequencies at all stringency levels relative to the reference MRLs using the MRL–based index. We then compare the frequencies to those from MRL–factor–based index (see Table 5a). When international standards exist (General case), the data structure is not impacted since no Codex MRL is zero in this case. Thus, the comparison is between pair MRLs when international standards do not exist**.** The results show that excluding the drug–commodity–product pairs with zero median MRLs does not impact the frequencies across all the stringency levels.

Statistical difference between MRL factors and MRL-based proportional variation indices

We aggregate the stringency variation at country, commodity, product, and drug levels for both when Codex MRLs exist and otherwise. For each aggregate, we provide a formal context for the differences or similarities between the MRL-factor-based and MRL-based indices. This allows us to check for potential changes in construction of M_i using MRL factors.

When international standards exist, at each level of M_i, there are no statistically significant differences in the aggregate proportional stringency variation M_i using MRL-factor-based and the MRL-based indices (see Table 5b). This suggests that the use of MRL factor to construct our indices of aggregation presents no bias and could be used to accommodate drugs whose international standards are zeros. When international standards do not exist (i.e., the non-specified MRLs), we find no significant difference between MRL-factor-index and MRL-based index to aggregate at country level. However, we find significant differences in the aggregate proportional variation at commodity, product, and drugs levels.

Now we turn to the signs. Whether or not international standards exist, when MRLs are more stringent, the t-statistics are negative. This means proportional stringency variation is higher using MRL-based index compared to our MRL-factor-based index. Also, when MRLs are laxer, the t-statistics are positive, implying that laxity is characteristically higher using MRL–based index. Thus, our MRL-factor-based index moderately characterizes the regulatory variation in food-animal regulation across the countries in our dataset.

<Tables 5a and 5b about here>

Distribution of stringency variation of MRLs using MRL-factor-based and MRL-based indices

We visualize the distribution of the proportional variation of the MRL–based index (see Figures E2 a–c in Appendix E). We then compare distribution of MRL–based proportional stringency variation to our MRL–factor–based index. We use the higher order moments to characterize the distribution of the proportional variation using both indices (see Table D4 in Appendix D).

Whether or not international standards exist, skewness and kurtosis are mostly of the same signs for using both indices. The exception is the kurtosis of the cattle market when international standards do not exist. In this case, the stringent cattle market has a heavier tail using the MRL-based index, suggesting that probability of higher stringency in the tails is high with MRL-based index.

When international standards exist and MRLs are more stringent, we observe the values of the higher moments are not substantially different for both indices. However, when international standards do not exist, and MRLs are laxer than the median MRLs, variances from MRL-based index are higher for the three meat markets. As in the case of using MRL-factor-based index, whether or not international standards exist, proportional stringency variation is higher when MRLs are laxer than the reference MRLs in the three meat markets using the MRL-based index.

Conclusion

We proposed a veterinary-drug MRL-factor-based aggregation indices to characterize stringency variation in livestock, poultry and aquaculture market, at different levels and in a global context. We applied the indices to a large dataset of veterinary drugs with and without Codex international standards. We accommodated drug-commodity-product pairs without Codex MRLs using the median MRL across countries for each drug-commodity-product pair as the pseudo standard. Our unique focus on a large set of veterinary drug residues is novel and allows us to characterize regulatory stringency in global food animal market related to vet drug residues. Our index is robust to the use of MRL factors and inclusion of full deferral countries in the full dataset. This provides the basis for the application of our index to international dataset.

We found compliance with Codex MRLs to be higher than compliance with the median pseudo standard in the absence of Codex. This finding is robust to the range of values used for the pseudo standard. Both tails of the MRL distributions (more stringent and laxer) are lower when Codex MRLs exist relative to their dispersion in absence of Codex. The percentage of pairs with missing MRLs are also lower when international standards exist. In summary, greater heterogeneity among MRLs prevails in the absence of Codex MRLs. Cattle, swine, chicken, and sheep are the most regulated production system by frequency. Muscle, liver, and kidney are the most regulated edible tissues across all countries. This is due to the greater possibilities of residues from drugs and substances to accumulate in these tradable edible tissues, especially if label-use protocols are not strictly adhered to.

Fewer countries are systematically protectionist when we aggregate proportional variations by country whether or not international standards exist. There are no commodities whose aggregate exhibit Codex MRLs. More than half of the commodities are laxer than Codex MRLs when they exist, including the major meats commodities. Poultry residues are mostly more stringent when Codex MRLs exist and mostly laxer when otherwise. In terms of income categories, when international standards exist, high income countries are jointly the most stringent and most lax. When they do not exist, lower middle-income countries are the most stringent and high income countries are the laxest. By continent, Europe is the most stringent continent and Oceania is the laxest continent when international standards exist. Otherwise, Asia is the most stringent and Oceania is the laxest.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

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Data availability statement

The datasets presented in this article are not readily available because they are a proprietary database purchased from FoodChain ID Group Inc. Anonymized data may be made available upon request, for statistical purposes only, and completion of non-disclosure training, forms, and review of any output products. Requests to access the data sets should be directed to ED.

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Supporting Tables

Table 1. Stringency of country-level MRLs

	MRLs for which Codex exists:								**MRLs without Codex**	
	Special Cases				*General Case*		*All*		*Non-Specified*	
	RMR		Exempt							
	N	%	N	%	N	%	N	%	N	%
Compliant	88,199	85%	848	81%	70,530	88%	159,577	86%	336,044	68%
Stringent	-	-	202	19%	6,625	8%	6,827	4%	57,394	12%
Lax	6,575	6%	-	-	2,729	3%	9,304	5%	72,217	15%
Unknown	9,051	9%	-	-	408	1%	9,459	5%	25,976	5%
Total	**103,825**	**100%**	**1,050**	**100%**	**80,292**	**100%**	**185,167**	**100%**	**491,631**	**100%**

Source: Authors calculations using FoodChain ID Group, Inc. database (2020)
Note: RMR are drug categorized by Codex not to have an established safe residue level in food animal products for human consumption. Exempt pairs are drug-commodity pairs categorized by Codex to pose no health risks to human beings. To accommodate the RMR drugs, we replaced their MRLs with zero to align with their “not to be detected” status. Countries with MRLs greater than zero in drug-commodity pairs associated with these drugs are considered laxer than Codex. In exempt case, setting an MRL is not necessary. To accommodate these pairs, we replaced the (missing) country and Codex MRLs with the supremum MRL across all countries for each pair. Countries with no set MRLs for exempt pairs are considered compliant with Codex. Countries with any level of set MRL for exempt pairs are considered more stringent than Codex.

Table 2. Significant difference test for frequencies of compliance, stringency, and laxity

Stringency	$\boldsymbol{X^2}$	**p-value**
Compliant	12,754.0	0.000***
More stringent than reference	813.2	0.000***
Laxer than reference	7,725.5	0.000***

Source: Authors. ***, **, * significant at 1%, 5%, and 10%. The chi-square test compares the frequency of each stringency when Codex MRL exists and otherwise. Note that drug-commodity-product pairs categorized as RMR and Exempt by Codex are not included in these tests. The chi-square test index is given as $\chi^2 = \sum_{r=1}^{R}\sum_{c=1}^{C}\frac{\left(O_{ij-E_{ij}}\right)^2}{E_{ij}}$, where O_{ij} is the actual frequency and E_{ij} is the expected frequency in the i^{th} row and j^{th} columns, r and c are the number of rows and columns respectively.

Table 3a. Significant difference test for MRL-factor-based proportional stringency variation when codex exist and otherwise

Aggregation level	**Country**		**Commodity**		**Products**		**Drugs**	
Stringency	t-stat	p-value	t-stat	p-value	t-stat	p-value	t-stat	p-value
Compliant	–	–	–	–	–	–	–	–
More stringent than reference	–0.909	0.367	–2.741	0.009***	–3.753	0.000***	–5.493	0.000***
Laxer than reference	4.262	0.000***	2.247	0.030**	1.721	0.089*	0.481	0.632

Source: Authors. ***, **, * significant at 1%, 5%, and 10%. The test compares the aggregate mean proportional variation at country, drug, commodity group and commodity levels when Codex MRL exists and otherwise.

Table 3b. Average aggregate proportional stringency variation in MRL factors

Aggregation level	**Country**	**Commodity**	**Products**	**Drugs**
Stringency level	**International standards exist**			
Compliant	0	0	0	0
More stringent than Codex MRLs	0.64	0.66	0.67	0.61
Laxer than Codex MRLs	–4.27	–5.79	–6.69	–6.23
	International standards do not exist			
Compliant	0	0	0	0
More stringent than median MRLs	0.67	0.72	0.72	0.75
Laxer than median MRLs	–7.58	–7.54	–8.16	–6.79

Source: Authors. These results are the average aggregate proportional stringency variation in MRL factors. N_i is the number of observations and PV_{cxdp} is the proportional variation at countries ($i = c$), commodity ($i = x$), product ($i = p$) and drugs ($i = d$) levels. The average aggregate proportional stringency variation in MRL factors is estimated as $\bar{X}_{SL} = \frac{1}{N_{SL}} \sum_{i=1}^{N} PV_{cxdp}$, where SL is the stringency level (i.e., compliant, more stringent, and laxer MRLs) when international standards exist and otherwise.

Table 4a. Summary of aggregate MRL stringency

Stringency level	When international standards exist			When international standards do not exist		
	Country aggregate					
	N	**%**	**Aggregate mean**	**N**	**%**	**Aggregate mean**
Compliant	47	49%	0.00	-	-	-
More stringent	13	15%	0.06	3	6%	0.16
Laxer	28	36%	-1.40	44	94%	-1.35
Total	**88**	**100%**		**47**	**100%**	
Stringency level	**Commodity aggregate**					
	N	**%**	**Aggregate mean**	**N**	**%**	**Aggregate mean**
Compliant	-	-	-	-	-	-
More stringent	20	43%	0.03	-	-	-
Laxer	26	57%	-0.14	60	100%	-1.09
Total	**46**	**100%**		**60**	**100%**	
Stringency level	**Product aggregate**					
	N	**%**	**Aggregate mean**	**N**	**%**	**Aggregate mean**
Compliant	-	-	-	-	-	-
More stringent	47	44%	0.04	-	-	-
Laxer	60	56%	-0.17	164	100%	-1.28
Total	**107**	**100%**		**164**	**100%**	

Source: Authors calculations. The count of countries, commodities, and products (i.e., N) and the percentage share are reported. The aggregate means are the average aggregate proportional variation at country, commodity, and product levels at each stringency level (i.e., compliant, more stringent, and laxer). The average aggregate proportional stringency variation in MRL factors is estimated as $\bar{Z}_{i_{SL}} = \frac{1}{K_i}\sum_{k=1}^{K} M_i$, where K_i is the number of observations of countries, commodities or products whose aggregate values are zero, greater or less than zero (i.e., aggregate regulatory complaint with reference standards, more stringent or laxer than reference standards respectively) and M_i is the aggregate proportional variation at countries ($i = c$), commodity ($i = x$), and product ($i = p$) levels. We obtain the estimates when international standards exist and otherwise.

Table 4b. Ranking of stringency by income group

Stringency level	When international standards exist			
	Income group	**No of countries**	**Aggregate mean**	**Rank**
Compliant	High income	8	0.00	-
	Low income	11	0.00	-
	Lower middle income	13	0.00	-
	Upper middle income	15	0.00	-
More stringent	High income	3	0.07	1st
	Low income	-	-	-
	Lower middle income	6	0.06	2nd
	Upper middle income	4	0.04	3rd
Laxer	High income	14	-2.30	1st
	Low income	-	-	-
	Lower middle income	2	-0.16	3rd
	Upper middle income	12	-0.55	2nd
Total		**88**		
	When international standards do not exist			
Compliant	High income	-	-	-
	Low income	-	-	-
	Lower middle income	-	-	-
	Upper middle income	-	-	-
More stringent	High income	-	-	-
	Low income	-	-	-
	Lower middle income	1	0.28	1st
	Upper middle income	2	0.10	2nd
Laxer	High income	18	-1.73	1st
	Low income	-	-	-
	Lower middle income	8	-0.94	3rd
	Upper middle income	18	-1.15	2nd
Total		**47**		

Source: Authors. Ranking of country aggregates ($\bar{Z}_c$) by income group.

Table 4c. Ranking of stringency by continent

Stringency level	When international standards exist			
	Continent	**No of countries**	**Aggregate mean**	**Rank**
Complaint	Africa	16	0.00	-
	Americas	17	0.00	-
	Asia	10	0.00	-
	Europe	1	0.00	-
	Oceania	3	0.00	-
More stringent	Africa	2	0.08	2nd
	Americas	7	0.04	4th
	Asia	3	0.06	3rd
	Europe	1	0.10	1st
	Oceania	-	-	-
Laxer	Africa	1	-0.14	4th
	Americas	9	-1.78	2nd
	Asia	8	-0.11	5th
	Europe	5	-0.33	3
	Oceania	5	-4.08	1st
Total		**88**		
	When international standards do not exist			
Complaint	Africa	-	-	-
	Americas	-	-	-
	Asia	-	-	-
	Europe	-	-	-
	Oceania	-	-	-
More stringent	Africa	1	0.18	2nd
	Americas	1	0.01	3rd
	Asia	1	0.28	1st
	Europe	-	-	-
	Oceania	-	-	-
Laxer	Africa	2	-0.09	5th
	Americas	18	-0.71	3rd
	Asia	13	-2.02	2nd
	Europe	6	-0.61	4th
	Oceania	5	-3.28	1st
Total		**47**		

Source: Authors. Ranking of country aggregates $(\bar{Z}_c)$ by continent.

Table 4d. Ranking of stringency by production system

Stringency level	Category	No of commodities	Aggregate mean	Rank
	When international standards exist			
Complaint	Aquaculture	-	-	-
	Dairy	-	-	-
	Livestock	-	-	-
	Poultry	-	-	-
More stringent	Aquaculture	4	0.02	4th
	Dairy	4	0.02	3rd
	Livestock	6	0.03	2nd
	Poultry	6	0.04	1st
Laxer	Aquaculture	13	-0.10	4th
	Dairy	2	-0.12	3rd
	Livestock	7	-0.13	2nd
	Poultry	4	-0.29	1st
Total		**46**		
When international standards do not exist				
Complaint	Aquaculture	-	-	-
	Dairy	-	-	-
	Livestock	-	-	-
	Poultry	-	-	-
More stringent	Aquaculture	-	-	-
	Dairy	-	-	-
	Livestock	-	-	-
	Poultry	-	-	-
Laxer	Aquaculture	26	-0.93	4th
	Dairy	6	-1.05	3rd
	Livestock	16	-1.06	2nd
	Poultry	12	-1.49	1st
Total		**60**		

Source: Authors. Ranking of commodity aggregate ($\bar{Z}_x$) by category.

Table 5a. MRL-factor-based and MRL-based indices by stringency distribution

Stringency	International standards do not exist				International standards exist	
	MRL-factor-based index		MRL-based index		Codex General case	
	N	%	N	%	N	%
Compliant	336,044	68%	334,827	68%	70,530	88%
Stringent	57,394	12%	57,394	12%	6,625	8%
Lax	72,217	15%	71,895	15%	2,729	3%
Unknown	25,976	5%	25,893	5%	408	1%
Total	**491,631**	**100%**	**490,009**	**100%**	**80,292**	**100%**

Source: Authors calculations using FoodChain ID Group, Inc. database (2020)

Table 5b. Difference test of aggregate proportional stringency variation between MRL-factor-based and MRL-based indices.

When international standards exist								
Aggregation level	**Country**		**Commodity**		**Products**		**Drugs**	
Stringency	t-stat	p-value	t-stat	p-value	t-stat	p-value	t-stat	p-value
Compliant	–	–	–	–	–	–	–	–
More stringent than reference	-0.253	0.801	-0.264	0.792	-0.399	0.690	-0.542	0.589
Laxer than reference	1.092	0.278	1.045	0.302	1.377	0.172	1.040	0.302
When international standards do not exist								
Stringency	t-stat	p-value	t-stat	p-value	t-stat	p-value	t-stat	p-value
Compliant	–	–	–	–	–	–	–	–
More stringent than reference	–1.154	0.252	–6.385	0.000***	–9.440	0.000***	–1.912	0.056**
Laxer than reference	1.169	0.246	4.513	0.000***	4.771	0.000***	1.997	0.046**

Source: Authors. ***, **, * indicate significant at 1%, 5%, and 10%. This test compares proportional variation estimation using MRL factors and MRLs at each stringency, aggregate level and in each case of when international standards exist or otherwise. For examples, the test compares the PV of non-specified (MRL-factor-based index) with PV (MRL-based index) when MRLs are more stringent and laxer than median MRLs.

Supporting Figures

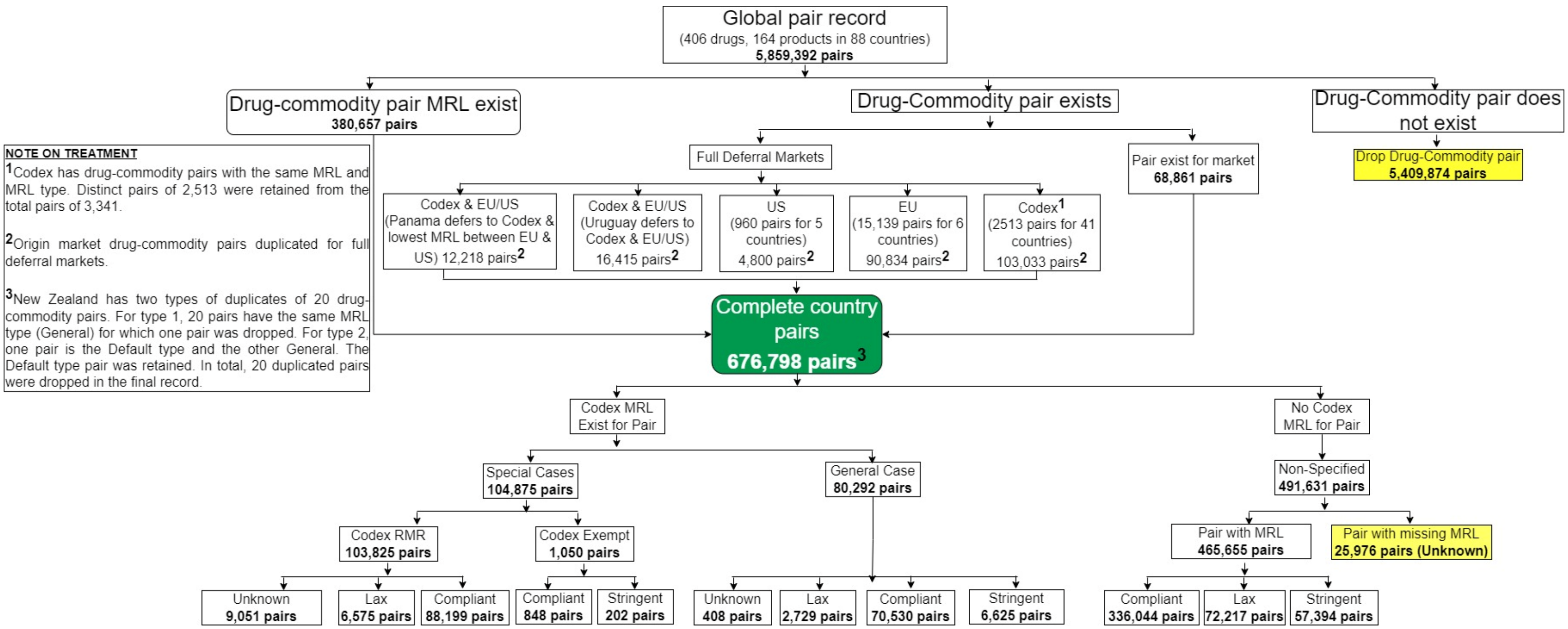

Figure 1: Database setup flowchart.
Source: Authors using data from FoodChain ID Group, Inc. (2020)

Supplemental Appendix

Appendix A: Countries Covered in the Database

Table A1. List of countries and full deferral countries

Non-deferral countries		Codex deferral countries		EU deferral countries	US deferral countries
Argentina	Malaysia	Afghanistan	Lebanon	Algeria	American Samoa
Australia	Mexico	Angola	Libya	French West Indies	Guam
Brazil	New Zealand	Bahamas	Malawi	Georgia	Northern Mariana Islands
Canada	Nicaragua	Barbados	Mozambique	Montenegro	Puerto Rico
Chile	Peru	Belize	Myanmar	Suriname	U.S. Virgin Islands
China	Singapore	Bermuda	Nigeria	United Kingdom	
Colombia	South Africa	Bosnia and Herzegovina	Pakistan		
Costa Rica	Taiwan	British Virgin Islands	Papua New Guinea		
Dominican Republic	Thailand	Cambodia	Senegal		
Egypt	Turkey	Cameroon	Sint Maarten		
El Salvador	United States	Cayman Islands	Sudan		
Eurasian Economic Union	Vietnam	Cuba	Syria		
European Union		Dominica Republic	Tanzania		
Guatemala		Eswatini	Tonga		
Gulf Cooperation Council		Fiji	Trinidad and Tobago		
Honduras		Gambia	Tunisia		
Hong Kong		Ghana	Uganda		
India		Grenada	Venezuela		
Indonesia		Haiti	Zimbabwe		
Japan		Jamaica	Panama*		
Korea		Jordan	Uruguay**		
Macau		Kenya			

Note: *Defers to Codex but where drug-commodity-product pair does not exist in Codex, defers to the pair with the lower MRL between EU and US; ** Defers to Codex but where drug-commodity-product pair does not exist in Codex, defers to EU first and then US.

Table A2. List of Codex exempt drug–commodity–product pairs

Drugs	Commodity	Product
Estradiol	Cattle	Cattle, fat
Estradiol	Cattle	Cattle, kidney
Estradiol	Cattle	Cattle, live
Estradiol	Cattle	Cattle, muscle
Porcine somatotropin	Swine	Swine, fat
Porcine somatotropin	Swine	Swine, kidney
Porcine somatotropin	Swine	Swine, liver
Porcine somatotropin	Swine	Swine, muscle
Progesterone	Cattle	Cattle, fat
Progesterone	Cattle	Cattle, kidney
Progesterone	Cattle	Cattle, liver
Progesterone	Cattle	Cattle, muscle
Testosterone	Cattle	Cattle, fat
Testosterone	Cattle	Cattle, kidney
Testosterone	Cattle	Cattle, liver
Testosterone	Cattle	Cattle, muscle

Table A3. List of risk management recommendations (RMR) and banned drugs

Drugs	Codex RMR Drugs	Japan's not detectable drugs	China's banned drugs
Carbadox	X	X	
Chloramphenicol	X	X	
Chlorpromazine	X	X	X
Clorsulon		X	
Coumaphos		X	
Diazepam			X
Diethylstilbestrol		X	
Dimetridazole	X	X	X
Estradiol			X
Furaltadone		X	
Furazolidone	X	X	
Gentian violet	X	X	
Ipronidazole	X	X	
Malachite green	X	X	
Metronidazole	X	X	X
Nitarsone		X	
Nitrofural	X		
Nitrofurantoin		X	
Nitrofurazone		X	
Olaquindox	X	X	
Ronidazole	X	X	

Roxarsone		X	
Sodium nifurstyrenate		X	
Stilbenes	X		
Testosterone			X
Xylzaine (Milk products)			X

Appendix B

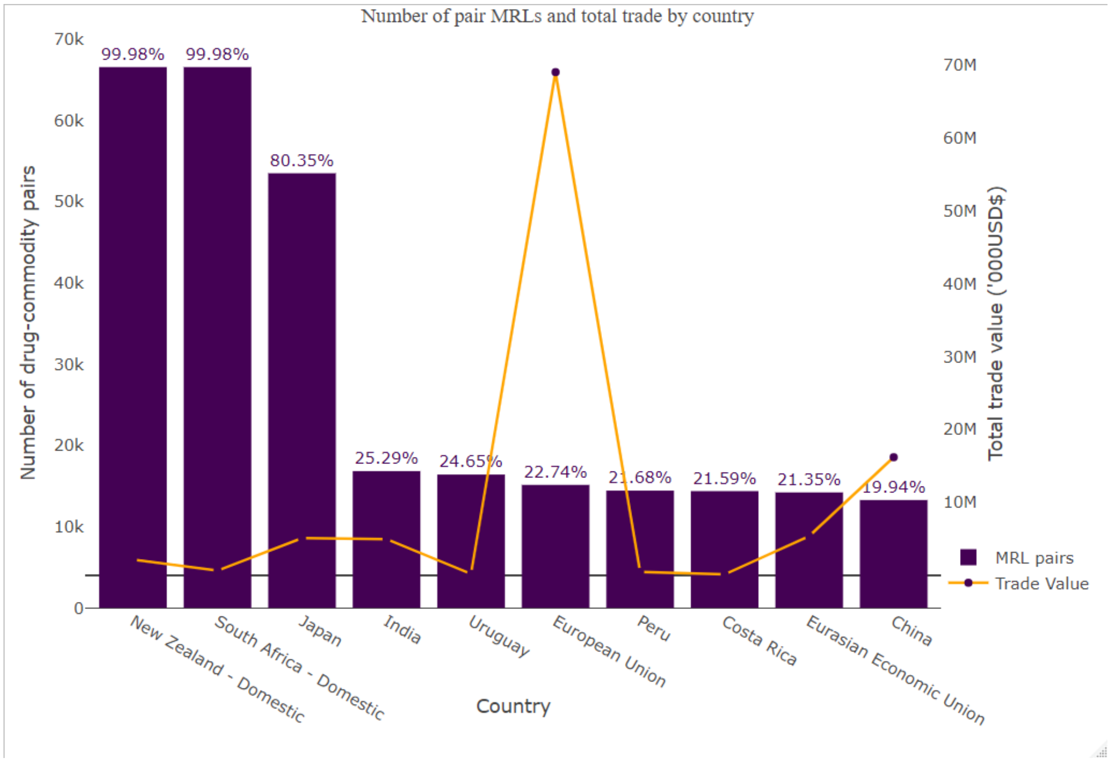

Figure B1: Country-level count of regulated pair MRL, coverage of regulation and trade values.

Source: Authors calculations

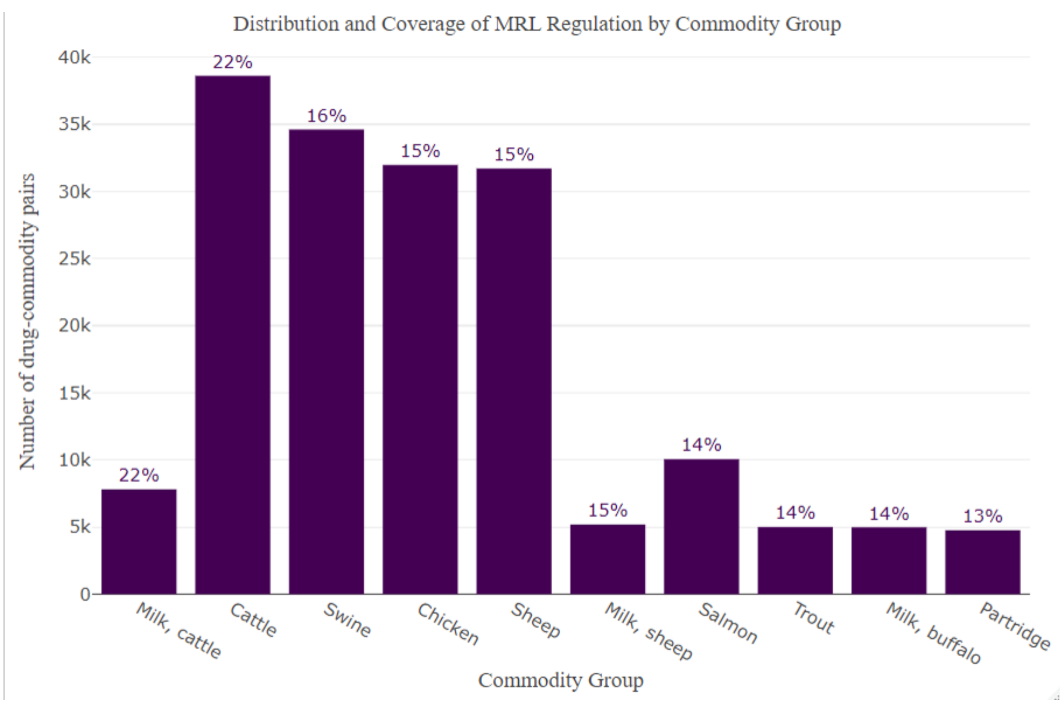

Figure B2: Rank of commodities by number of drug-commodity pairs regulated.

Source: Authors

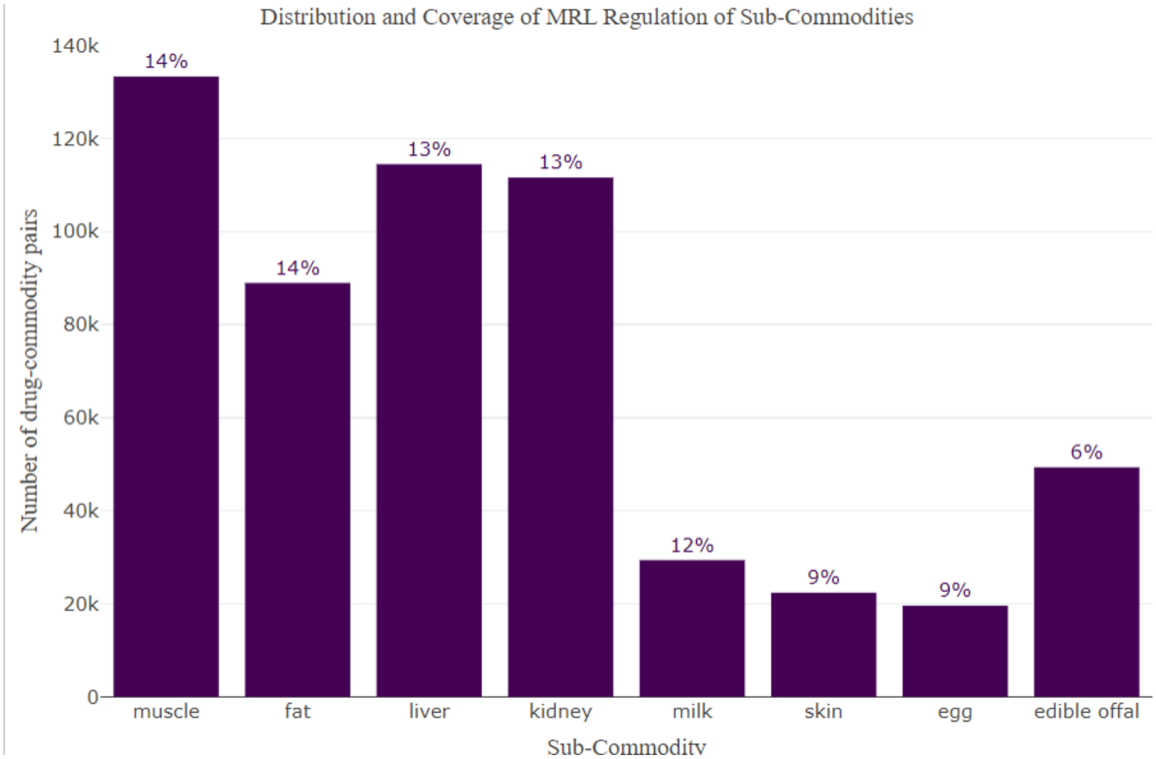

Figure B3: Rank of products by number of drug-commodity pairs regulated.
Source: Authors

Appendix C

Table C1: Stringency aggregate by country

Country	Continent	Income group	Codex Exists			Codex Does Not Exist		
			MRL	World Ranking	Continent Ranking	MRL	World Ranking	Continent Ranking
Algeria	Africa	Upper middle income	-0.14	70	19	-0.10	13	3
Angola	Africa	Upper middle income	0.00	14	3		73	NA
Cameroon	Africa	Lower middle income	0.00	14	3		74	NA
Egypt	Africa	Lower middle income	0.12	1	1	-0.08	12	2
Eswatini	Africa	Lower middle income	0.00	14	3		75	NA
Gambia	Africa	Low income	0.00	14	3		76	NA
Ghana	Africa	Lower middle income	0.00	14	3		77	NA
Kenya	Africa	Low income	0.00	14	3		78	NA
Libya	Africa	Upper middle income	0.00	14	3		79	NA
Malawi	Africa	Low income	0.00	14	3		80	NA
Mozambique	Africa	Low income	0.00	14	3		81	NA
Nigeria	Africa	Lower middle income	0.00	14	3		82	NA

Senegal	Africa	Lower middle income	0.00	14	3		83	NA
South Africa	Africa	Upper middle income	0.04	5	2	0.18	2	1
Sudan	Africa	Lower middle income	0.00	14	3		84	NA
Tanzania	Africa	Low income	0.00	14	3		85	NA
Tunisia	Africa	Upper middle income	0.00	14	3		86	NA
Uganda	Africa	Low income	0.00	14	3		87	NA
Zimbabwe	Africa	Low income	0.00	14	3		88	NA
Argentina	Americas	Upper middle income	-0.02	65	27	-0.92	26	14
Bahamas	Americas	High income	0.00	14	8		59	NA
Barbados	Americas	High income	0.00	14	8		60	NA
Belize	Americas	Lower middle income	0.00	14	8		61	NA
Bermuda	Americas	High income	0.00	14	8		62	NA
Brazil	Americas	Upper middle income	-0.01	61	25	-0.58	24	13
British Virgin Islands	Americas	High income	0.00	14	8		63	NA
Canada	Americas	High income	-1.15	80	31	-1.95	38	17
Cayman Islands	Americas	High income	0.00	14	8		64	NA

Chile	Americas	Upper middle income	-0.01	61	25	-0.25	22	12
Colombia	Americas	Upper middle income	-0.03	66	28	-3.48	43	18
Costa Rica	Americas	Upper middle income	0.04	5	1	-0.03	4	2
Cuba	Americas	Upper middle income	0.00	14	8		65	NA
Dominica	Americas	Upper middle income	0.00	14	8		66	NA
Dominican Republic	Americas	Upper middle income	0.04	5	1	-0.03	4	2
El Salvador	Americas	Lower middle income	0.04	5	1	-0.03	4	2
Grenada	Americas	Upper middle income	0.00	14	8		67	NA
Guatemala	Americas	Lower middle income	0.04	5	1	-0.03	4	2
Haiti	Americas	Low income	0.00	14	8		68	NA
Honduras	Americas	Lower middle income	0.04	5	1	-0.03	4	2
Jamaica	Americas	Upper middle income	0.00	14	8		69	NA
Mexico	Americas	Upper middle income	0.00	14	8	-1.70	37	16

Nicaragua	Americas	Lower middle income	0.04	5	1	-0.03	4	2
Panama	Americas	Upper middle income	0.00	14	8	0.01	3	1
Peru	Americas	Upper middle income	0.04	5	1	-0.06	11	8
Puerto Rico	Americas	High income	-4.88	83	32	-1.13	27	15
Sint Maarten	Americas	High income	0.00	14	8		70	NA
Suriname	Americas	Upper middle income	-0.14	70	29	-0.10	13	9
Trinidad and Tobago	Americas	High income	0.00	14	8		71	NA
U.S. Virgin Islands	Americas	High income	-4.88	83	32	-1.13	27	15
United Kingdom	Americas	High income	-0.14	70	29	-0.10	13	9
Uruguay	Americas	Upper middle income	0.00	14	8	-0.13	21	11
Venezuela	Americas	Upper middle income	0.00	14	8		72	NA
Afghanistan	Asia	Low income	0.00	14	4		52	NA
Cambodia	Asia	Low income	0.00	14	4		53	NA
China	Asia	Upper middle income	-0.09	69	18	-1.22	35	8
Georgia	Asia	Lower middle income	-0.14	70	19	-0.10	13	3
Hong Kong	Asia	High income	0.07	4	2	-0.05	10	2

India	Asia	Lower middle income	0.09	3	1	0.28	1	1
Indonesia	Asia	Lower middle income	-0.17	77	20	-4.14	44	13
Japan	Asia	High income	0.03	13	3	-1.21	34	7
Jordan	Asia	Upper middle income	0.00	14	4		54	NA
Korea	Asia	High income	-0.06	68	17	-2.38	40	10
Lebanon	Asia	Upper middle income	0.00	14	4		55	NA
Macau	Asia	High income	0.00	14	4	-0.50	23	5
Malaysia	Asia	Upper middle income	-0.04	67	16	-1.23	36	9
Myanmar	Asia	Low income	0.00	14	4		56	NA
Pakistan	Asia	Lower middle income	0.00	14	4		57	NA
Singapore	Asia	High income	-0.01	61	14	-0.67	25	6
Syria	Asia	Lower middle income	0.00	14	4		58	NA
Taiwan	Asia	High income	-0.38	78	21	-3.30	42	12
Thailand	Asia	Upper middle income	0.00	14	4	-8.32	47	14
Turkey	Asia	Upper middle income	-0.01	61	14	-0.12	20	4

Vietnam	Asia	Lower middle income	0.00	14	4	-3.06	41	11
Bosnia and Herzegovina	Europe	Upper middle income	0.00	14	2		51	NA
Eurasian Economic Union	Europe	Upper middle income	-1.10	79	6	-1.14	33	5
European Union	Europe	High income	-0.14	70	3	-0.10	13	1
French West Indies	Europe	High income	-0.14	70	3	-0.10	13	1
Gulf Cooperation Council	Europe	High income	0.10	2	1	-2.11	39	6
Montenegro	Europe	Upper middle income	-0.14	70	3	-0.10	13	1
United States	Europe	High income	-4.88	83	7	-1.13	27	4
American Samoa	Oceania	Upper middle income	-4.88	83	6	-1.13	27	1
Australia	Oceania	High income	-4.35	82	5	-7.34	46	5
Fiji	Oceania	Lower middle income	0.00	14	1		48	NA
Guam	Oceania	High income	-4.88	83	6	-1.13	27	1
New Zealand	Oceania	High income	-1.43	81	4	-5.67	45	4
Northern Mariana Islands	Oceania	High income	-4.88	83	6	-1.13	27	1
Papua New Guinea	Oceania	Lower middle income	0.00	14	1		49	NA
Tonga	Oceania	Lower middle income	0.00	14	1		50	NA

Source: Authors calculations.

Table C2: Aggregate MRL by country-drug-product pairs when CODEX does and does not exist by commodity

Commodity	Category	Codex MRLs exist:			Codex MRLs do not exist:		
		MRL	CODEX - World	CODEX - Category	MRL	NO CODEX - World	NO CODEX - Category
Abalone	Aquaculture		NA	NA	-0.93	18	13
Barramundi	Aquaculture	-0.12	29	8	-0.90	7	3
Carp	Aquaculture	-0.12	29	8	-0.90	7	3
Catfish, freshwater	Aquaculture	-0.12	29	8	-0.89	5	2
Clam	Aquaculture		NA	NA	-0.93	18	13
Cockle	Aquaculture		NA	NA	-0.93	18	13
Crab	Aquaculture		NA	NA	-0.92	15	11
Eel	Aquaculture	-0.12	29	8	-0.85	1	1
Flatfish	Aquaculture	-0.12	29	8	-0.90	7	3
Frog	Aquaculture		NA	NA	-0.94	24	19
Kangaroo	Aquaculture	0	13	5	-1.05	37	26
Lobster	Aquaculture		NA	NA	-0.96	28	23
Mussel	Aquaculture		NA	NA	-0.93	18	13
Oyster	Aquaculture		NA	NA	-0.93	18	13
Prawn/shrimp	Aquaculture	0.04	3	1	-0.94	24	19
Rockfish	Aquaculture	0.01	12	2	-0.92	15	11
Salmon	Aquaculture	-0.09	26	6	-1.02	32	25
Scallop	Aquaculture		NA	NA	-0.93	18	13
Sea bream	Aquaculture	-0.12	29	8	-0.90	7	3
Sturgeon	Aquaculture	-0.12	29	8	-0.90	7	3
Sweetfish	Aquaculture	0.01	12	2	-0.91	14	10
Tilapia	Aquaculture	-0.12	29	8	-0.90	7	3
Trout	Aquaculture	-0.10	28	7	-1.01	30	24
Tuna	Aquaculture	-0.12	29	8	-0.90	7	3
Turtle	Aquaculture	0.01	12	2	-0.95	27	22

Yellowtail	Aquaculture	-0.12	29	8	-0.94	24	19
Milk, buffalo	Dairy	0.01	12	3	-0.92	15	2
Milk, camel	Dairy	0.01	12	3	-1.30	52	6
Milk, cattle	Dairy	-0.24	43	6	-0.87	2	1
Milk, goat	Dairy	0.03	6	1	-1.01	30	3
Milk, horse	Dairy	0.03	6	1	-1.16	46	5
Milk, sheep	Dairy	0.00	13	5	-1.04	35	4
Alpaca	Livestock	0.01	12	3	-1.08	41	11
Buffalo	Livestock	0.03	6	2	-0.99	29	4
Camel	Livestock	0.01	12	3	-1.08	41	11
Cattle	Livestock	-0.19	41	11	-0.89	5	3
Deer	Livestock	-0.03	24	8	-1.02	32	5
Donkey	Livestock		NA	NA	-1.05	37	8
Goat	Livestock	-0.08	25	9	-0.88	3	1
Hare	Livestock	0.00	13	6	-1.03	34	6
Honey	Livestock		NA	NA	-1.53	55	16
Horse	Livestock	-0.24	43	NA	-0.88	3	1
Llama	Livestock	0.01	12	3	-1.08	41	11
Possum	Livestock		NA	NA	-1.05	37	8
Rabbit	Livestock	0.09	1	1	-1.04	35	7
Sheep	Livestock	-0.15	39	10	-1.09	44	14
Swine	Livestock	-0.2	42	12	-1.15	45	15
Wallaby	Livestock	0	13	6	-1.07	40	10
Chicken	Poultry	-0.57	46	10	-1.64	57	9
Duck	Poultry	-0.09	26	7	-1.91	58	10
Egg	Poultry	0.02	11	6	-1.35	53	6
Emu	Poultry		NA	NA	-1.29	50	4
Goose	Poultry	0.04	3	2	-1.93	59	11
Guinea-fowl	Poultry	0.03	6	4	-1.18	47	1
Ostrich	Poultry		NA	NA	-1.29	50	4

Partridge	Poultry	0.04	3	2	-1.19	49	3
Pheasant	Poultry	0.08	2	1	-1.57	56	8
Pigeon	Poultry	0.03	6	4	-1.18	47	1
Quail	Poultry	-0.18	40	8	-1.93	59	11
Turkey	Poultry	-0.32	45	9	-1.37	54	7

Source: Authors calculations.

Table C3: Stringency aggregate by product

Product	Codex Exist	Codex Does Not Exist
Abalone	NA	-0.93
Atlantic	-0.09	-1.02
Ayu	0.01	-0.91
Barramundi	-0.12	-0.9
Carp	-0.12	-0.9
Clam	NA	-0.93
Cockle	NA	-0.93
Crab	NA	-0.92
Edible Offal	NA	-2.47
Eel	-0.12	-0.85
Egg	0.04	-1.34
Fat	-0.02	-1.05
Flatfish	-0.12	-0.9
Freshwater	-0.12	-0.89
Frog	NA	-0.94
Honey	NA	-1.53
Kidney	-0.06	-1.14
Liver	-0.16	-1.02
Lobster	NA	-0.96
Milk	-0.03	-1.05
Muscle	-0.11	-0.96
Mussel	NA	-0.93
Oyster	NA	-0.93
Pacific	-0.09	-1.02
Prawn/Shrimp	0.04	-0.94
Rockfish	0.01	-0.92
Scallop	NA	-0.93
Sea Bream	-0.12	-0.9
Skin	-0.09	-1.7
Sturgeon	-0.12	-0.9
Tilapia	-0.12	-0.9
Trout	-0.1	-1.01
Tuna	-0.12	-0.9
Turtle	0.01	-0.95
Velvet	NA	-2.62
Yellowtail	-0.12	-0.94

Source: Authors calculations. Products without Codex MRLs do not have aggregate stringency values.

Appendix D

Table D1. Higher order moments to characterize proportional variation in MRL factors

Market	Stringency	Moment	Codex MRLs exist	No Codex MRLs
Cattle	Stringent	Mean	0.57	0.70
		Std. deviation	0.26	0.28
		Variance	0.07	0.08
		Skewness	-0.26	-1.06
		Kurtosis	-0.86	-0.03
	Lax	Mean	-6.23	-7.30
		Std. deviation	12.25	17.57
		Variance	150.11	308.60
		Skewness	-5.00	-8.34
		Kurtosis	36.31	103.54
Chicken	Stringent	Mean	0.63	0.77
		Std. deviation	0.24	0.26
		Variance	0.06	0.07
		Skewness	-0.36	-1.61
		Kurtosis	-0.59	1.61
	Lax	Mean	-11.40	-10.63
		Std. deviation	32.43	32.64
		Variance	1,051.94	1,065.59
		Skewness	-6.00	-11.10
		Kurtosis	40.61	188.36
Swine	Stringent	Mean	0.52	0.72
		Std. deviation	0.24	0.27
		Variance	0.06	0.07
		Skewness	0.10	-1.34
		Kurtosis	-0.74	0.60
	Lax	Mean	-4.92	-9.06
		Std. deviation	9.80	22.22
		Variance	96.08	493.61
		Skewness	-7.55	-7.98
		Kurtosis	84.73	79.36

Source: Authors

Appendix D
Robustness Checks
RC1. Inclusion of deferral markets

When a drug–commodity–product pair MRL is within the range, it is "compliant", when it is greater or lower than the range, it is laxer or more stringent respectively. At ±5% median MRL values, about 27% of the country MRLs are either laxer or more stringent (see Table D2 in Appendix C). The percentage of pair MRLs that are laxer or more stringent decreased to approximately 25% when using the ±10% and ±25% median MRL values.

Table D2. Frequency of stringency of country-level MRLs for expanded median MRL ranges

Stringency	Median MRL		± 5% Median MRL		± 10% Median MRL		± 25% Median MRL	
	N	%	N	%	N	%	N	%
Compliant	336,044	68%	337,016	68%	342,475	70%	343,719	70%
Stringent	57,394	12%	57,152	12%	52,377	11%	51,928	11%
Lax	72,217	15%	71,487	15%	70,803	14%	70,008	14%
Unknown	25,976	5%	25,976	5%	25,976	5%	25,976	5%
Total	**491,631**	**100%**	**491,631**	**100%**	**491,631**	**100%**	**491,631**	**100%**

Source: Authors calculations using FoodChain ID Group, Inc. database (2020)

RC2. Comparison of stringency frequencies with and without deferral countries

RC2a

We focus on comparing the general and non-specified cases. The exclusion of the EU and the US deferral countries increased the share of compliant pairs from 88% to 93% when Codex MRLs exist (see Table 1 and Table D3a). The percentage of pairs that are more stringent and laxer decreased from 8% to 5% and 3% to 1%, respectively. The pairs with missing MRLs whose stringency cannot be classified remained unchanged at 1%. When international standards do not exist, the share of pairs at the median MRLs decreased from 68% to 63%. The share of pairs whose MRLs are more stringent or laxer than the median MRLs increased from 12% to 14% and 15% to 18% respectively. The percentage of pairs with missing MRLs whose state of stringency cannot be established remains 5%.

Table D3a. Frequency of stringency of pairs in MRL factors without the EU and US full deferral countries

	MRL with Codex								**MRL without Codex**	
	Special Case				*General Case*		*All*		*Non-Specified*	
	RMR		Exempt							
	N	%	N	%	N	%	N	%	N	%
Compliant	86,327	88%	792	82%	67,730	93%	154,849	90%	259,390	63%
Stringent	-	-	174	18%	3,736	5%	3,910	2%	55,330	14%
Lax	6,570	7%	-	-	1,267	2%	7,837	5%	72,321	18%
Unknown	5,055	5%	-	-	408	1%	5,463	3%	22,064	5%
Total	**97,952**	**100%**	**966**	**100%**	**73,141**	**100%**	**172,059**	**100%**	**409,105**	**100%**

Source: Authors calculations using FoodChain ID Group, Inc. database (2020)

RC2b

We formally test for significant differences between the frequencies of the stringency levels in Table 1 and Table D3a. We compare the variances of the distribution of the proportional stringency variation with and without the full deferral countries of the three major markets.

Table D3b. Significant different test on frequencies of stringency between with and without the EU and US full deferral countries

MRL status	**General Case**		**Non-specified**	
Stringency	X^2	**p-value**	X^2	**p-value**
Compliant	972.7	0.000***	1968.0	0.000***
Stringent	600.0	0.000***	780.9	0.000***
Lax	418.4	0.000***	1128.4	0.000***

Source: Authors calculations. ***, **, * indicate significant at 1%, 5%, and 10%. This test checks if the frequency of each stringency level is different with or without EU and US full deferral countries. For instance, we check if the frequency of compliant in full dataset in Table 1 is different from the frequency compliant in Table D3a. The chi-square test index is given as $\chi^2 = \sum_{r=1}^{R}\sum_{c=1}^{C}\frac{\left(O_{ij-E_{ij}}\right)^2}{E_{ij}}$, where O_{ij} is the actual frequency and E_{ij} is the expected frequency in the i^{th} row and j^{th} columns, r and c are the number of rows and columns respectively.

RC2c

Since the frequencies of stringency are significantly different when the pair MRLs of deferral countries are excluded from the dataset, we examine how the exclusion of the MRLs of these countries changes the proportional stringency variation. The stringency variation density plots are shown in Figures E1 d–f in Appendix E. We compare these distributions with the distribution of the proportional variation estimating the full dataset (Figures E1 a–c in Appendix E).

Table D3c. Higher order moments of proportional stringency variation with and without full deferral countries

Market	**Stringency**	**Moment**	**Full dataset**		**Without deferral countries**	
			Codex MRLs exist	**No Codex MRLs**	**Codex MRLs exist**	**No Codex MRLs**
Cattle	Stringent	Mean	0.57	0.70	0.61	0.71
		Std. deviation	0.26	0.28	0.26	0.27
		Variance	0.07	0.08	0.07	0.07
		Skewness	-0.26	-1.06	-0.35	-1.16
		Kurtosis	-0.86	-0.03	-0.87	0.27
	Lax	Mean	-6.23	-7.30	-6.81	-7.21
		Std. deviation	12.25	17.57	15.26	15.91
		Variance	150.11	308.60	232.99	253.25
		Skewness	-5.00	-8.34	-4.69	-8.87
		Kurtosis	36.31	103.54	28.10	133.39
Chicken	Stringent	Mean	0.63	0.77	0.65	0.75

		Std. deviation	0.24	0.26	0.24	0.26
		Variance	0.06	0.07	0.06	0.07
		Skewness	-0.36	-1.61	-0.44	-1.51
		Kurtosis	-0.59	1.61	-0.65	1.27
	Lax	Mean	-11.40	-10.63	-9.77	-10.60
		Std. deviation	32.43	32.64	25.92	32.66
		Variance	1051.94	1065.59	671.59	1066.48
		Skewness	-6.00	-11.10	-6.07	-11.43
		Kurtosis	40.61	188.36	46.93	197.25
Swine	Stringent	Mean	0.52	0.72	0.57	0.72
		Std. deviation	0.24	0.27	0.26	0.27
		Variance	0.06	0.07	0.07	0.07
		Skewness	0.10	-1.34	-0.08	-1.39
		Kurtosis	-0.74	0.60	-0.95	0.77
	Lax	Mean	-4.92	-9.06	-5.70	-8.53
		Std. deviation	9.80	22.22	13.56	19.73
		Variance	96.08	493.61	183.99	389.35
		Skewness	-7.55	-7.98	-6.47	-8.65
		Kurtosis	84.73	79.36	53.37	100.52

Source: Authors calculations

RC2d

We compare the variances of the distribution of the proportional stringency variation with and without the full deferral countries of the three major markets. We use the F-test under the null hypothesis that the ratio of the variances of the proportional variation in MRL factors with and without full deferral countries is unity.

Table D3d: Significant difference test of variances of proportional variations with and without full deferral countries

Commodity	More stringent			More Lax		
	F-stat	p-value	DF	F-stat	p-value	DF
			When international standards exist			
Cattle	0.983	0.787	(1346, 743)	0.644	0.000	(577, 289)
Chicken	0.952	0.512	(916, 564)	1.566	0.000	(476, 205)
Swine	0.911	0.262	(802, 435)	0.522	0.000	(521, 212)
			When international standards do not exist			
Cattle	1.057	0.164	(2645, 2436)	1.219	0.000	(2502, 2397)
Chicken	0.987	0.741	(2550, 2321)	0.999	0.982	(2922, 2769)
Swine	1.035	0.392	(2540, 2442)	1.268	0.000	(2540, 2559)

Source: Authors calculations. ***, **, * indicate significant at 1%, 5%, and 10%. DF is the degree of freedom. This F-test check if the variance of PV_{cpd} is difference in full dataset and excluding the EU and US full deferral countries. The test is done for major meat markets when MRLs are more stringent and laxer than reference MRLs.

RC3

In this case, only the "non-specified" case (i.e., when international standards do not exist) is impacted. As stated earlier, when international standards exist, the drug–commodity–product pairs of RMR/banned/undetectable drugs with zero MRL values are excluded from further analysis. There are 1,217 pairs with ratios of zeros, 322 pairs with $MRL \neq 0$ but with zero median MRL, and 83 pairs with missing MRLs with zero median MRLs. Altogether, 1,622 pairs are excluded from the "non-specified". Accounting for MRLs with zero median MRLs, there are 490,009 pair MRLs. Here we carry out three sub-tests.

We aggregate the stringency variation at country, commodity group, commodity, and drug levels for both when Codex MRLs exist and otherwise. For each aggregate, we provide a formal context for the differences or similarities between our MRL-factor-based and MRL-based indices. We formally test for significant differences in aggregate proportional stringency variation at each stringency level. We test when MRLs are more stringent and laxer than reference MRLs (i.e., when international standards exist and otherwise). This allows us to check for potential changes in construction of M_i using MRL factors. We test under the null hypothesis that the means of M_i using MRL-factor-based and MRL-based indices are not different when MRLs are more stringent and laxer than the reference MRLs.

Although, there are no changes to the frequency stringency distribution of pair MRLs when international standards exist (i.e., no zero Codex MRLs in General case), using MRL-based index to estimate PV_{cpd} in the General case can potentially change the results. In this case, when MRLs are more stringent, $PV_{cpd} \in (0,1]$ (i.e., PV_{cpd} can take a value from 0 to 1, with 1 inclusive). Thus, it is important to formally check for significant changes in the construction of PV_{cpd} and consequently M_i using the MRL-based index compared to our MRL-factor index.

Table D4. Higher order moment to characterize MRL stringency variation using MRL-factor-based and MRL-based indices

Market	Stringency	Moment	MRL-factor-based index		MRL-based index	
			Codex MRLs exist	No Codex MRLs	Codex MRLs exist	No Codex MRLs
Cattle	Stringent	Std. deviation	0.26	0.28	0.25	0.28
		Variance	0.07	0.08	0.06	0.08
		Skewness	-0.26	-1.06	-0.23	-1.15
		Kurtosis	-0.86	-0.03	-0.91	0.17
	Lax	Std. deviation	12.25	17.57	33.56	40.09
		Variance	150.11	308.60	1,126.51	1,607.17
		Skewness	-5.00	-8.34	-11.44	-12.98
		Kurtosis	36.31	103.54	156.58	227.92
Chicken	Stringent	Std. deviation	0.24	0.26	0.24	0.26
		Variance	0.06	0.07	0.06	0.07
		Skewness	-0.36	-1.61	-0.39	-1.68
		Kurtosis	-0.59	1.61	-0.62	1.81
	Lax	Std. deviation	32.43	32.64	32.78	40.96
		Variance	1,051.94	1,065.59	1,074.58	1,677.70
		Skewness	-6.00	-11.10	-5.90	-11.08
		Kurtosis	40.61	188.36	39.52	173.74
Swine	Stringent	Std. deviation	0.24	0.27	0.24	0.27
		Variance	0.06	0.07	0.06	0.08
		Skewness	0.10	-1.34	0.12	-1.41
		Kurtosis	-0.74	0.60	-0.75	0.75
	Lax	Std. deviation	9.80	22.22	11.71	23.17
		Variance	96.08	493.61	137.01	536.80
		Skewness	-7.55	-7.98	-7.07	-7.84
		Kurtosis	84.73	79.36	65.67	77.20

Source: Authors calculations

Appendix E
With full deferral countries

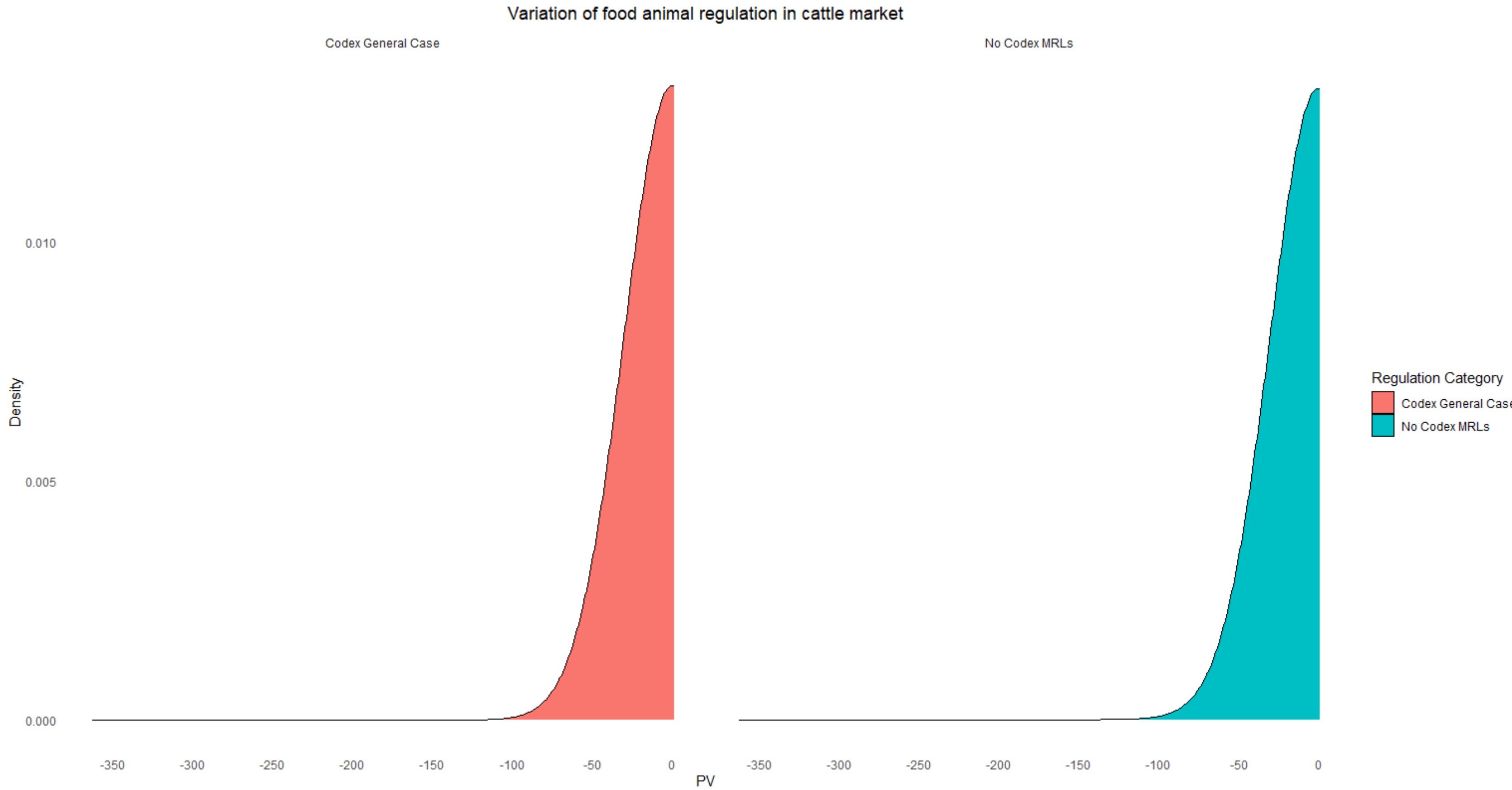

Figure E1 (a): MRL-factor-based index density plot of country-level MRL proportional variation
Source: Authors calculations

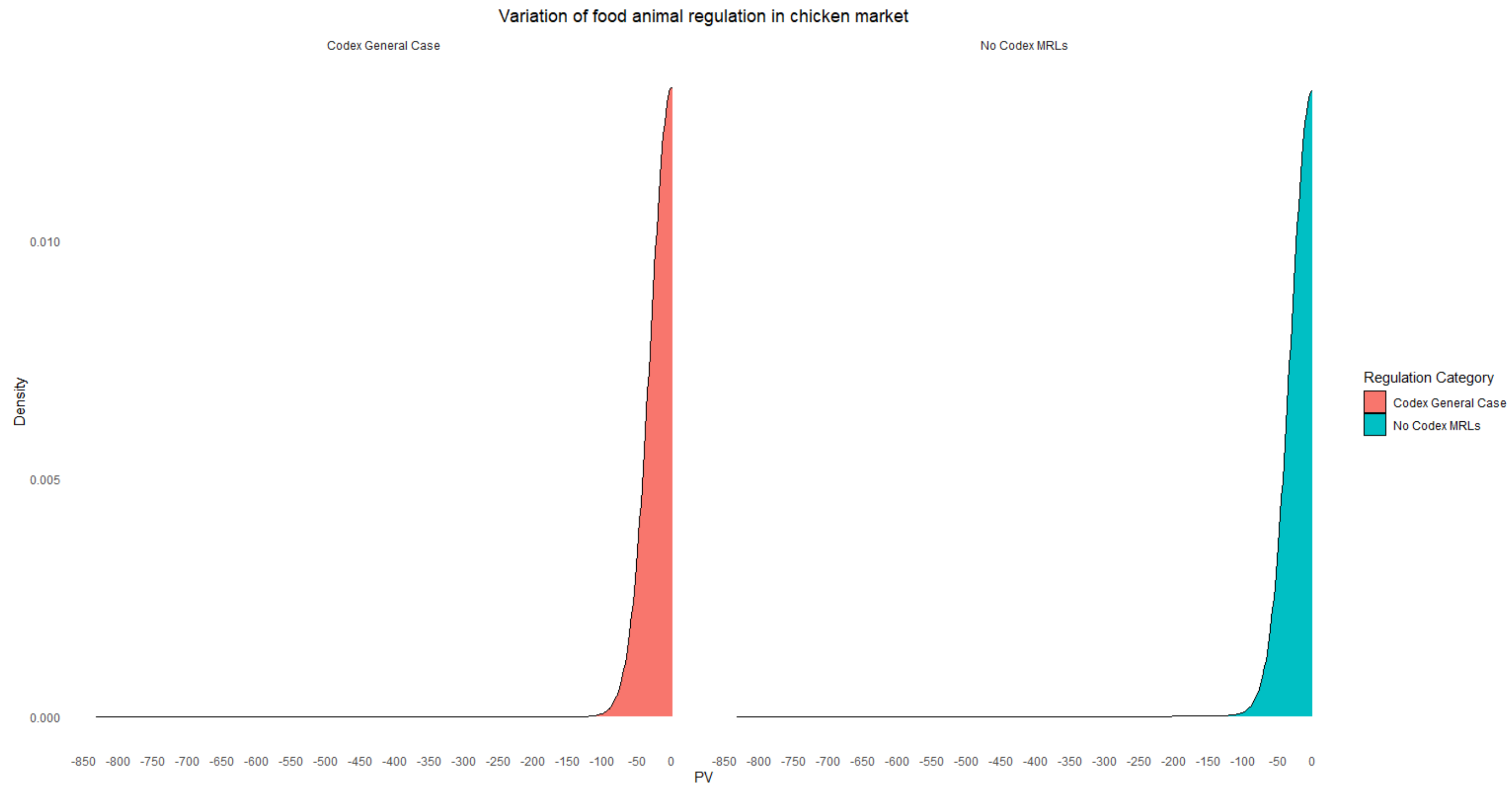

Figure E1 (b): MRL-factor-based index density plot of country-level MRL proportional variation

Source: Authors calculations

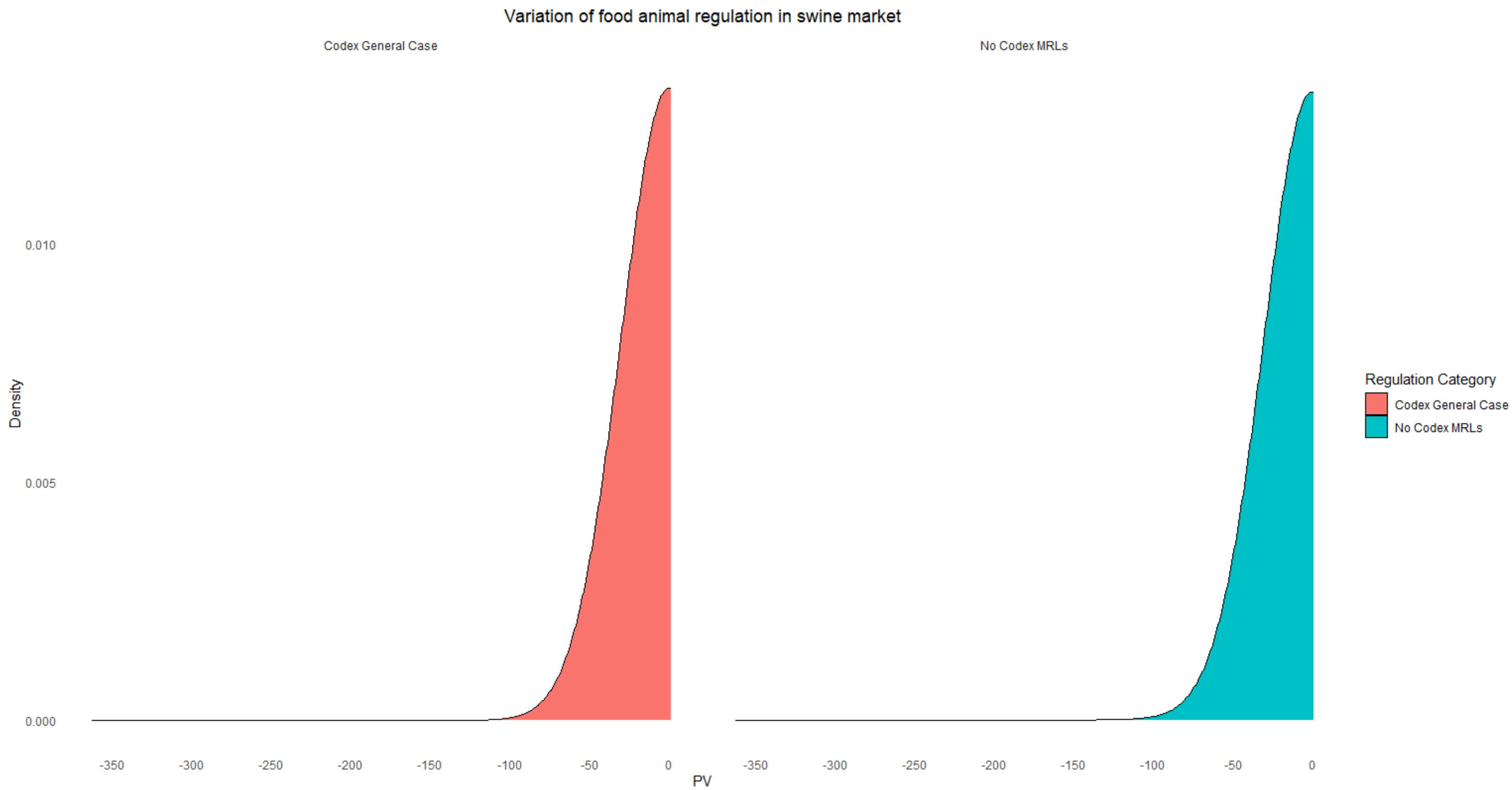

Figure E1 (c): MRL-factor-based index density plot of country-level MRL proportional variation
Source: Authors calculations

Without EU & US full deferral countries

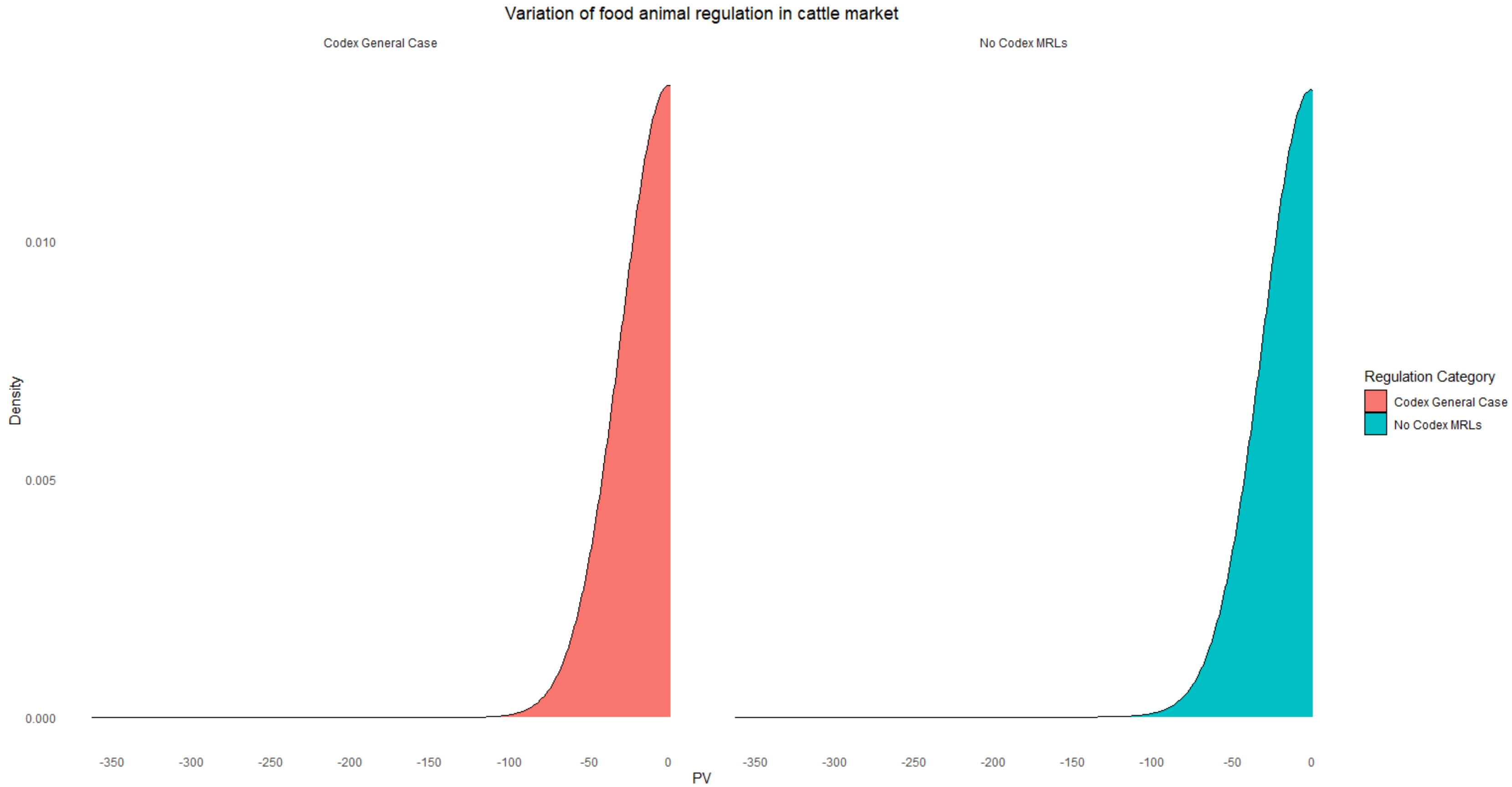

Figure E1 (d): MRL-factor-based index density plot of country-level MRL proportional variation
Source: Authors calculations

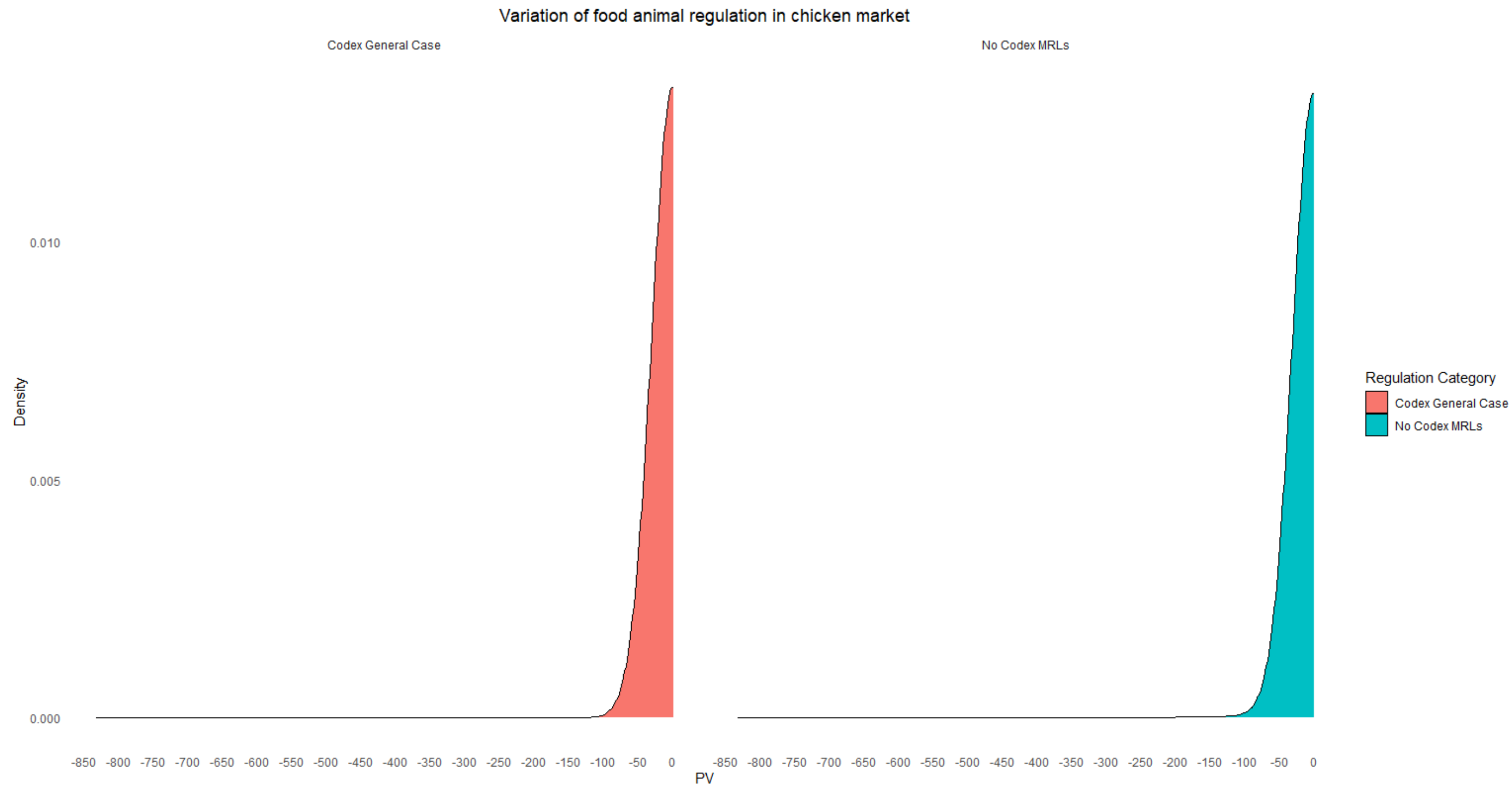

Figure E1 (e): MRL-factor-based index density plot of country-level MRL proportional variation
Source: Authors calculations

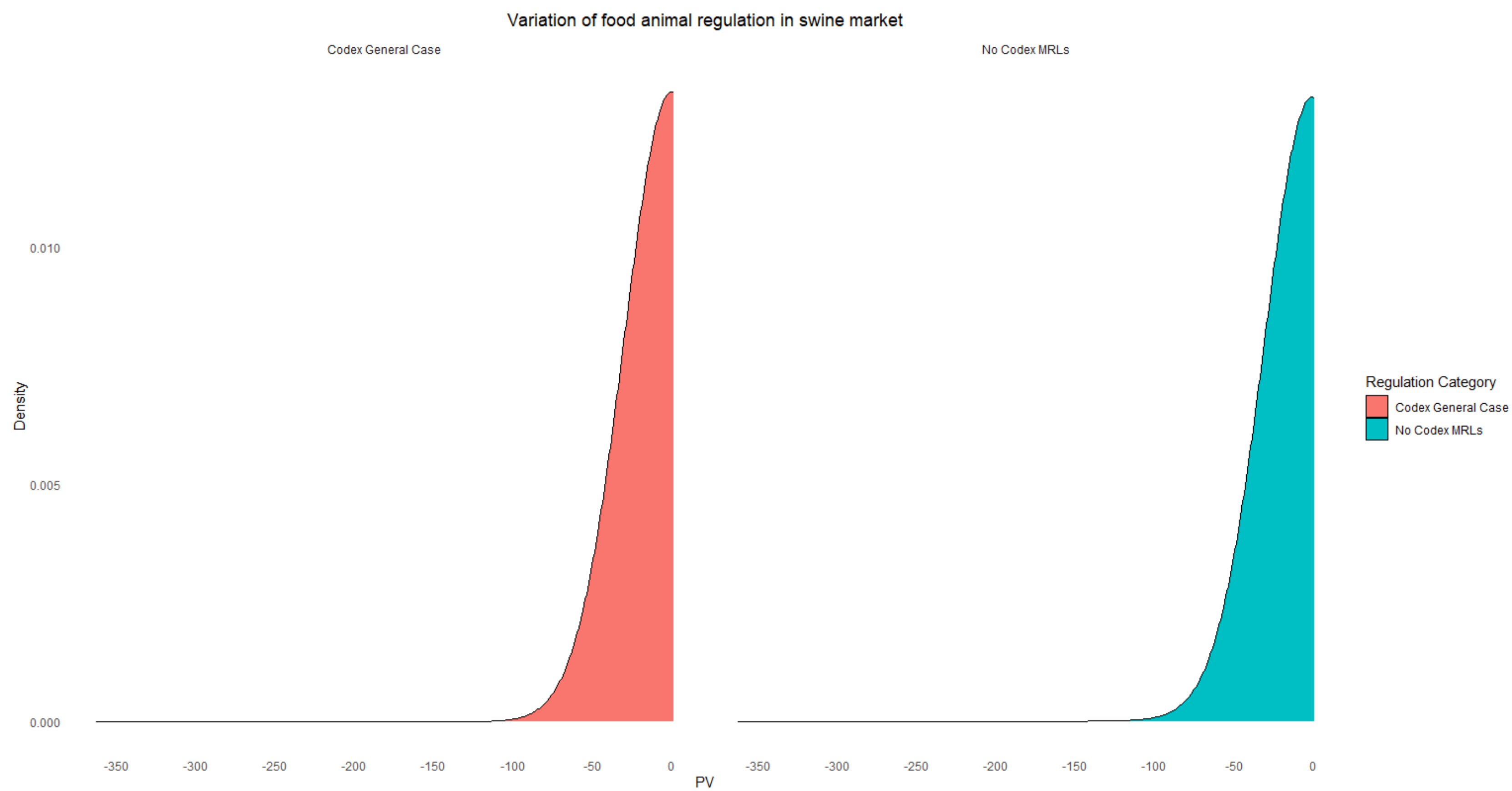

Figure E1 (f): MRL-factor-based index density plot of country-level MRL proportional variation
Source: Authors calculations

Density plots of MRL-based proportional stringency variation

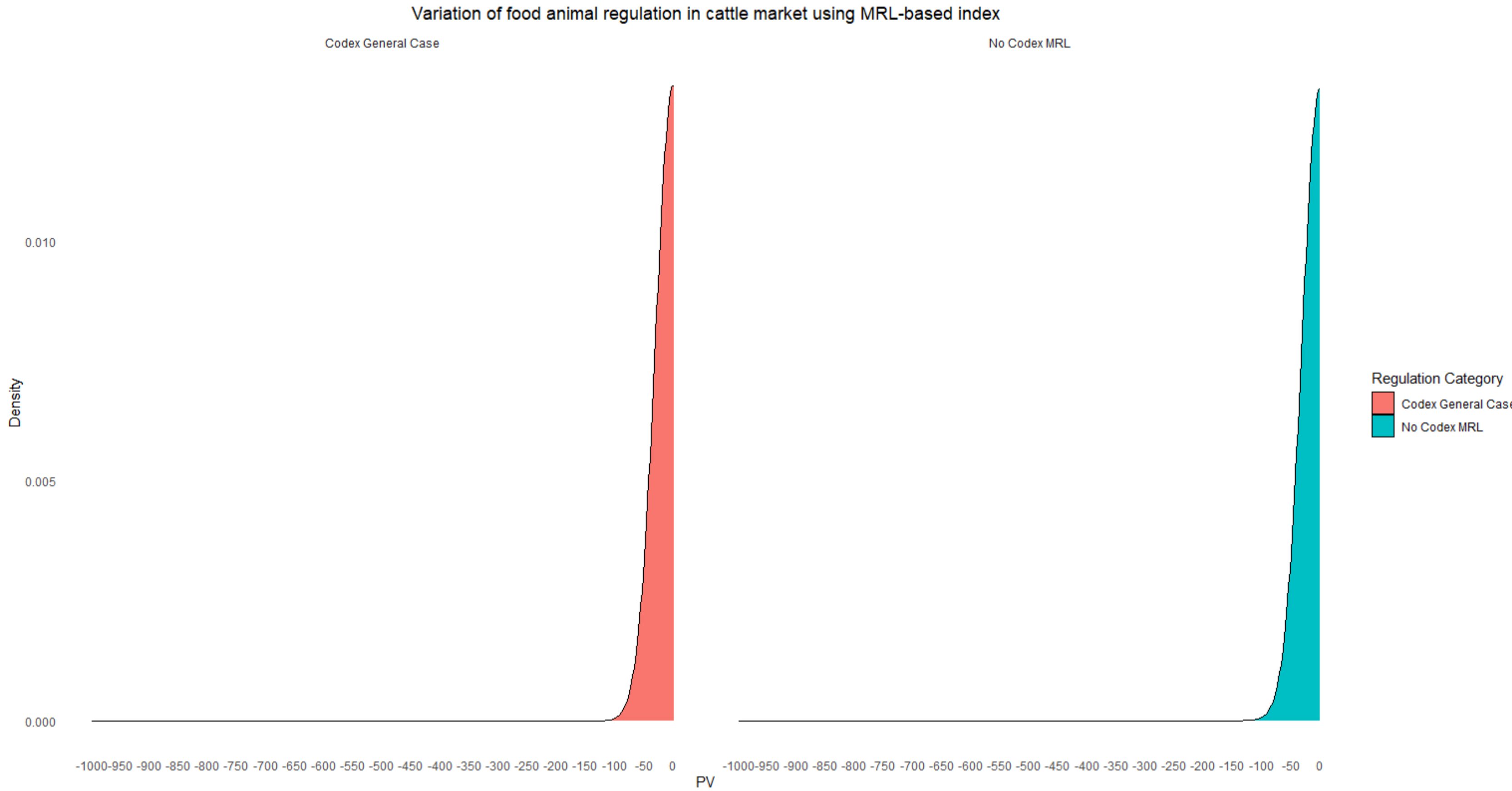

Figure E2 (a): MRL-based index density plot of country-level MRL proportional variation
Source: Authors calculations

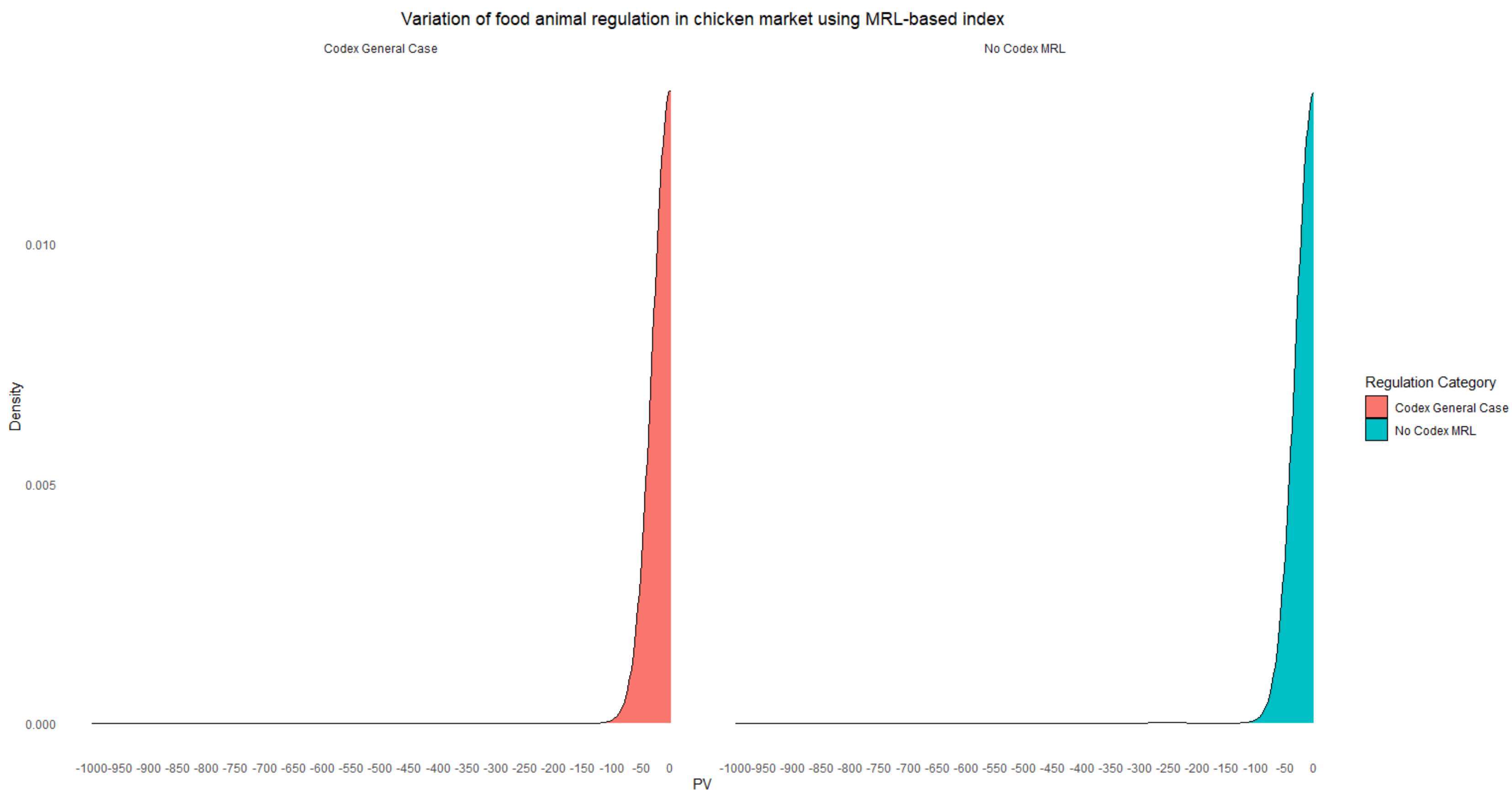

Figure E2 (b): MRL-based index density plot of country-level MRL proportional variation
Source: Authors calculations

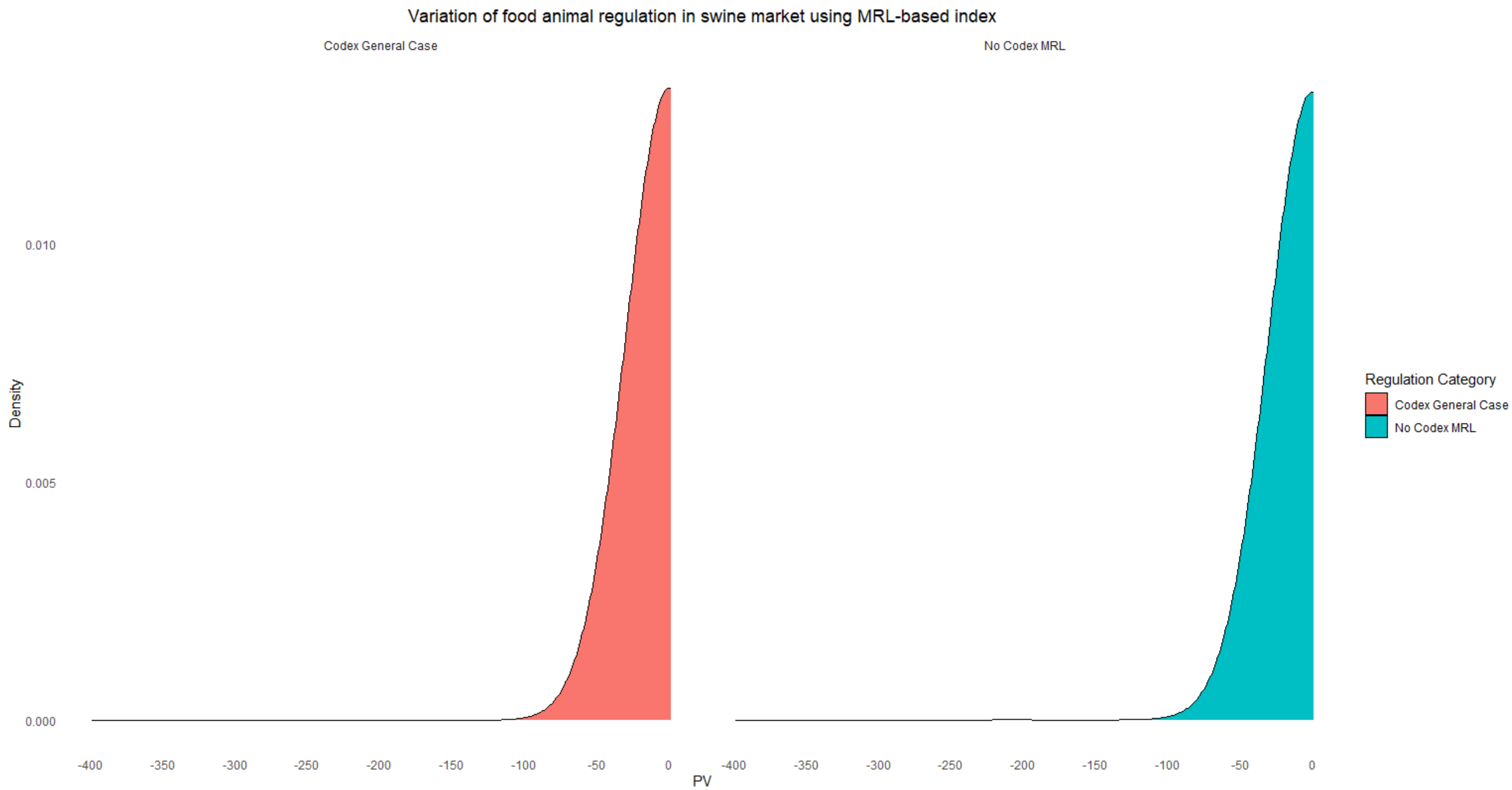

Figure E2 (c): MRL-based index density plot of country-level MRL proportional variation

Source: Authors calculations