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TRACEABILITY OF AGRI-FOOD PRODUCTS: THE KEY TO CONSCIOUS TRADE

PAPER

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SCARLETT QUEEN ALMEIDA BISPO FERNANDA APARECIDA SILVA MICHELLE MÁRCIA VIANA MARTINS MARCELO JOSÉ NONNENBERG RUAN DA SILVA VIANNA CARLA CRISTINA PASSOS CRUZ





### TRACEABILITY OF AGRI-FOOD PRODUCTS: THE KEY TO CONSCIOUS TRADE<sup>1</sup>

SCARLETT QUEEN ALMEIDA BISPO<sup>2</sup> FERNANDA APARECIDA SILVA<sup>3</sup> MICHELLE MÁRCIA VIANA MARTINS<sup>4</sup> MARCELO JOSÉ NONNENBERG<sup>5</sup> RUAN DA SILVA VIANNA<sup>6</sup> CARLA CRISTINA PASSOS CRUZ<sup>7</sup>

7. Fellow researcher at Ipea.

APER

<sup>1.</sup> The authors thank Krisley Mendes from University of Brasilia (UnB) and Alessandro Nicita and Ralf Peters from the United Nations Conference on Trade and Development (UNCTAD) for their suggestions and recommendations.

<sup>2.</sup> Fellow researcher at the Institute of Applied Economic Research (Ipea); and master's student at UnB.

<sup>3.</sup> Fellow researcher at Ipea; PhD in applied economics; and economics professor at the Federal University of Viçosa (UFV).

<sup>4.</sup> Fellow researcher at Ipea; PhD in applied economics; and economics professor at UFV.

<sup>5.</sup> Economist at Ipea; and PhD in economic sciences.

<sup>6.</sup> PhD candidate in statistics at Federal University of Rio de Janeiro (UFRJ).

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#### ABSTRACT

The globalization of food trade has needed robust traceability systems to ensure consumer safety, quality and sustainability product. By fostering transparency in agricultural practices and encouraging responsible resource use, traceability plays a key role in protecting the environment and supporting sustainable development. This study examines the trade effects of traceability-related non-tariff measures (NTMs) on international trade, focusing on input and processing traceability in agricultural sector, with specific analyses in the meat, fruit, and fisheries sectors. Utilizing a structural gravity model and Poisson pseudo-maximum likelihood estimation with high-dimensional fixed effects (FE), we analyze trade flows across 53 exporting and 56 importing countries, covering 2,081 agri-products from 2012 to 2021. The findings reveal that input traceability measures generally increase trade, while processing traceability often poses trade barriers. The interaction between input and processing traceability measures presents positive effects in the meat sector. These results underscore the nuanced role of traceability measures, highlighting the need for tailored policy approaches that consider the unique characteristics of different sectors and countries. The findings emphasize the critical need to balance trade facilitation with stringent safety, quality, and sustainability standards.

Keywords: traceability; NTMs; international trade; food safety; agri-products.

#### SINOPSE

A globalização do comércio de alimentos tem exigido sistemas robustos de rastreabilidade para garantir a segurança do consumidor, a qualidade dos produtos e a sustentabilidade. Ao promover a transparência nas práticas agrícolas e encorajar o uso responsável dos recursos, a rastreabilidade desempenha um papel importante na proteção do meio ambiente e no apoio ao desenvolvimento sustentável. Este estudo examina os efeitos comerciais das medidas não tarifárias (MNTs) relacionadas à rastreabilidade no comércio internacional, com foco na rastreabilidade de insumos e processos no setor agrícola, com análises específicas nos setores de carne, frutas e pescados. Utilizando um modelo de gravidade estrutural e estimativa de Pseudo Máxima Verossimilhança de Poisson com efeitos fixos (FE) de alta dimensão, analisamos fluxos comerciais entre 53 países exportadores e 56 países importadores, abrangendo 2.081 produtos agrícolas de 2012 a 2021. Os resultados revelam que as medidas de rastreabilidade de insumos geralmente aumentam o comércio, enquanto a rastreabilidade de processos muitas vezes impõe barreiras comerciais. A interação entre as medidas de rastreabilidade de insumos e processos apresenta efeitos positivos no setor de carne. Esses resultados ressaltam o papel diferenciado das medidas de rastreabilidade, destacando a necessidade de abordagens de políticas personalizadas que considerem as características únicas de diferentes setores e países. As descobertas enfatizam a necessidade crítica de equilibrar a facilitação do comércio com padrões rigorosos de segurança, qualidade e sustentabilidade.

**Palavras-chave**: rastreabilidade; MNTs; comércio internacional; segurança alimentar; produtos agrícolas.

#### **1 INTRODUCTION**

Globalization and the growth of trade flows have enabled exchange of food products between countries. However, the need to manage trade exchanges responsibly, to ensure mutual benefits without compromising the environment or public health, has become a complex challenge for both importers and exporters (D'Amico et al., 2014). In agri-products trade, issues related to food safety, sanitary and phytosanitary (SPS) conditions can be considered the main concerns of the importing country, often making the traceability of information about the entire production process chain a requirement for the exporting country.

According to the International Organization for Standardization (ISO), traceability is formally defined in ISO 22005:2007 as the ability to track the path of a food or feed through the various stages of production, processing and distribution. Although the interpretation of traceability may vary according to the type of food, knowledge of the path and stages of the production process facilitates the identification and removal of products unfit for consumption (Qian et al., 2020). This approach contributes to improving consumer safety and increasing their confidence in the product (Tharatipyakul and Pongnumkul, 2021).

Traceability requirements can also be used to protect the environment. In 2023, the European Parliament approved legislation that prohibits the import of certain agricultural products originating from deforested areas. This legislation covers the entire production chain, from origin to consumption, ensuring that imported goods meet stricter environmental standards (Haahr, 2023). In this case, traceability should be used to identify the origin and processing of these goods, monitoring and ensuring the use of techniques and practices that reduce the carbon footprint and promote sustainability. It is also important for the bioeconomy, as it documents the use of bioproducts and bioenergy, clearly demonstrating and verifying the environmental and economic benefits of these practices (Bracco et al., 2019).

On the other hand, traceability can also be beneficial to agricultural producers by strengthening governance, improving property and cost management, and improving risk management from both an environmental and health perspective (D'Amico et al., 2014). Traceability can also be particularly important in cases of outbreaks of animal diseases or plant pests, as observed during outbreaks of Bovine Spongiform Encephalopathy (Vinholis and Azevedo, 2002). The traceability of the origin of the disease has allowed the implementation of more effective control measures, prevented

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its spread and minimized adverse effects on the agricultural sector and the environment (Schroeder and Tonsor, 2012).

The implementation of a robust traceability system requires meticulous management of several stages of production, from the supply of inputs such as seeds and fertilizers to the processing and distribution of food to consumers. However, in traditional food supply chains, a central entity is usually the one who manages the information and can disclose only the information that serves its interests, resulting in concerns about transparency and reliability (Peng et al., 2015).

The adoption of NTMs is a way for importing countries to impose requirements on exporting countries to maintain market access. Thus, the adoption of non-tariff measures (NTMs) with traceability requirements may raise concerns about the ability of some exporters to comply. They influence multilateral governance, as they involve attributes that countries must meet in order to consolidate trade. The World Trade Organization (WTO) has reinforced the idea of trade liberalization and determines that countries should not use this mechanism as trade barriers.

The UNCTAD (2019) provides information on each country's mandatory traceability requirements and categorizes them as technical NTMs. Although these measures correctly aim to mitigate information asymmetries associated with trade flows, their effect can unintentionally resemble that of protectionist barriers.

In international trade, agricultural products are the target of a significant portion of technical NTMs. This is due to the organic and perishable nature of these products, as well as their purpose related to food, so governments have a particular interest in ensuring that imports of such products do not pose risks to health or the environment. Traceability requirements established by trade regulations are categories of NTMs of SPS measures and technical barriers to trade (TBTs). The impact of traceability requirements and other technical NTMs on trade outcomes is not uniform; they can have a negative, positive or insignificant effect. The outcomes depend on the exporting firm's ability to adapt to these requirements while maintaining its competitiveness in international markets (Fiankor, Curzi and Olper, 2021).

Bispo et al. (2024) analyzed traceability NTMs for agricultural products, but their results did not focus specifically on production stages and were largely ambiguous. Thus, a gap remains in the literature regarding the lack of consensus on a predominant effect. To contribute to the findings bridge this gap, we propose an analysis of traceability NTMs related to inputs and processing. Our study differs by providing a detailed and

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specific analysis of these two production stages. Input traceability identifies the origin and quality of materials used in agricultural production, ensuring that the final products are free of contaminants and meet the quality and safety standards required by the market and regulators. Processing traceability monitors and controls all stages of the production chain, enabling the rapid identification and correction of any failures or deviations that may compromise the quality of the final product. Sustainability issues are another significant aspect of traceability, the environmental impact of each production stage must be identified to be more responsible and efficient practices. With input and processing traceability data, we discuss trade costs and quality signalization to agricultural products.

First, we created a customized database. The database provided by United Nations Conference on Trade and Development (UNCTAD), although intended for researchers, did not meet the requirements of this study due to the omission of relevant countries, such as the European Union, for the period under study (2012-2021) on the most recent collection dates. This limitation necessitated extensive data processing from SPS and TBT regulations to make it suitable for econometric modeling, a process explained in detail in the methodology section. Second, we categorized countries based on their levels of economic development to determine whether the impact of traceability-related NTMs differs when applied to trading partners at various development stages. Third, we divided the agricultural sector into traceability-sensitive segments, such as meats, fruits, and fisheries, to examine differences in estimates for these segments. This analysis assesses whether traceability NTMs vary considerably across sectors, reinforcing that generalizing their impacts to the entire agricultural sector may not be appropriate. Such generalizations may obscure the formulation of effective traceability policies across different segments of farming. Finally, we estimated the interaction between input and processing traceability measures to assess the impact of their simultaneous implementation by an importer on trade. This approach allows us to analyze how these factors interact and jointly influence trade outcomes. The results were interpreted with the theoretical framework of trade costs.

Different from previous empirical studies that analyzed mainly the impact of SPS and TBT measures in a general context (Disdier and Marette, 2010; Shang and Tonsor, 2019; Peci and Sanjuán, 2020), this study introduces a particular approach to the international trade literature. It conducts a specific assessment of NTMs in the context of inputs and processing traceability.

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Our study focuses on determining the impact of traceability NTMs in 53 exporting and 56 importing countries, covering a total of 2,081 agricultural products. We employ a structural gravity approach estimated by the Poisson pseudo-maximum likelihood estimator with high-dimensional fixed effects (FE). The hypothesis posits that the effects vary across sectors. Additionally, we test the hypothesis that negative impacts are more pronounced for trade from developing countries, attributable to their financial and technological limitations. While regulatory requirements related to traceability are driven by public objectives such as health protection, environmental preservation and quality enhancement, they have disparate effects on sectors and countries at different development stages.

The paper is divided in sections. The second section provides a brief review of the NTMs trade effects. In section 3 we present the models and empirical methodologies. Section 4 discusses the main results. The last section presents conclusions and proposes policies.

#### **2 TRACEABILITY AND TRADE EFFECT**

The traceability concept might seem straightforward, but defining it precisely presents a challenge. Originally, traceability was a tool for quality management in the production of highly engineered products. Initially, it focused on collecting extensive information about products and processes to reduce costs. Today, traceability has a more strategic role, extending beyond the data collection to track a product's entire journey through the supply chain, from origin to end-user. This involves identifying the product, monitoring raw materials, ingredients, production processes, packaging, and distribution. In agriculture, traceability is a key for tracking product origins, detecting contamination, and ensuring compliance with stringent food safety and quality regulations (Vinholis and Azevedo, 2002; Oliveira et al., 2019; Yu et al., 2022).

To Moe (1998) the definition of traceability for agricultural products is the ability to track a batch of produce and its way through the entire production chain – from harvest through transportation, storage, processing, distribution, and sale. While this definition is precise, it does not fully capture the complexity of the agri-food production chain, which begins before harvest. Opara (2003) proposes that food traceability involves identifying the farm where the commodity was produced and the sources of materials used, allowing for full traceability in both directions along the supply chain through detailed records. Olsen and Borit (2013) argue that a comprehensive definition of traceability must include all characteristics of the food and its ingredients throughout the production chain,

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based on systematic records to complete and accurate traceability. Modern definitions consider recent technological advances. According to Gupta et al. (2023), traceability is the capability of a food chain to track and trace food throughout the entire supply chain, employing technological innovations such as radio frequency technologies, blockchain, and barcodes. Salah et al. (2019) focuses on developing traceability techniques based on blockchain. All these definitions focus on the characteristics of the product, including information about the production process. Since the 1990s, attention has also been focused on the biosecurity issue of genetically modified organisms (GMOs) and the information associated with these products (Miraglia et al., 2004).

While it is expected that sustainability issues in the supply chain will play an increasingly important role in traceability requirements, there is no explicit concern for sustainability in traceability definitions. The recent European legislation banning the import of certain deforestation-free products from 2024 is at the forefront of sustainability-based traceability criteria. However, even the United Nations Economic Commission for Europe's (UNECE, 2016) Handbook on Sustainable International Trade does not differentiate between these criteria.

Traceability is an important subject in agri-products international trade. Countries require detailed information about the origin, production, processing, and distribution of agricultural products. With traceability information, importers gain confidence that products meet safety and quality requirements (Tharatipyakul and Pongnumkul, 2021). This is essential because foreign markets have stringent safety, quality, and origin requirements for the products they consume (Opara and Mazaud, 2001) and these requirements are expressed in country-specific regulations, many of which are mandatory for agrifoods imports.

Traceability regulations are listed in chapters A85 and B85 (based on UNCTAD classification of NTMs) at SPS measures (starting with the letter A) and TBT (B), respectively. SPS measures describe rules restricting substances, guarantee food security, and prevent dissemination of plagues and diseases. They also include certification, tests and inspection requirements. TBT measures provide a set of technical measures regarding products characteristics, such as technical characteristics, quality requirements production methods and procedures and other rules such as labeling and packaging, consumer and national security. Both include compliance assessment measures (UNCTAD, 2019).

UNCTAD documents (UNCTAD, 2019; 2023a; 2023b) explain that measures are divided into subcategories of traceability requirements based on their clear objectives in terms

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of origin and processing. We consider traceability related to the "Origin of materials and parts", which aggregated A851 and B851 measures as "Inputs". The aggregation of SPS and TBT measures occurs because require the same information, such as the origin of materials used in the final product, such as the location of the farm, the name of the farmer, or the origin of pesticides. Another traceability-related NTM is "Processing History", which aggregated A852 and B852 measures as "Processing". Both measures are about processing history, which requires the disclosure of information about all stages of the production process, including location, processing methods, and equipment used. An example of the application of Input and Processing NTMs is in the production of fruit, where it may be necessary to disclose information about the farm where the fruit was grown, the location of the packing facility, and the identity of the final distributor.

Regulatory measures, such as NTMs, impact production costs and competitiveness (Navaretti et al., 2018). These costs can vary based on the regulatory environment, company size, the technology used, product and production process characteristics, supply chain structure and complexity, the volume of information to be stored and others (Asioli, Boecker and Canavari, 2014).

Compliance with NTMs typically involves three types of costs that impact trade flows, domestic market structures, and welfare (Melo and Shepherd, 2018). In the context of compliance with traceability requirements, producers may face these three costs. Implementation costs, which deal with the resources that companies must allocate to comply with each regulation. Process adaptation costs, which include the capital expenditures required to meet specific standards. As well as costs associated with meeting technical requirements, which involve additional improvements to products and processes. According to Melo and Shepherd (2018) the first two types of costs are fixed costs, while the latter is considered a variable cost. Medin (2003) suggests that fixed and variable costs almost equally influence export capacity. However, proposes an approach similar to that of Fiankor, Haase and Brümer (2021), arguing that fixed costs impact the likelihood of exporting, whereas variable costs presumably do not affect already established commercial relationships.

Understanding the compliance costs faced by exporters is important to explaining the various impacts of NTMs, such as traceability requirements. According to Melitz (2003) and Helpman, Melitz and Rubinstein (2008), the implementation of regulations, such as traceability, leads to a selection effect by increasing the costs of trade. This differentiation can determine which producers participate in trade.

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The fixed costs can create distinctions between exporting and non-exporting firms, even within the same import market. Melitz (2003) emphasizes that this heterogeneity arises from productivity differences: more productive firms are more competitive in the global market, while less productive firms are not. Compliance with traceability requirements necessitates initial investments (fixed costs) in appropriate systems for tracking and documenting production processes, including software acquisition and training. Additionally, activities such as market research, technology to adapt processes to comply with foreign regulations, the distribution network establishment in foreign markets and trading costs, also are fixed costs (Medin, 2003).

In already established trade relationships, fixed costs have likely been incurred. Moreover, bilateral relationships with higher import volumes may indicate that the exporter has gained extensive experience in meeting the importer's requirements. This aligns with the concept of "learning by doing," where higher volumes in bilateral trade relationships enable exporters to handle regulations more efficiently as they gain experience. However, for countries still in the process of consolidating trade relationships, this fixed cost can be relatively high, thereby negatively affecting the probability of trade (Fiankor, Haase and Brümer, 2021).

The variable cost component refers to the cost of adjustments incurred in trade relationships for products that have already exceeded entry costs (Fiankor, Haase e Brümer, 2021) and cover expenditures related to ongoing compliance with regulations, such as control activities, testing, audits, the renewal of specific components, operational costs for recording and continuously monitoring production and for information storage. These costs are necessary to ensure the products eventually complies with NTMs, for goods already traded. Experience in complying with specific regulations in one country can facilitate similar processes in other countries (Grant, Peterson and Ramniceanu, 2015). The impact of these costs is uncertain because, while they may reduce export volumes due to higher expenses, they could be offset by improved market access resulting from enhanced quality and the availability of more information to consumers. These costs are generally higher when the regulatory differences between partner countries are significant, necessitating greater adaptation by the exporter (Shingal and Ehrich, 2022).

Another important consideration is the trade relationship between the exporter and importer. Impacts on trade costs tend to occur when the importer's requirements are more stringent than those of the exporter. For instance, if an exporter already enforces strict traceability requirements domestically, there may be no additional costs if these

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requirements are stricter than those of the importer (Winchester et al., 2012; Ferro, Otsuki and Wilson, 2015; Shingal et al., 2020). If the traceability requirements, such as those related to input measures, for example, are more rigorous in the importing country, additional costs will be incurred by the exporter. Therefore, the adoption of NTMs may or may not increase trade costs.

The impact of NTMs on trade is unpredictable and ambiguous. Studies demonstrate a dual impact: "standards as barriers" and "standards as catalysts" (Santeramo and Lamonaca, 2022). These contradictions arise because, while technical NTMs aim to improve the quality of goods, reduce information asymmetries and promote sustainability, they can also create trade barriers due to the costs associated with compliance (Navaretti et al., 2018). A positive result indicates that NTMs lead to an increase in import demand, outweighing the costs. Conversely, a negative effect occurs when the compliance costs of NTMs outweigh the positive demand effect (Xiong and Beghin, 2014). According to Maskus, Otsuki and Wilson (2013), exporters must diversify their production to meet the varying demands of different markets, which can lead to higher costs. However, this may confer advantages on markets that can adapt their production processes compared to less adaptable countries. This explains why regulatory requirements act as commercial catalysts for countries with already established trade flows and as barriers for countries that are not commercially consolidated. Fiankor, Haase e Brümer (2021) find that for larger trade flows (90% >), the negative effects of NTMs are less significant or even non-existent compared to lower percentages of trade flows.

Santeramo and Lamonaca (2022a) argue that the costs associated with NTMs may be higher for developing countries compared to developed ones. Food safety requirements vary based on the technologies available in each country, their operational and financial capacity to meet international standards. Analyses of countries with different development levels show varied results: NTMs benefit imports of meat, vegetables, and meat and fish preparations in developed countries but negatively affect the imports in fish and fruits. Conversely, developing countries benefit your imports from NTMs regulations in the fruit and vegetable sector. This reinforces the idea that NTMs do not have a uniform impact and vary depending on the industry and the income level of the countries involved in trade.

This ambiguity prevents the generalization of results related to NTMs and hinders the understanding of their true regulatory impact on trade. To address this issue, the literature suggests conducting analyses for specific NTMs within particular sectors (Shang and Tonsor, 2019; Peci and Sanjuán, 2020; Traoré and Tamini, 2021). This

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approach enhances the interpretation of results and supports the formulation of more effective trade policy proposals tailored to different sectors and regions.

Although Bispo et al. (2024) attempted to contribute to the field, their results were ambiguous and did not reveal a clear predominance of any specific effect related to traceability. The findings suggest that traceability measures can have heterogeneous effects. Multilateral information disclosure requirements tend to have positive trade effects, while bilateral information disclosure often results in negative effects. Other measures yield mixed outcomes depending on the type of 16 NTMs measures analysed. The analysis concludes that there is no consistent pattern in the effects. This reinforces the idea that NTMs must be investigated on a case-by-case basis, as their effects cannot be generalized.

#### **3 METHODOLOGY**

#### 3.1 Empirical model and estimation method

The empirical model adopted in this study is based on the theory developed by Anderson and Van Wincoop (2003). The gravity model is derived from supply and demand functions for exporting and importing countries under general equilibrium conditions. In the demand system, is used a utility function model of the Constant Elasticity of Substitution (CES) type, in which consumers in the importing country maximize their utility subject to budget restrictions. The result of maximization is expressed by the following structural form:

$$X_{ijkt} = \frac{E_{jkt}Y_{ikt}}{Y_{kt}} \left(\frac{\tau_{ijkt}}{P_{jkt}\Pi_{ikt}}\right)^{1-\sigma_k} e_{ijkt}$$
(1)

$$(\Pi_{ikt})^{1-\sigma_k} = \sum_j \left(\frac{\tau_{ijkt}}{P_{jkt}}\right)^{1-\sigma_k} \frac{E_{jkt}}{Y_{ikt}}$$
(2)

$$(P_{jkt})^{1-\sigma_k} = \sum_{i} \left(\frac{\tau_{ijkt}}{P_{jkt}}\right)^{1-\sigma_k} \frac{Y_{ikt}}{Y_{kt}}$$
(3)

Where  $X_{ijkt}$  represent exports of good k from country i to country j in year t refer to the production of good k in country i and the global aggregate production of k in year

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*t*, respectively;  $E_{jkt}$  is country j expenditure to obtain the good *k* in year *t*,  $\tau_{ijkt}$  are the trade costs incurred by exporters for importer *j* in year *t*,  $\sigma_k$  is the elasticity of substitution between all goods,  $e_{ijkt}$  is the random error term, and  $P_{jkt}$  and  $\Pi_{ikt}$  are the Multilateral Resistance (MR) terms, being the price indices for each economy *j* and *i*, respectively.

The MR terms refer to the average resistance to trade between a country and its trading partners. The inclusion of the terms  $P_{jkt}$  and  $\Pi_{ikt}$  indicates that trade flows do not only depend on the costs between countries *i* and *j*, but also on the costs between these countries and their other trading partners. Anderson and Van Wincoop (2003) did not consider the inclusion of terms that represented MR, which could lead to biased estimates due to the omission of these variables. Therefore, the incorporation of these terms is crucial for a more accurate and comprehensive analysis of trade relations between countries.

Anderson and Van Wincoop's (2003) theoretical model also included a log-linear function with variables representing transaction costs, such as distance, trade agreements, contiguity, etc. From this information, and by applying the logarithm to equation (1), we obtain the gravitational equation. Therefore, trade between countries i and j depends on the income of the countries, certain trade barriers, and MR.

The main recommendations for using the gravity model by Yotov et al. (2016), Anderson, Larch and Yotov (2020) and Larch, Luckstead and Yotov (2024) are as follows,

- Use panel data to estimate the gravity model: the use of a panel generates more consistent estimates and allows the inclusion of high-dimensional FE to address the problem of endogeneity of trade policy variables. This FE are a sophisticated econometric technique employed to account for unobserved heterogeneity in panel data models, particularly in the context of international trade analysis using structural gravity models. These effects are essential for addressing potential biases that arise from unobservable factors that vary across entities such as countries, sectors, or country pairs, but remain constant over time.
- Use panel data with time intervals rather than consecutive years: this approach provides a more accurate adjustment of trade flows and more robust results of policy changes or trade costs.

 Include time-varying directional FE for the importer and exporter: the use of these FE makes it possible to control for unobservable MR and other observable or unobservable characteristics that vary over time for both countries.

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- Include country pair FE: these effects correct the problem of endogeneity of trade policy variables and capture the effects of time-invariant bilateral trade costs.
- Use the Poisson Pseudo Maximum Likelihood (PPML) method to estimate the gravity model: this estimator takes into account the heteroscedasticity present in many trade data and uses the information contained in zero trade flows. In this study, PPML-HDFE (High-Dimensional Fixed Effects) was used, as suggested by Correia et al. (2020). It is a statistical method used to deal with a large number of categories or levels for FE. This combination allows you to efficient control country- or country-pair specific FE in gravity models, even when there are a large number of categories.

The gravitational equations in their multiplicative form, as estimated in this study, are represented in equations (4), (5), and (6). The variables used in these equations are detailed in table 1.

$$M_{ijkt} = \exp\left(\beta_0 NTMinput_{ikt} + \gamma_{it} + \delta_{jt} + \eta_{ij} + \tau_k\right) + \varepsilon_{ijkt}$$
(4)

$$M_{ijkt} = \exp(\beta_0 NTM process_{ikt} + \gamma_{it} + \delta_{jt} + \eta_{ij} + \tau_k) + \varepsilon_{ijkt}$$
(5)

 $M_{ijkt} = \exp(\beta_0 NTMinput_{ikt} + \beta_1 NTMprocess_{ikt} + \beta_2 NTMinput_{ikt} * NTMprocess_{ikt} + \gamma_{it} + \delta_{jt} + \eta_{ij} + \tau_k +) + \varepsilon_{ijkt}$ (6)

#### **TABLE 1**

# Description and data source of the variables to be estimated using the gravitational equation

	Variable				
M <sub>ijkt</sub>	Nominal value of imports <sup>1</sup> of good <i>k</i> by country <i>i</i> from country <i>j</i> in year <i>t</i> . The subscripts <i>i</i> , <i>j</i> and <i>k</i> are respectively 56 importing countries, <sup>2</sup> 53 exporters, <sup>3</sup> 2,081 six-digit products according to the Harmonized System classification of agribusiness products according to the Ministry of Agriculture, Livestock and Food Supply from Brazil1,2 and t is the period between 2012 and 2021.	Current USD	UN CONTRADE – World Integrated Trade Solution (WITS)		
NTMinput <sub>ikt</sub>	Dummy take value 1 if importing country $i$ imposes traceability measures related to the origin of inputs for good $k$ in year $t$ ; 0 otherwise.	Binary			
NTMprocess <sub>ikt</sub>	Dummy take value 1 if importing country <i>i</i> imposes traceability measures related to processing for good <i>k</i> in year <i>t</i> ; 0 otherwise.	Binary	UNCTAD – The Global Database on Non-Tariff Measures		
NTMinput <sub>ikt</sub> * NTMprocess <sub>ikt</sub>	The variable represents the combined effect of two dummies variables, each taking the value of 1 if the importing country imposes traceability measures (input and processing) for good $k$ in year $t$ .	Binary	(TRAINS)		

(Continue)

<sup>1.</sup> Although the theoretical model is defined in terms of country exports and for j ( $M_{ijkt}$ ), import data are used because they are more reliable traditions. Import flows are monitored more carefully by customs agents, as they are subject to import tariffs (Baldwin and Taglioni, 2006).

<sup>2.</sup> Importing countries: Argentina, Australia, Austria, Belgium, Brazil, Canada, Chile, China, Colombia, Czech Republic, Denmark, Egypt, Finland, France, Germany, Greece, Hong Kong, Hungary, India, Indonesia, Ireland, Israel, Italy, Japan, Lebanon, Malaysia, Mexico, Morocco, Netherlands, New Zealand, Nigeria, Norway, Pakistan, Peru, Philippines, Poland, Portugal, Romania, Russia, Saudi Arabia, Singapore, Slovakia, Slovenia, South Africa, South Korea, Spain, Sweden, Switzerland, Taiwan, Thailand, Turkey, Ukraine, United Arab Emirates, United Kingdom, United States, and Vietnam.

<sup>3.</sup> Exporting countries: Argentina, Australia, Austria, Belgium, Brazil, Canada, Chile, China, the Czech Republic, Denmark, Finland, France, Germany, Hong Kong, Hungary, India, Indonesia, Iran, Ireland, Israel, Italy, Japan, Kazakhstan, Kuwait, Malaysia, Mexico, the Netherlands, New Zealand, Nigeria, Norway, Peru, the Philippines, Poland, Portugal, Qatar, Romania, Russia, Saudi Arabia, Singapore, the Slovak Republic, South Africa, South Korea, Spain, Sweden, Switzerland, Taiwan, Thailand, Turkey, Ukraine, the United Arab Emirates, the United Kingdom, the United States, and Vietnam.

#### (Continuation)

	Units Source		
$egin{aligned} & \gamma_{it} \ & \delta_{jt} \ &  au_k \ & \eta_{ij} \end{aligned}$	Importer-year ( $\gamma_{it}$ ) and exporter-year ( $\gamma_{it}$ ) FE, which control specific phenomena in each country and that vary over time; <sup>3</sup> $\tau_k$ is the product EF and $\eta_{ij}$ is the EF for the country pair, which controls for pair- specific phenomena that do not vary over time.	Econome	trics procedures
E <sub>ijkt</sub>	Error term		

#### Authors' elaboration.

Notes: <sup>1</sup> Available at: https://indicadores.agricultura.gov.br/agrostat/index.htm.

- <sup>2</sup> We used the agri-products categories defined by Ministry of Agriculture, Livestock and Supply from Brazil. The products were grouped according to the following sectors: live animals (except fisheries); beverages; cocoa and cocoa products; coffee; meat; cereals, flours and preparations; tea, mate and spices; soy complex; sugar and alcohol industry; leather, leather products; other products of animal origin; other products of plant origin; fibers and textile products; fruits (including nuts and chestnuts); tobacco and its products; dairy; fisheries; live plants and floricultural products; others food products; bee products; forest products; vegetables, legumes, roots and tubers; oil products (excludes soy); animal feed; juices.
- <sup>3</sup> The inclusion of import-year and export-year FE characterizes the structural gravity model. The inclusion of these FEs prevents the use of each country's individual gross domestic product (GDP) in the estimated models, since these effects are already captured by the FEs.

For the *NTMinput*<sub>ikt</sub> measure, was conducted an aggregation of measures A851 (SPS) and B851 (TBT), which pertaining to the "origin of materials and parts". Similarly, for the *NTMprocess*<sub>ikt</sub> measure, A852 (SPS) and B852 (TBT) were aggregated, which report to "processing history". The variable *NTMinput*<sub>ikt</sub> \* *NTMprocess*<sub>ikt</sub> captures the combined impact of both traceability measures – related to inputs and processing – on trade. It assesses whether the simultaneous implementation of these measures by the importer influences the trade. The estimated equations in (4) and (5) eliminate the possible mutual interference of the NTMs. The interaction between the variables, in turn, allows us to evaluate how one can influence the result of the other, revealing the additional effect that occurs when both are present. When estimating equation (6), considering the interactions between the variables *NTMinput*<sub>ikt</sub>,  $\beta_1$  (*NTMprocess*<sub>ikt</sub>)

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and  $\beta_2$  (*NTMinput<sub>ikt</sub>* \* *NTMprocess<sub>ikt</sub>*) are calculated as follows:1)  $\beta_0$  (coefficient) is  $(\beta_0 = 1) - (\beta_0 = 0)$  at  $\beta_1 = 0$ ; 2)  $\beta_1$  (coefficient) is  $(\beta_1 = 1) - (\beta_1 = 0)$  at  $\beta_0 = 0$ ; 3)  $\beta_2$  (coefficient) is  $[(\beta_0 = 1) - (\beta_0 = 0)$  at  $\beta_1 = 1] - [(\beta_0 = 1) - (\beta_0 = 0)$  at  $\beta_1 = 0]$ . For inputs and processing traceability measures, the analysis included measures that are either bilateral, applied by an importer to a specific exporter, or multilateral, applied by an importer to all exporters.

The inclusion of country pair FE is relevant to correct the endogeneity between trade flows and certain explanatory variables, such as NTMs (Yotov et al., 2016). These effects capture the influence of traditional gravity model variables, such as bilateral distance and colonial relationships, which, as shown by Agnosteva, Anderson and Yotov (2019), have limitations as proxies for bilateral trade costs. Baier and Bergstrand (2007) argue that incorporating these FE provides a more accurate representation of bilateral cost measures than standard variables.

After estimating the regression for all agri-products, equations (4), (5) and (6) were applied to the meat, fruit and fisheries sectors. These sectors were selected based on the products that received the most traceability related measures during the analyzed period. Furthermore, traceability measures are developed and implemented at the sector-specific level, which means their effects on trade are likely to vary across different sectors. Estimates were made for different income levels of the exporter and importer. Upper-middle and lower-middle income countries were grouped as "developing" countries, while high-income countries were considered as "developed" countries.

The models were estimated in three different ways: i) developing countries as exporters (lower middle income and upper middle income) and developed countries (high income) as importers; ii) exporters and importers are developing countries; and iii) exporters and importers are developed countries.

The literature shows that market access in high-income countries differs according to the income level of the exporting country (Murina and Nicita, 2017; Santeramo and Lamonaca, 2022). The trade effects of traceability measures (input and processing) differ between developed and developing countries due to differences in consumer preferences, institutional quality, production cost advantages and information asymmetry (Santeramo and Lamonaca, 2022). Consequently, the impact of traceability measures is likely to vary across different economic contexts. This analysis is relevant to understand

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the dynamics of international trade and identifying potential variations in the impact of traceability-related measures based on the economic profiles of trading partners.

The analysis period is from 2012 to 2021 because it is the most recent period with available data. Wall and Cheng (2005) and Yotov et al. (2016) recommend using panel data with time intervals to account for adjustments in trade flows due to changes in trade policy costs, as these effects are typically not immediate. Consequently, intervals of 3 and 5 years were tested, as recommended by Olivero and Yotov (2012), to more accurately capture the delayed effects of policy changes. We chose a time interval of 3 years, as did Santeramo and Lamonaca (2022), Carneiro et al. (2022) and Anderson, Larch and Yotov (2020). Estimates were also calculated for a 5-year time interval, but no significant changes were observed.<sup>4</sup> Therefore, only the estimates with the 3-year interval are presented.

#### 3.2 Data processing

A consortium led by UNCTAD is responsible for collecting and systematizing mandatory regulations that may impact foreign trade, characterized as NTMs. Teams periodically collect these measures in several countries, but not all at once, which are identified in national legislative documents. Each provision is classified into specific codes, although the same regulation may cover several NTMs. However, there are limitations in the use and interpretation of data, such as the omission of measurements and the possibility of double counting due to notifications in different committees. These limitations are related to the nature and process of collecting information (Melo and Nicita, 2018).

Although UNCTAD provides a file in *dta* format with data on treated NTMs, the data has limitations that prevented its use in this study. The information is out of date. For some countries/blocs relevant in the context of international agricultural trade, such as the European Union, the most recent year with records of NTMs issued was 2018. However, in the UNCTAD detailed search database has more complete and up-to-date information, with data collected until 2021, which made this information more suitable for the present study. Based on this, a systematic collection of all information available on the platform was carried out to incorporate all countries that issued and were affected by NTMs. The data covers all products classified in six digits according to the 2012 harmonized commodity classification system. The queries resulted in 85,632 NTMs.

<sup>4.</sup> The results of the estimates for the 5-year time interval available at: https://docs.google.com/ document/d/1dOYU6IeB5b4NVmz72xFZk0sPofQgw2PPdYD5I4PO9VE/edit?usp=sharing.

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After data collection, data processing was carried out in four main stages: i) base reduction through filters without pre-treatment; ii) treatment of sample countries; iii) treatment of products; and iv) verification of the NTMs implementation period. In the first stage, a simple filtering was performed based on the NTMs codes, keeping only those related to traceability. Next, a temporal filter was applied to keep only the NTMs implemented between 2012 and 2021. Subsequently, it was decided to consider the collection years 2019, 2020 and 2021 as a single year, removing duplicate NTMs. This strategy allowed us to reduce the number of expired NTMs in older periods, while maintaining a significant number of observations with more recent implementation dates.

The objective of the second stage was to select only those countries that imposed NTMs that represented, on average, 95% of global imports between 2012 and 2021, and the affected countries responsible for 95% of global exports in the same period. To achieve this, pre-treatment of the emitting and affected countries was necessary. In the case of countries that imposed NTMs, only the European Union was split into its member countries. For the affected countries, the original data grouped them into: trading blocs; countries separated by commas (in a single cell); "all countries in the world except (...)" and "all countries in the world".

The next step was to divide the European Union into all its countries; groups of countries contained in a single cell were separated by row; and in the case of the lines containing "all countries in the world except (list of countries)" it was replaced by the sample exporters and the countries contained in the list of exceptions were excluded. The third and most complex step was the treatment of the products. This was due to three reasons: first, the products or sets of products affected by a given NTM were grouped in a single cell in the database; second, product codes were at different levels of aggregation (2, 4, 6, 8 and 10 digits); Third, in addition to the codes, there were additional explanations of the products affected by NTMs, containing letters and symbols from different languages, as well as numbers to provide more precise specifications. Therefore, it was necessary to carry out a data cleaning process to remove unwanted characters without compromising the classification of products according to the harmonized classification system.

Then, the products were disaggregated to achieve the 6-digit classification. This involved disaggregating the 2 and 4-digit products and aggregating the 8 and 10-digit products, ensuring that all products were classified into 6 digits. The fourth and final step aimed to ensure that the NTMs were active until their expiration date. In the UNCTAD database, each NTM has an implementation date and may have an expiration date. NTMs were found with expiration dates, but some were set to the year "9999" and had

an empty expiration date. Then, for expiration dates after 2021, those containing the year 9999 and empty expiration dates, it was considered that the NTMs were valid until 2021, the limit year of the analysis. The entire process of treating the NTM base sought to establish coherence with the base for researchers provided by UNCTAD. All procedures were performed using R software.

#### **4 RESULTS AND DISCUSSIONS**

#### 4.1 Descriptive analysis

The descriptive analysis objective is to identify some characteristics of the sample included in the study. The total number of traceability NTMs in our sample was 150. Input NTMs totaled 122, of which 91 were imposed by high-income countries and 31 by middle-income countries. Processing NTMs totaled 28, of which 18 were imposed by high-income countries and 10 by middle-income countries. However, to obtain a greater level of detail on the NTMs scenario, it was necessary to disaggregate the NTMs by income level of the affected country (table 2) and by affected sector (table 3). This disaggregation results in a larger number of NTMs because the same NTM can affect more than one country and products from more than one sector.

In order to identify whether there is a difference in the number of countries affected by traceability NTMs according to income level, it was necessary to disaggregate the NTMs based on the affected country. In cases where a bilateral NTM affected a specific group of countries, it was accounted for by multiplying it by the number of affected countries in the group. This treatment resulted in a higher number of NTMs. From the disaggregation of NTMs by affected country, as shown on table 2, the number of NTMs resulted in 275.<sup>5</sup> The data showed that most of the NTMs are related to Input and analyzing by type of NTMs, the SPS NTMs are more prominent than TBTs, especially the A851 type. Furthermore, the data show that 109 NTMs were issued by high-income countries, approximately 73%, while 41 were imposed by middle-income countries, about 27%. High-income countries were also the most affected by these measures, when bilateral. In total, 145 (53%) were specifically targeted at high-income countries and 21 (8%) at middle-income countries. Multilateral measures totaled 108, representing 39%.

<sup>5.</sup> The total number of NTMs was calculated by disaggregating the affected countries when the NTM was not multilateral. This means that the same NTM can be issued to more than one country and still be considered bilateral. In these cases, the count of a single NTM is multiplied by the number of countries affected by it. In the case of multilateral NTMs, the count is unique and the partner is counted as "World".

At the country level, the imposition of traceability NTMs related to input and processing was concentrated, with only 5 countries imposing around 45% of all measures. As shown in figure 1, the country that issued the most NTMs was United States, with a total of 20 NTMs, 12 of which were related to processing traceability and 8 related to input traceability. Next, Peru and New Zealand stand out with the issuance of, 16 and 15 NTMs, respectively.

#### TABLE 2

Number of NTMs by income level of countries imposing NTMs and by countries affected by them

		Imposing NTMs		Afected by NTMs		Ms
NTM type	Total	High income	Middle income	High income	Middle income	Multilateral
Input	237	91	31	132	17	88
A851	193	51	27	132	17	44
B851	44	40	4	0	0	44
Processing	38	18	10	14	4	20
A852	36	18	8	14	4	18
B852	2	0	2	0	0	2
Total	275	109	41	145	21	108

Authors' elaboration.

Obs.: The number of NTMs from affected countries is greater than the number of NTMs from imposing countries because it was necessary to disaggregate groups of countries affected by a single NTM.

When analyzing the countries affected by these NTMs, on the other hand, the data show that NTMs tend to affect countries more equally. The main reason is that approximately 39% (108) of the NTMs are multilateral, that is, they affect all countries. Bilateral NTMs, in total, were shown to target almost all countries in the sample. Australia and Spain were the countries most affected by bilateral NTMs, with 14 and 11, respectively. It is important to note that, when considering the geographical distribution of NTMs, the results may reflect disparities in the data collection methodology used by UNCTAD. In addition, transparency may also differ across countries. Table 3 shows the number of NTMs based on sectors. Overall, agri-products were affected by 415<sup>6</sup> traceability NTMs, with the majority being of the SPS type, accounting for about 98%.

#### FIGURE 1

**Countries imposing traceability NTMs** 

NTM type: • input • processing



Authors' elaboration.

Obs.: The bubbles represent the total of traceability NTMs, with the green portion representing input NTMs and the blue portion representing the quantity of processing NTMs.

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#### FIGURE 2

#### **Countries affected by traceability NTMs**

TM type: 
 Input
 Processing



Authors' elaboration.

Obs.: The bubbles represent the total of traceability NTMs, with the green portion representing input NTMs and the blue portion representing the quantity of processing NTMs.

NTM type	Agri-products	Fruits	Meats	Fisheries
Input	239	12	22	11
A851	235	12	22	11
B851	4	0	0	0
Processing	176	18	6	7
A852	172	17	6	7
B852	4	1	0	0
Total	415	30	28	18

#### TABLE 3

#### Number of NTMs by agri-products sectors

#### Authors' elaboration.

At the sector level, fruits have the highest number of NTMs, followed by meat and fish, with a predominance of SPS measures, and for the last two NTMs related to inputs. Although

the number of NTMs does not seem to be significant, when disaggregating the products of these sectors into 6 digits of the harmonized system of classification of goods, they are the sectors most sensitive to these types of NTMs, corresponding to 49% of NTMs.

#### **4.2 Econometric results**

The econometric results presented in the "All countries" column show the results for all countries in the sample. The other columns correspond to specific trade flows: column (1) represents exports from developing countries to developed countries; (2) represents trade between developing countries; and (3) represents trade from developed countries to other developed countries. As the purpose of the paper is to analyze agricultural goods it does not seem important to include exports from developed to developing countries. Column (1) is particularly interesting because high-income importers tend to impose stricter regulations than middle-income countries. The literature consistently emphasizes that high-income countries have no difficulty meeting the requirements set by emerging countries, because they have stricter regulations and face no technical difficulty and significant costs in serving markets with more lenient requirements (Ferro, Otsuki and Wilson, 2015; Fiankor, Haase e Brümer, 2021; Traoré and Tamini, 2021; Santeramo and Lamonaca, 2022). Disdier et al. (2008), for example, conclude that SPS measures implemented by developed countries have an insignificant impact on OECD exports. This justifies the exclusion of trade between high-income exporters and middle-income importers from the analysis.

To facilitate analysis, NTMs that showed significant results were highlighted in red to represent negative impacts and in green to represent positive impacts. The NTMs are applied at the sectoral level, and the magnitudes and observed signs vary among the agri-products, fruit, meat and fisheries sectors. Additionally, the impact differs between developed and developing countries. This variation can be explained by the differing consumer preferences regarding food quality and safety standards in different countries; developed countries tend to have stronger institutions for implementing and monitoring these standards, which can pose challenges for developing countries. Moreover, information channels about food risks differ between developed and developing countries (Santeramo and Lamonaca, 2022).

The results in table 4 showed that considering all agri-products the effect of traceability NTMs related to input and processing (equations 4 and 5) is not strong enough to be determined conclusively from the data. The lack of significance highlights the complexity of traceability systems' impacts on trade.

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Bispo et al. (2024) estimated the effects of traceability for all countries and across different income levels, considering measures A851 and B851 (we referred to as "Input") and A852 and B852 (we referred to as "Processing"). They found significant positive results for multilateral A851 measures and negative results for bilateral A851 measures. For B851 measures, the results were positive but not significant for both multilateral and bilateral contexts. For processing measures, multilateral A852 and B852 results were negative, with A852 being insignificant and B852 significant. These mixed results illustrate the diverse effects traceability measures can have depending on the specific circumstances and the nature of the trade relationships involved. Santeramo and Lamonaca (2019) argue that generalizations are neither feasible nor sensible. The variation in trade effects can be attributed to differences in food safety regulations and standards across countries, as well as the varying preferences of consumers regarding food quality and safety. These factors can influence the need for traceability systems differently, depending on the country and sector.

Variables	All countries	(1)	(2)	(3)
NTMinnut	0.033	0.029	0.209	0.029
WI Milipat	(0.105)	(0.251)	(0.258)	(0.090)
Comstant	8.928***	9.436***	9.825***	9.037***
Constant	(0.017)	(0.046)	(0.004)	(0.021)
Observations	16,756,740	3,385,448	1,823,076	7,336,212
R <sup>2</sup>	0.567	0.635	0.636	0.632
NTMprocess	-0.009	0.222	-0.559	0.073
in improcess	(0.237)	(0.397)	(0.379)	(0.191)
Comstant	8.934***	9.414***	9.828***	9.039***
Constant	(0.016)	(0.051)	(0.000)	(0.013)
Observations	16,756,740	3,385,448	1,823,076	7,336,212
R <sup>2</sup>	0.567	0.635	0.636	0.632

# TABLE 4Estimation results for all agri-products

Authors' elaboration.

- Notes: <sup>1</sup> Model (1): developing countries as exporters (lower middle income and upper middle income) and developed countries (high income) as importers. Model (2): exporters and importers are developing countries. Model (3): exporters and importers are developed countries.
  - <sup>2</sup> Values in parentheses refer to robust standard errors clustered by country pair.
     \* p < 0.10; \*\* p < 0.05; \*\*\*p < 0.01. FEs are for importer year, exporter year, product, and country pair. Missing values in the dependent variable have been replaced with zero, indicating that there is no bilateral trade for the pair combination of country, product, and year.</li>

### **DISCUSSION PAPER**

The results presented in table 5 reveal the interaction effects between the input and processing traceability measures on agricultural trade (equations 6). When the regression is conducted with only the *NTMinput* variable, the results reflect the difference between the effect of *NTMinput* when *NTMprocess* = 0 and *NTMinput* = 0 and *NTMprocess* = 0. In other words, it measures the isolated effect of *NTMinput*, when there is only the effect of this measure, without considering the presence of other measures, such as *NTMprocess*. However, when including the *NTMinput* \* *NTMprocess* interaction, the result shows the change in the effect of *NTMinput* on the value of exports when *NTMprocess* is also present, compared to when *NTMprocess* is not present. Basically, it measures how much the effect of *NTMinput* on the value of exports is altered by the presence of *NTMprocess*. This reflects the individual impacts of the two measures also how they interact and reinforce each other in trade.

Variables	All countries	(1)	(2)	(3)
NTMinnut	0.053	-0.273***	0.236	0.003
ΜΠΜΠΡαί	(0.047)	(0.084)	(0.262)	(0.059)
NTMnrocass	-0.502***	-0.377	0.288	-0.365*
NT MPT OCESS	(0.173)	(0.426)	(0.285)	(0.218)
NTMinnut * NTMnrocess	0.453	0.864	-1.816***	0.447*
111 Milipul * 111 Mpi 00033	(0.282)	(0.536)	(0.593)	(0.256)
Constant	8.928***	9.431***	9.825***	9.038***
Constant	(0.017)	(0.051)	(0.004)	(0.021)
Observations	16,756,740	3,385,448	1,823,076	7,336,212
R <sup>2</sup>	0.567	0.636	0.635	0.601

# TABLE 5Estimation results for all products, with interaction

Authors' elaboration.

- Notes: <sup>1</sup> Model (1): developing countries as exporters (lower middle income and upper middle income) and developed countries (high income) as importers; model (2): exporters and importers are developing countries; and model (3): exporters and importers are developed countries.
  - <sup>2</sup> Values in parentheses refer to robust standard errors clustered by country pair.
     \* p < 0.10; \*\* p < 0.05; \*\*\*p < 0.01. FEs are for importer year, exporter year, product, and country pair. Missing values in the dependent variable have been replaced with zero, indicating that there is no bilateral trade for the pair combination of country, product, and year.</li>

### **DISCUSSION PAPER**

For the sample including all countries, first column, and developing countries exporting to developed countries (1), the coefficient (NTMinput \* NTMprocess) is not significant, suggesting that the combined impact of these requirements is unclear within this context. However, in the case of trade between developing countries (2), the interaction term is -1.816\*\*, indicating a significant negative impact. This suggests that combining input and processing requirements may impose an excessive regulatory burden, resulting in higher compliance costs when two traceability measures are applied simultaneously. High conformity costs can hinder trade in developing nations, as producers in these countries may face difficulties in adapting to multiple requirements, which could be seen as different or particularly costly when combined. Conversely, for trade between developed countries (3), the coefficient is 0.447\*, suggesting that the interaction of input and processing requirements has a positive impact. This might be because developed countries possess the necessary resources and infrastructure to manage these combined requirements effectively, turning them into a competitive advantage. For producers who have already adapted to one measure, the cost of complying with an additional measure could be less than anticipated, especially if the systems and processes established for the first measure can be leveraged to meet the second. However, in cases where the measures are distinct and involve substantially different compliance processes, the cost could increase, reflecting the complexity and resource demands of adhering to both requirements. Therefore, the impact of combined measures depends significantly on how closely related the measures are and the capacity of producers to integrate them efficiently into their existing systems.

*NTMinput* shows that for developing countries exporting to developed countries in column (1), the coefficient is -0.273\*\*\*, indicating a significant negative impact. This suggests that developing countries face significant costs in complying with input traceability requirements when exporting to developed countries, and these costs are not offset by increased trade in traceable products. However, it is possible that as exports increase, these costs are diluted, promoting economies of scale for the exporter.

The variable *NTMprocess* has a significant negative coefficient of -0.502\*\*\* for all countries, indicating that processing traceability requirements significantly hinder trade. This may be due to the additional costs and complexities involved in maintaining detailed records at each stage of production, particularly when there are no traceability requirements for an earlier stage in the production chain, such as inputs. Furthermore, for trade between developed countries, the coefficient is -0.365\*, indicating a significant negative impact, although less pronounced than in other contexts. This implies that even

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developed countries face some difficulties with processing traceability due to the high complexity of tracking and the need for traceability information for inputs that come from other developing countries that do not have well-established traceability systems. In the context of developing countries exporting to developed countries, the coefficient is insignificant, suggesting that processing requirements do not significantly affect this trade flow. For individual sectors, significant results were observed.

For meats (table 6), all traceability measures were positive and significant, except for trade between high-income countries, where the results were negative but insignificant. Processing traceability measures havea higher magnitude than those for input traceability. According to UNCTAD definitions, input traceability involves keeping detailed records about the origins of materials used, such as the farm where the animal was raised and any feed or medicines administered. Processing traceability tracks the meat through each stage of production, from slaughtering and deboning to packaging. Each step of processing presents risks of microbiological, chemical, or physical contamination. This traceability measure allows for the rapid identification and isolation of contamination sources, preventing the spread of disease and enabling swift responses to incidents such as contamination outbreaks or product recalls. This, in turn, reduces the costs associated with widespread disease treatment and the losses of infected animals (Greene, 2010). While input traceability is important for food safety, the immediate risks associated with contamination during processing generally make processing traceability more urgent, critical and valued by the international trade.

The highest estimated impact of traceability measures occurs in trade from developing countries exporting to developed countries. This reflects the stringent traceability standards that developed countries often require to ensure food safety and quality. The positive effects suggest that developing countries meeting these standards can enhance access to lucrative markets in high-income countries, thereby overcoming the associated costs (Greene, 2010). However, the results indicate that trade between high-income countries did not show significant impacts, likely because these countries already have robust systems in place that meet or exceed these standards.

Beyond safety concerns, traceability in the meat sector is increasingly important due to environmental considerations, such as deforestation and other ecological impacts. Meat production, particularly cattle ranching, is a major driver of deforestation, especially in regions like the Amazon in Brazil. Traceability systems, as defined by UNCTAD, help ensure that meat products do not originate from illegally deforested areas, supporting environmental conservation efforts and adherence to sustainability standards. These

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systems can enable importers to verify that the meat they purchase is produced sustainably, aligning with international environmental regulations and consumer preferences for eco-friendly products.

Variables	All countries	(1)	(2)	(3)
NTMinnet	0.631**	1.065*	2.321***	-0.143
ΝΙΜιπραι	(0.310)	(0.615)	(0.159)	(0.312)
Constant	9.847***	10.26***	12.18***	9.913***
Constant	(0.0575)	(0.148)	(0.00194)	(0.0709)
Observations	593,362	115,875	44,352	295,526
R <sup>2</sup>	0.686	0.727	0.883	0.709
NTMprocess	4.265***	4.831***	-	4.153***
NT Mprocess	(0.245)	(0.427)	-	(0.270)
Constant	9.586***	9.540***	12.20***	9.504***
	(0.0218)	(0.0865)	(6.09e-11)	(0.0245)
Observations	593,362	115,875	44,352	295,526
R²	0.686	0.727	0.882	0.709

# TABLE 6 Estimation results for meats

Authors' elaboration.

- Notes: <sup>1</sup> Model (1): developing countries as exporters (lower middle income and upper middle income) and developed countries (high income) as importers; model (2): exporters and importers are developing countries; and model (3): exporters and importers are developed countries.
  - <sup>2</sup> Values in parentheses refer to robust standard errors clustered by country pair.
     \* p < 0.10; \*\* p < 0.05; \*\*\*p < 0.01. FEs are for importer year, exporter year, product, and country pair. Missing values in the dependent variable have been replaced with zero, indicating that there is no bilateral trade for the pair combination of country, product, and year.</li>

Moreover, the implementation of comprehensive traceability measures addresses the growing consumer demand for transparency about the environmental footprint of their purchases. As consumers become more environmentally conscious, they seek products certified to have minimal environmental impact. This demand encourages producers to adopt sustainable practices and integrate traceability systems that ensure food safety and verify the environmental credentials of their products. For developing countries, compliance with traceability requirements can be initially costly, but meeting these standards presents opportunities to access new markets and enhance market competitiveness.

The interaction term *NTMinput* \* *NTMprocess* highlights the combined impact of both measures (table 7). For all countries, the significantly positive interaction term (5.491\*\*) suggests that the simultaneous implementation of both traceability measures considerably enhances trade in the meat sector. This indicates that when both input and processing traceability are applied, they provide a robust framework that ensures food safety, quality and environmental footprint, and boosts importer confidence, facilitating trade.

#### TABLE 7

#### Estimation results for meats, with interaction

Variables	All countries	(1)	(2)	(3)
NTMinnut	0.0825	-5.065***	2.321***	-1.005
ΝΙΜπραι	(0.499)	(1.224)	(0.159)	(0.643)
NTMprocess	-1.292***	-1.539***	-	-0.823
	(0.319)	(0.324)	-	(0.609)
NT Minmut & NT Managaga	5.491***	11.510***	-	5.923***
101 Millipat * 101 Mp10cess	(0.562)	(1.304)	-	(0.856)
Constant	9.577***	9.725***	12.18***	9.647***
Constant	(0.0550)	(0.100)	(0.00194)	(0.0932)
Observations	593,362	115,875	44,352	295,526
R <sup>2</sup>	0.686	0.728	0.883	0.710

Authors' elaboration.

- Notes: <sup>1</sup> Model (1): developing countries as exporters (lower middle income and upper middle income) and developed countries (high income) as importers; model (2): exporters and importers are developing countries; and model (3): exporters and importers are developed countries.
  - <sup>2</sup> Values in parentheses refer to robust standard errors clustered by country pair. \* p < 0.10; \*\* p < 0.05; \*\*\*p < 0.01. FEs are for importer year, exporter year, product, and country pair. Missing values in the dependent variable have been replaced with zero, indicating that there is no bilateral trade for the pair combination of country, product, and year.</p>

When examining the individual columns, distinct patterns appear across trade flows. column (1), representing trade from developing countries to developed countries, shows a highly positive and significant interaction term (11.510\*\*\*). This indicates that developing countries implementing both input and processing traceability measures can enhance their export potential to developed nations. Regulations that improve quality and reduce market failures can stimulate the meat trade (Santeramo and Lamonaca, 2022). For developing countries, the initial adoption of these measures involves considerable

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costs, as establishing a robust traceability system is resource-intensive. However, the combination shows once the infrastructure for one traceability measure is established, the marginal cost of implementing the second measure is likely to be lower. This is because input traceability systems and processes can often be adapted for processing traceability requirements. Consequently, implementing both measures enhances supply chain transparency and reliability, bolstering importers confidence in product safety and quality. Ultimately, the benefits of accessing lucrative markets and aligning with international standards outweigh the initial costs, facilitating increased market access and providing a competitive advantage globally.

Column (2), which represents trade between developing countries, does not provide a significant coefficient for the interaction term. In column (3), representing trade between developed countries, the interaction term is again significantly positive (5.923\*\*\*), reinforcing the notion that developed nations have facilitate to effectively implement and benefit from combined traceability measures. Developed countries often have advanced systems already in place, allowing them to leverage existing infrastructure to comply with additional traceability requirements at a lower marginal cost. This established capability enables them to turn compliance with both input and processing traceability measures into a competitive advantage, enhancing their market positions.

The positive interaction effects in developed countries suggest that the marginal costs are manageable within existing systems, whereas the significant positive impact for developing countries indicates that these nations find value in meeting dual requirements despite potential challenges. The negative coefficients observed for certain traceability measures across different trade flows warrant careful consideration. For example, in column (1), which represents trade from developing to developed countries, the negative coefficient for NTMinput (-5.065\*\*\*) suggests that implementing input traceability requirements when there is no simultaneous need to meet processing requirements may initially represent a higher cost for developing country exporters, mainly due to the greater relevance of meat processing traceability than input traceability for the meat sector. In addition, these countries may face difficulties in establishing the systems necessary to initially comply with input traceability requirements, leading to potential reductions in trade. Similarly, the negative coefficient for NTMprocess (-1.292\*\*\*) across all countries highlights the negative impact of processing traceability on trade when there is no simultaneous input traceability requirement. This means that traceability is not the most relevant for meat, but it is necessary to ensure traceability of processing, given the nature and responsibility of meatpackers in the traceability of producers who

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supply the meat. Thus, countries may have to deal with the initial cost of traceability of the input, even when this is not a compliance requirement to access certain markets, leading to an increase in cost without a directly related return.

The negative coefficients do not necessarily imply that traceability measures are inherently detrimental to trade; rather, they highlight the complexities and potential trade-offs involved. It is possible that the negative impacts observed are temporary and may diminish over time as exporters adapt to new requirements and improve their compliance capabilities. Additionally, these negative effects may be offset by the positive impacts observed in the interaction term (*NTMinput* \* *NTMprocess*), which indicates that the combined implementation of both traceability measures can ultimately facilitate trade by enhancing the transparency and reliability of the supply chain. While traceability measures can present challenges, they also offer opportunities once the initial hurdles are overcome.

The results are different for fruits (table 8). A predominant negative signal is observed, but significance occurs when trade originates from developing exporters.

Santeramo and Lamonaca (2022) noted that SPS measures generally harm fruit trade. The processing of fruits involves steps to ensure quality and safety. First, the time of harvesting is carefully selected to ensure the fruits are picked at their optimal ripeness, contributing to the quality of the final product. Following, sorting and grading take place, where fruits are assessed and separated based on quality standards. Effective waste management practices are implemented to handle any by-products or damaged fruits. Precooling is another important step, utilizing field containers or plastic crates lined with appropriate materials to prevent contamination from soil. This step also involves removing field heat to maintain freshness. In all cases, is necessary to avoid exposing the fruits to the sun to prevent heat build-up. By adhering to these steps, the risk of contamination is minimized, and the fruits maintain their quality and safety from the field to the market (Samarasinghe, Kumara and Kulatunga, 2021). Implementing processing traceability, while costly, ensures that these characteristics are established (Hassoun et al., 2023). One of the greatest challenges in supply chain traceability is exchanging information in a standardized format across the various links in the chain. This information must be shared accurately, efficiently and electronically (Aung and Chang, 2014).

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#### TABLE 8

**Estimation results for fruits** 

Variables	All countries	(1)	(2)	(3)
NTMinnut	-0.0255	0.738	-0.613	-0.0104
NT Minput	(0.281)	(0.818)	(0.386)	(0.265)
Comptant	9.032***	9.172***	9.685***	9.096***
Constant	(0.0758)	(0.367)	(0.00408)	(0.0689)
Observations	801,878	168,838	86,838	365,064
R <sup>2</sup>	0.623	0.641	0.656	0.704
NTMprocess	0.452	-0.598*	-8.108***	0.949
NT Mprocess	(0.879)	(0.309)	(1.196)	(1.246)
Comptant	8.955***	9.714***	9.678***	9.010***
Constant	(0.135)	(0.109)	(1.81e-09)	(0.110)
Observations	801,878	168,838	86,838	365,064
R <sup>2</sup>	0.623	0.641	0.656	0.704

Authors' elaboration.

Notes: <sup>1</sup> Model (1): developing countries as exporters (lower middle income and upper middle income) and developed countries (high income) as importers; model (2): exporters and importers are developing countries; and model (3): exporters and importers are developed countries.

<sup>2</sup> Values in parentheses refer to robust standard errors clustered by country pair.
 \* p < 0.10; \*\* p < 0.05; \*\*\*p < 0.01. FEs are for importer year, exporter year, product, and country pair. Missing values in the dependent variable have been replaced with zero, indicating that there is no bilateral trade for the pair combination of country, product, and year.</li>

The analysis in table 9 shows the impact of the interaction of the traceability measures. Notably, the interaction term (*NTMinput* \* *NTMprocess*) is omitted from the estimation results, likely due to multicollinearity or lack of variation, which can occur when there is insufficient independent variation in both traceability measures in the observed data. This omission indicates that the simultaneous effect of implementing the input and processing traceability measures could not be separately identified in this analysis. In other words, omitting the interaction between input and process means that the model assumes that the NTM of input traceability affects the value of exports in the same way regardless of whether or not there is an NTM for processing traceability. Furthermore, the results for the individual terms are the same as in table 8.

#### TABLE 9

Estimation results for fruits, with interaction

Variables	All countries	(1)	(2)	(3)
NTMinnut	-0.0255	0.738	-0.613	-0.0105
WI Minput	(0.281)	(0.818)	(0.385)	(0.265)
NTMprocess	0.452	-0.598*	-8.106***	0.949
WI MPI OCESS	(0.879)	(0.309)	(1.196)	(1.246)
NTMinput * NTMprocess	-	-	-	-
Constant	8.962***	9.383***	9.685***	9.013***
Constant	(0.155)	(0.363)	(0.00408)	(0.129)
Observations	801,878	168,838	86,838	365,064
R <sup>2</sup>	0.623	0.641	0.656	0.704

Authors' elaboration.

Notes: <sup>1</sup> Model (1): developing countries as exporters (lower middle income and upper middle income) and developed countries (high income) as importers; model (2): exporters and importers are developing countries; and model (3): exporters and importers are developed countries.

<sup>2</sup> Values in parentheses refer to robust standard errors clustered by country pair. \* p < 0.10; \*\* p < 0.05; \*\*\*p < 0.01. FEs are for importer year, exporter year, product, and country pair. Missing values in the dependent variable have been replaced with zero, indicating that there is no bilateral trade for the pair combination of country, product, and year.</p>

For fisheries (table 10), there is only one significant and negative effect, on input traceability and trade flow between developing countries column (2). This suggests that traceability measures act as a barrier to trade between these countries. Santeramo and Lamonaca (2022) also found negative results for SPS measures in fisheries trade. Input traceability involves monitoring the origin of materials such as feed, additives, and other ingredients used in the production and processing of fish products, helping to prevent microbiological, chemical, or physical contamination, managing risks, and ensuring that all components meet safety standards. Additionally, input traceability is important for regulatory compliance and facilitates audits and certifications, such as those by the Marine Stewardship Council (MSC), which promotes sustainable fishing practices through certification to ensure that products meet sustainability and quality criteria (Dodd, 2021).

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#### **TABLE 10**

#### **Estimation results for fisheries**

Variables	All countries	(1)	(2)	(3)
NTMinnut	-0.010	-0.027	-1.519*	0.156
WI Milipat	(0.227)	(0.306)	(0.829)	(0.332)
Constant	8.559***	9.510***	8.751***	8.628***
Constant	(0.059)	(0.098)	(0.011)	(0.101)
Observations	2,013,326	442,897	214,332	912,051
R <sup>2</sup>	0.595	0.651	0.633	0.701
NTMprocess	-0.038	0.039	-0.233	0.004
NT Mprocess	(0.284)	(0.362)	(0.592)	(0.663)
Constant	8.562***	9.491***	8.731***	8.675***
Constant	(0.045)	(0.097)	(0.001)	(0.088)
Observations	2,013,326	442,897	214,332	912,051
R <sup>2</sup>	0.595	0.651	0.633	0.701

Authors' elaboration.

Notes: <sup>1</sup> Model (1): developing countries as exporters (lower middle income and upper middle income) and developed countries (high income) as importers; model (2): exporters and importers are developing countries; and model (3): exporters and importers are developed countries.

<sup>2</sup> Values in parentheses refer to robust standard errors clustered by country pair.
 \* p < 0.10; \*\* p < 0.05; \*\*\*p < 0.01. FEs are for importer year, exporter year, product, and country pair. Missing values in the dependent variable have been replaced with zero, indicating that there is no bilateral trade for the pair combination of country, product, and year.</li>

High costs of implementing traceability systems can impede trade, especially in a sector made up mostly of small and artisanal producers, in a context where the initial investments do not justify the benefits and the domestic market may be more attractive. The supply chain is complex when inputs from multiple suppliers, can make it challenging to obtain accurate information. Additionally, complying with stringent international standards and certifications, such as those from the MSC, is often difficult for developing countries due to their capacity to adapt to requirements. Environmental factors, including natural variations in fish quality and changes in conditions, further complicate traceability efforts. Together, these challenges create great trade barriers.

In table 11, the input traceability outcomes are the same as presented in table 10 and there is the omission of the interaction term for input and process traceability, suggesting that the data did not yield a significant interaction effect. The lack of

an interaction effect indicates that while input and process traceability measures individually impact trade, their combination does not create additional barriers or benefits in this context.

#### TABLE 11

#### Estimation results for fisheries, with interation

Variables	All countries	(1)	(2)	(3)
NTMinnut	0.028	-0.274	-1.519*	0.257
NI Milipat	(0.182)	(0.246)	(0.829)	(0.180)
NTMprocess	-0.058	0.294	-0.233	-0.205
NT Mpi ocess	(0.283)	(0.419)	(0.592)	(0.696)
NTMinput * NTMprocess	-	-	-	-
Constant	8.558***	9.511***	8.752***	8.625***
Constant	(0.057)	(0.099)	(0.011)	(0.090)
Observations	2,013,326	442,897	214,332	912,051
R <sup>2</sup>	0.597	0.633	0.701	0.651

Authors' elaboration.

Notes: <sup>1</sup> Model (1): developing countries as exporters (lower middle income and upper middle income) and developed countries (high income) as importers; model (2): exporters and importers are developing countries; and model (3): exporters and importers are developed countries.

<sup>2</sup> Values in parentheses refer to robust standard errors clustered by country pair. \* p < 0.10; \*\* p < 0.05; \*\*\*p < 0.01. FEs are for importer year, exporter year, product, and country pair. Missing values in the dependent variable have been replaced with zero, indicating that there is no bilateral trade for the pair combination of country, product, and year.</p>

In general, while implementing traceability measures may involve initial costs, the long-term benefits of accessing lucrative markets and meeting international standards can outweigh these expenses over time (Traoré and Tamini, 2021). According to Swinnen (2016), the rapid spread of regulations in high-value sectors such as fruits, vegetables, meat, seafood, and fish has been linked to export growth from developing countries. Compliance with SPS and TBT requirements can be a strategic move for countries aiming to reposition themselves in global markets (Santeramo and Lamonaca, 2022). However, this strategy only succeeds if accompanied by improvements in domestic supply chains and the introduction of standards (Swinnen, 2016).

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Once infrastructure and systems are established for one traceability measure, they can often be leveraged for a second measure, enhancing transparency and reliability. These requirements, while sometimes perceived as trade barriers due to increased production costs, can also reduce transaction costs and act as catalysts for trade once standards are met (Santeramo and Lamonaca, 2022). This positive impact is primarily observed in trade relations between developing countries and developed nations, where the capacity to meet both standards exists. However, the analysis also highlights the challenges faced by developing countries in meeting processing traceability requirements. Specifically, in columns (1) and (2) of the analysis, if outcomes are negatives, suggest an adverse impact on trade. This outcome may arise from the high costs and technical limitations in developing countries, to maintaining detailed records at each production stage, which requires coordination among various supply chain agents to ensure traceability and product differentiation. Exporters may find it more challenging to adapt production processes to comply with specific SPS and TBT measures (e.g., covering specific products or production chain stages) compared to broader safety requirements (e.g., involving multiple products within a category or the entire production process) (Swinnen, 2016).

Developing countries often lack the capacity to meet these stringent requirements, creating trade barriers within this group. NTMs impose sunk costs and can act as barriers to entry, especially for exporters with limited financial and technical resources (Crivelli and Gröschl, 2016). Despite these challenges, the overall benefits of meeting both traceability requirements can include increased trade opportunities and enhanced competitiveness in international markets. This suggests that, while initially costly, investing in processing traceability can be advantageous for developing countries in the long term. In column (3), representing trade between developed countries, the coefficients for *NTMinput* and *NTMprocess*, if positive, indicate that developed nations may not face the same challenges in implementing traceability measures. This is likely due to their better infrastructure and resources, which facilitate compliance with these requirements.

In the food sector, the understanding of the characteristics of food is important to understand the different impacts. For instance, in the fresh produce sector, such as fruits and fisheries, the creation of traceability systems is shaped by the nature of the products. The perishability and variability in the quality of fresh fruits and vegetables require proper storage conditions and identification of quality attributes, with negative results predominance. In contrast, the livestock industry has a long-standing history of

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using animal identification and traceability systems to control disease and ensure the safety of meat products, justifying the positive outcomes (Aung and Chang, 2014). From a technological standpoint, DNA-based methods such as DNA barcoding are interesting for verifying the origin and quality of raw materials and detecting adulterations in the food chain. In the fruit sector products are distinct in specific shapes, tastes, and smells through physical processes (such as heating, boiling, and UV radiation) or chemical treatments (such as the addition of preservatives and artificial sweeteners), which can alter DNA structure. While these techniques are too costly for routine testing, they can serve as reliable tools for confirming suspected fraud and ensuring confidence (Aung and Chang, 2014).

According to a review by Food Innovation Partners and Allan Bremner and Associates (Dodd, 2021), six essential elements must be considered in traceability analysis: product traceability, process traceability, genetic traceability, input traceability, disease and pest traceability, and measurement traceability. These elements underscore the multifaceted nature of traceability, which involves tracking the origin and handling of products, also managing biological, environmental, and procedural factors that can affect food safety and quality. Although the traceability information provided by UNCTAD does not encompass all of these dimensions, it offers an overview of how input and process traceability can have distinct impacts across different sectors and income levels and when considering the interaction between both types of traceability. This is in line with as suggested in Santeramo and Lamonaca (2019), the heterogeneous impacts of NTM occur across different geo-economic areas, across different products, compliance costs and specific political objectives. The costs of implementing traceability systems are often viewed as barriers for supply chain actors, particularly for small-scale producers in less developed countries. However, the benefits of traceability for high-risk and high-value foods significantly outweigh these costs (Aung and Chang, 2014).

#### **5 CONCLUSIONS**

In the context of international trade, traceability can become a tool to maintain trust within a supply chain and build a reputation for producing high-quality products when companies' behavior is not perfectly observed by consumers. The hypothesis postulates that the effects of traceability on trade vary across sectors and across countries' incomes, where negative impacts are more pronounced for developing countries' trade, attributable to their financial and technological limitations. Our findings corroborated our hypotheses. It was clear that the results vary across sectors, and the more the international market

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demands that a given product be traceable, or that traceability is already well-established, the result is positive, as in the case of the meat sector. In sectors where traceability of inputs is most required, such as fruit and fish, the requirement for processing traceability has a negative effect on exports. Furthermore, the negative effects are more pronounced when exporters are middle-income, and importers are high-income.

The results of the main terms and interactions allowed us to obtain results that were closer to reality. This is because traceability requirements are often intended for more than one stage of production. With the main terms in the interacted equation, we were able to reduce the influence of the other traceability requirement, having the isolated effect and, in some cases, achieving more significant results that maintained the robustness of the hypothesis that middle-income countries have the most affected exports. Furthermore, the factorial interaction showed that the presence of NTMs in both phases of the production chain can generate synergies, especially in sectors where traceability is more prominent in the processing phase, offsetting the costs required to implement traceability of inputs. This is particularly relevant in the case of meat, where processors purchase live animals from multiple producers, and quality attributes such as flavor and texture are discovered after the supplier's identity is no longer linked to the product. Meat quality, in turn, is influenced by practices both on and off the farm. In addition, the presence of both NTMs is more beneficial when the exporting countries are high-income, due to their technical and financial implementation capabilities.

It is important to highlight that traceability can contribute to promoting more sustainable and safe practices in agri-food trade, but its impact on trade varies depending on the specific context. Additionally, traceability plays a significant role in sustainability and environmental protection by ensuring responsible resource management, reducing waste, and monitoring the impact of agricultural practices. Governments and public authorities need to find balanced solutions that serve public interests, promoting efficiency and competitiveness on a global scale, and providing sufficient logistical and technological infrastructure so that producers can adhere to traceable systems.

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#### **APPENDIX A**

#### **ESTIMATION RESULTS: 5-YEAR TIME INTERVAL**

#### TABLE A.1

#### **Estimation results for all products**

Variables	All countries	(1)	(2)	(3)
NTMinnut	-0.003	-0.054	0.098	-0.012
Νημιμαί	(0.108)	(0.270)	(0.306)	(0.096)
Constant	8.973***	9.394***	9.886***	9.118***
Constant	(0.026)	(0.069)	(0.004)	(0.034)
Observations	8,875,672	1,804,020	1,012,815	3,752,736
R <sup>2</sup>	0.571	0.641	0.643	0.626
NTMnrocess	-0.054	0.197	-0.617	0.004
WI Mpi Ocess	(0.245)	(0.446)	(0.404)	(0.206)
Constant	8.977***	9.349***	9.888***	9.113***
Constant	(0.020)	(0.074)	(0.000)	(0.018)
Observations	8,875,672	1,804,020	1,012,815	3,752,736
R <sup>2</sup>	0.571	0.641	0.643	0.626

#### Authors' elaboration

- Notes: <sup>1</sup> Model (1): developing countries as exporters (lower middle income and upper middle income) and developed countries (high income) as importers; model (2): exporters and importers are developing countries; and model (3): exporters and importers are developed countries.
  - <sup>2</sup> Values in parentheses refer to robust standard errors clustered by country pair. \* p < 0.10; \*\* p < 0.05; \*\*\*p < 0.01. FEs are for importer year, exporter year, product, and country pair. Missing values in the dependent variable have been replaced with zero, indicating that there is no bilateral trade for the pair combination of country, product, and year.</p>

#### TABLE A.2

#### **Estimation results for meats**

Variables	All countries	(1)	(2)	(3)
NTMinput	0.648*	0.992	2.568*	-0.322
	(0.349)	(0.618)	(0.197)	(0.359)
Ct	9.900***	10.171*	12.552*	10.015*
Constant	(0.101)	(0.210)	(0.001)	(0.139)
Observations	0.691	0.728	0.900	0.711
R²	289,905	56,364	21,964	143,374

(Continue)

(Continuation)				
Variables	All countries	(1)	(2)	(3)
NTMmmocoss	4.160*	4.666*	-	4.058*
NT Mprocess	(0.318)	(0.498)	-	(0.275)
	9.638*	9.277*	12.565*	9.423*
Constant	(0.034)	(0.131)	(0.000)	(0.032)
Observations	289,905	56,364	21,964	143,374
R <sup>2</sup>	0.691	0.728	0.899	0.711

Authors' elaboration.

- Notes: <sup>1</sup> Model (1): developing countries as exporters (lower middle income and upper middle income) and developed countries (high income) as importers; model (2): exporters and importers are developing countries; and model (3): exporters and importers are developed countries.
  - <sup>2</sup> Values in parentheses refer to robust standard errors clustered by country pair.
     \* p < 0.10; \*\* p < 0.05; \*\*\*p < 0.01. FEs are for importer year, exporter year, product, and country pair. Missing values in the dependent variable have been replaced with zero, indicating that there is no bilateral trade for the pair combination of country, product, and year.</li>

#### TABLE A.3

#### **Estimation results for fruits**

Variables	All countries	(1)	(2)	(3)
NTMinnut	-0.074	0.581	-0.526	-0.056
Πημηραί	(0.295)	(0.826)	(0.384)	(0.290)
Constant	9.185***	9.361***	9.954***	9.175***
Lonstant	(0.116)	(0.488)	(0.003)	(0.125)
Observations	415,412	89,380	48,685	184,172
R <sup>2</sup>	0.628	0.657	0.673	0.704
NTMprocess	-0.290***	-	-	-0.256**
	(0.103)	-	-	(0.112)
Constant	9.210***	9.704***	9.951***	9.179***
	(0.019)	(0.000)	(0.000)	(0.012)
				(Continue)

#### (Continuation)

Variables	All countries	(1)	(2)	(3)
Observations	415,412	89,380	48,685	184,172
R <sup>2</sup>	0.628	0.657	0.673	0.704

Authors' elaboration.

- Notes: <sup>1</sup> Model (1): developing countries as exporters (lower middle income and upper middle income) and developed countries (high income) as importers; model (2): exporters and importers are developing countries; and model (3): exporters and importers are developed countries.
  - <sup>2</sup> Values in parentheses refer to robust standard errors clustered by country pair. \* p < 0.10; \*\* p < 0.05; \*\*\*p < 0.01. FEs are for importer year, exporter year, product, and country pair. Missing values in the dependent variable have been replaced with zero, indicating that there is no bilateral trade for the pair combination of country, product, and year.</p>

Variables	All countries	(1)	(2)	(3)
NTMinnut	-0.072	-0.113	-1.565*	0.113
WI Minput	(0.223)	(0.317)	(0.816)	(0.319)
Comstant	8.691***	9.587***	8.820***	8.828***
Constant	(0.086)	(0.140)	(0.002)	(0.154)
Observations	1,009,484	231,973	106,981	449,190
R <sup>2</sup>	0.600	0.702	0.659	0.647
NTMprocess	-0.225	-0.029	-0.795	-0.121
NI Mpi Ocess	(0.305)	(0.377)	(0.653)	(0.687)
Comstant	8.708***	9.547***	8.817***	8.904***
Constant	(0.061)	(0.129)	(0.001)	(0.118)
Observations	1,009,484	231,973	106,981	449,190
R <sup>2</sup>	0.600	0.702	0.659	0.647

#### TABLE A.4

#### **Estimation results for fisheries**

Authors' elaboration.

Notes: <sup>1</sup> Model (1): developing countries as exporters (lower middle income and upper middle income) and developed countries (high income) as importers; model (2): exporters and importers are developing countries; and model (3): exporters and importers are developed countries.

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<sup>2</sup> Values in parentheses refer to robust standard errors clustered by country pair. \* p < 0.10; \*\* p < 0.05; \*\*\*p < 0.01. FEs are for importer year, exporter year, product, and country pair. Missing values in the dependent variable have been replaced with zero, indicating that there is no bilateral trade for the pair combination of country, product, and year.</p>

#### **APPENDIX B**

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#### **RESULTS OF ESTIMATES WITH A 5-YEAR TIME INTERVAL: RESULTS OF INTERACTIONS**

#### TABLE B.1

#### Estimation results for all products, with interaction

Variables	All countries	(1)	(2)	(3)
NTMinnut	0.021	-0.340***	0.120	-0.022
WI Miliput	(0.050)	(0.088)	(0.310)	(0.058)
NTMprocess	-0.543***	-0.507	0.288	-0.420*
INT MPTOCESS	(0.180)	(0.353)	(0.272)	(0.236)
NTMinnut * NTMnrocess	0.479*	1.002*	-2.200***	0.451
Wi Minput * Wi Mpi Ocess	(0.289)	(0.518)	(0.610)	(0.286)
Constant	8.973***	9.389***	9.886***	9.119***
constant	(0.024)	(0.076)	(0.004)	(0.031)
Observations	8,875,672	1,804,020	1,012,815	3,752,736
R <sup>2</sup>	0.571	0.641	0.643	0.626

#### Authors' elaboration.

- Notes: <sup>1</sup> Model (1): developing countries as exporters (lower middle income and upper middle income) and developed countries (high income) as importers; model (2): exporters and importers are developing countries; and model (3): exporters and importers are developed countries.
  - <sup>2</sup> Values in parentheses refer to robust standard errors clustered by country pair. \* p < 0.10; \*\* p < 0.05; \*\*\*p < 0.01. FEs are for importer year, exporter year, product, and country pair. Missing values in the dependent variable have been replaced with zero, indicating that there is no bilateral trade for the pair combination of country, product, and year.</p>

#### **TABLE B.2**

#### Estimation results for meats, with interation

Variables	All countries	(1)	(2)	(3)
NTMinnut	0.233	-6.575***	2.568***	-0.996
ΜΙΜτηραί	(0.526)	(1.228)	(0.197)	(0.710)
NTMprocess	-1.846***	-3.096***	-	-0.465
	(0.699)	(0.447)	-	(0.589)
NTMinput * NTMprocess	5.802***	14.432***	-	5.438***
	(0.826)	(1.315)	-	(0.896)
				(Continue)

(Continuation)				
Variables	All countries	(1)	(2)	(3)
Constant	9.593***	9.757***	12.552***	9.705***
constant	(0.105)	(0.163)	(0.001)	(0.200)
Observations	289,905	56,364	21,964	143,374
R <sup>2</sup>	0.691	0.729	0.900	0.711

Authors' elaboration.

- Notes: <sup>1</sup> Model (1): developing countries as exporters (lower middle income and upper middle income) and developed countries (high income) as importers; model (2): exporters and importers are developing countries; and model (3): exporters and importers are developed countries.
  - <sup>2</sup> Values in parentheses refer to robust standard errors clustered by country pair. \* p < 0.10; \*\* p < 0.05; \*\*\*p < 0.01. FEs are for importer year, exporter year, product, and country pair. Missing values in the dependent variable have been replaced with zero, indicating that there is no bilateral trade for the pair combination of country, product, and year.</p>

#### TABLE B.3

#### Estimation results for fruits, with interation

Variables	All countries	(1)	(2)	(3)
NTMinnut	-0.074	0.581	-0.526	-0.056
WI Milipat	(0.295)	(0.826)	(0.384)	(0.290)
NTMprocess	-0.289***	-	-	-0.256**
Wimprocess	(0.103)	-	-	(0.112)
NTMinput * NTMprocess	-	-	-	-
Constant	9.239***	9.361***	9.954***	9.203***
constant	(0.124)	(0.488)	(0.003)	(0.123)
Observations	415,412	89,380	48,685	184,172
R <sup>2</sup>	0.628	0.657	0.673	0.704

Authors' elaboration.

- Notes: <sup>1</sup> Model (1): developing countries as exporters (lower middle income and upper middle income) and developed countries (high income) as importers; model (2): exporters and importers are developing countries; and model (3): exporters and importers are developed countries.
  - <sup>2</sup> Values in parentheses refer to robust standard errors clustered by country pair. \* p < 0.10; \*\* p < 0.05; \*\*\*p < 0.01. FEs are for importer year, exporter year, product, and country pair. Missing values in the dependent variable have been replaced with zero, indicating that there is no bilateral trade for the pair combination of country, product, and year.</p>

#### TABLE B.4

Estimation results for fisheries, with interation

Variables	All countries	(1)	(2)	(3)
NTMinnut	0.101	-0.273	-1.565*	0.226
WI Minput	(0.204)	(0.270)	(0.816)	(0.207)
NTMprocess	-0.293	0.204	-0.795	-0.271
WI MPI OCESS	(0.325)	(0.410)	(0.653)	(0.710)
NTMinput * NTMprocess	-	-	-	-
Constant	8.682***	9.589***	8.821***	8.820***
Constant	(0.082)	(0.140)	(0.002)	(0.137)
Observations	1,009,484	231,973	106,981	449,190
R <sup>2</sup>	0.600	0.702	0.659	0.647

Authors' elaboration.

- Notes: <sup>1</sup> Model (1): developing countries as exporters (lower middle income and upper middle income) and developed countries (high income) as importers; model (2): exporters and importers are developing countries; and model (3): exporters and importers are developed countries.
  - <sup>2</sup> Values in parentheses refer to robust standard errors clustered by country pair. \* p < 0.10; \*\* p < 0.05; \*\*\*p < 0.01. FEs are for importer year, exporter year, product, and country pair. Missing values in the dependent variable have been replaced with zero, indicating that there is no bilateral trade for the pair combination of country, product, and year.</p>

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