Les normes agri-environnementales en amont et en aval : disparités entre pays, déterminants et effets commerciaux.

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Upstream and downstream agri-environmental regulations: cross-country differences, determinants and trade effects

Sous la direction de Nicolas PÉRIDY, Professeur des Universités
Et le co-encadrement de Gabriel Figueiredo De OLIVEIRA, Maître de conférences

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Résumé

Cette thèse étudie la relation entre le commerce mondial agricole et les normes destinées à protéger l'environnement qui interviennent en amont et en aval des échanges. Notre travail est structuré autour de trois chapitres. Dans le premier, nous analysons les caractéristiques du réseau des mesures non tarifaires liées à l'environnement. Le deuxième chapitre mesure et examine les déterminants de l'efficacité agro-environnementale d'un large panel de 108 pays au cours de la période 2003-2013. Le dernier chapitre traite les effets commerciaux de la rigueur des politiques agro-environnementales ainsi que l'impact de l'hétérogénéité des réglementations sur les flux commerciaux bilatéraux. À cette fin, nous avons utilisé différentes approches non paramétriques et économétriques, notamment l'analyse des réseaux dans le premier chapitre, un modèle de frontière non paramétrique dans le deuxième chapitre et un modèle de gravité théoriquement justifié dans le chapitre trois.

Nos résultats indiquent que la croissance des exportations agricoles des pays du Sud a été propice à la montée des conflits commerciaux liés à l'environnement. Alors que les pays d'Amérique latine et d'Asie du Sud-Est s'affirment de plus en plus comme des fournisseurs majeurs pour de nombreuses régions, nos résultats révèlent une nouvelle relation conflictuelle liée à l'environnement, ciblant les pays en développement et émergents d'un côté et se répandant de plus en plus au sein des pays du Sud de l'autre. Les résultats montrent aussi que, globalement, le secteur agricole a enregistré une hausse des scores d'efficacité agro-environnementale. Toutefois, de fortes disparités sont constatées entre les pays. Nous constatons également que l'ouverture commerciale et la spécialisation dans les exportations agricoles entravent l'inefficacité, confirmant ainsi l'hypothèse des «gains environnementaux du commerce». En outre, nous montrons que les mesures non tarifaires liées à l'environnement s'avèrent être des leviers pour améliorer la performance agro-environnementale des pays émergents, développés et à revenu intermédiaire, induisant ainsi un phénomène de «nivellement par le haut» dans leurs normes environnementales. Par ailleurs, nos résultats indiquent que la rigueur des réglementations environnementales réduit la capacité d'exporter du groupe des CAIRNS, confirmant ainsi l'hypothèse du « paradis des pollueurs ». En revanche, les politiques environnementales rigoureuses augmentent les exportations agricoles de l'Union Européenne et des États-Unis. Étonnamment, les exportateurs en voie de développement soutiennent également l'hypothèse de Porter, suggérant que des réglementations environnementales strictes peuvent renforcer leur capacité d'exportation. Enfin, nous concluons que l'hétérogénéité agro-environnementale entre les pays est plus déterminante pour la marge intensive des échanges agricoles que les accords commerciaux. Cependant, ses effets varient selon les groupes de revenus des pays exportateurs et importateurs.

Mots clés : Agriculture, produits végétaux, commerce international, analyse des réseaux, efficience, politiques agro-environnementales, modèle de gravité

Abstract

This thesis investigates the relationship between international agricultural trade and standards intended to protect the environment, considering both upstream and downstream measures. The work is structured around three chapters. In the first one, we analyze the network of environmentally-related non-tariff measures. Chapter 2 investigates the stringency and the determinants of agri-environmental regulations by measuring their efficiency in a large panel of 108 countries during the period 2003-2013. The last chapter examines the effects of agri-environmental regulations' stringency and heterogeneity on the intensive margin of trade between 108 countries over the same period. To this end, we used non-parametric and econometric approaches. We employ the network analysis in the first chapter whereas we use a non-parametric frontier model and the double bootstrapped truncated regression in chapter two. In chapter three, we use a theoretically justified gravity model of trade.

Our findings indicate that trade growth of southern countries has been conducive to rising environmentally-related trade conflicts. While Latin American and Southeast Asian countries are increasingly asserting themselves as major suppliers for many regions of the world, our results reveal new environmentally-related conflictual relation targeting developing and emerging countries on one side and increasingly spreading within southern agro-producers on the other. Further results show that the sector of crops has witnessed globally an increasing trend in average agri-environmental efficiency. An intriguing finding is that agricultural trade openness and the specialization in crop commodities' exports hamper the inefficiency, supporting therefore the "environmental gains-from-trade" hypothesis. In addition, our results show that environmentally-related NTMs turn out to be levers for enhancing the agri-environmental performance of exporters, especially in the BRICS and high as well as middle-income countries. Nonetheless, low income countries react differently and record a deteriorating agri-environmental performance due to environmentally-related NTMs. We also show that the stringency of environmental regulations turns out to be trade reducing in the CAIRNS group, supporting thereby the pollution haven hypothesis. By contrast, rigorous agri-environmental policies have a significant trade-enhancing effect on bilateral agricultural exports of the EU and the USA. Surprisingly, low and middle income countries support also the Porter hypothesis, suggesting that strict environmental regulations can enhance their competitive advantage against foreign rivals. Finally, we conclude that difference in exporter and importer environmental regulations is more relevant to agricultural trade than trade agreements. However, trade effects vary according to the income groups of exporting and importing countries.

Keywords: Agriculture, crops, trade, NTMs, network analysis, efficiency, agri-environmental regulation, gravity model

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List of acronyms

AEE	:	Agri-environmental efficiency
AEEH	:	Agri-environmental policies' heterogeneity
AEI	:	Agri-environmental inefficiency
AoA	:	Agreement on agriculture
ASEAN	:	Association of Southeast Asian Nations
AVE	:	Ad valorem equivalent
BCC	:	Banker, Charnes and Cooper model
BRICS	:	Brazil, Russia, India, China, and South Africa.
CAIRNS	:	An interest group composed of Argentina, Australia, Brazil, Canada, Chile, Colombia, Costa Rica, Guatemala, Indonesia, Malaysia, New Zealand, Pakistan, Paraguay, Peru, the Philippines, South Africa, Thailand, Uruguay, and Vietnam that seek to liberalize global trade in agricultural products.
CAP	:	Common agricultural policy
CCR	:	Charnes, Cooper, Rhodes model
CEMAC	:	Central African Economic and Monetary Community
CO_2	:	Carbon dioxide
COMESA	:	Common Market for Eastern and Southern Africa
CRS	:	Constant Returns to Scale
DEA	:	Data envelopment analysis
DEA-SE	:	Super-efficiency data envelopment analysis
DMU	:	Decision making units
DOT	:	Degree of openness to trade
Eq.	:	Equation
EU	:	European Union
FE	:	Fixed effects
FTA	:	Free trade agreements
F&Vs	:	Fruit and vegetables
G10	:	Group of ten
G20	:	Agricultural group of twenty
G33	:	Group of thirty-three
G90	:	Group of ninety
GATT	:	General Agreement on Tariffs and Trade
GDP	:	Gross domestic product
GHG	:	Greenhouse gas emissions
GLS	:	Generalized least squares
GMM	:	Gaussian Mixture Model
GNP	:	Gross national product
ha	:	Hectare
HDFE	:	High-dimensional fixed effects
HI	:	High income
HOS	:	Heckscher– Ohlin–Samuelson model
HT	:	Hausman-Taylor model

kg	:	kilograms
LI	:	Low income
MENA	:	Middle east and north Africa
MERCOSUR	:	The Common Market of the South
MI	:	Middle income
NAFTA	:	North American Free Trade Agreement
NFI	:	Net food-importing countries
NTB	:	Non-tariff barrier
NTM	:	Non-tariff measures
OECD	:	Organization for Economic Co-operation and Development
OLS	:	Ordinary least squares
PPML	:	Poisson pseudo maximum likelihood
PTA	:	Preferential trade agreements
RCA	:	Revealed comparative advantage
RE	:	Random effects
RTA	:	Regional trade agreements
SE	:	Super-efficiency
SEMC	:	Southern Eastern Mediterranean countries
SPS	:	Sanitary and Phytosanitary measures
STC	:	Specific trade concerns
TBT	:	Technical barriers to trade
Trade_agr	:	Trade agreements
UNCTAD	:	United Nations Conference on Trade and Development
US$	:	United States dollar
USA	:	United States of America
VA_agri	:	Value added of agriculture
VIF	:	Variance Inflation Factor
VRS	:	Variable Returns to Scale
WTO	:	World Trade Organization

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Introduction

"Until we understand why our society adopts its policies, we will be poorly equipped to give useful advice on how to change those policies."

(Stigler, 1975, page ix)

Agriculture was the subject of broad exceptions to the rules of multilateral trade laws until the 1980s. The exclusion of the primary sector was gradually perceived as problematic, whereas the international community was regularly criticizing border protection, domestic support and export subsidies in Europe and elsewhere (Croome, 1995). Although the inclusion of agricultural negotiations in GATT disciplines was crossed by strong oppositions, negotiations have made significant progress since the creation of the agreement on agriculture (AoA hereafter).

In fact, the Uruguay round (1986-1994) was launched with the aim of bringing peace on markets and deepen international trade while resolving the booming public agricultural expenditures in developed countries. On April 15th, 1994, the Marrakesh agreement was signed and marked the end of the Uruguay round of multilateral trade negotiations. Simultaneously, four major sub-agreements were reached under the "agricultural package". Among which, we note the AoA and the agreement on sanitary and phytosanitary (SPS) measures.

The AoA provides a framework for the long-term reform of agricultural trade and domestic policies by addressing the following issues. First, it tackles provisions that encourage the use of less trade-distorting domestic support policies to maintain the rural economy (Anderson, 2009) while ensuring a certain flexibility in the implementation of commitments. Second, the agreement addresses the specific concerns of developing countries, namely food security of net-food importing countries and the least-developed economies.

Additionally, the SPS agreement recognizes that governments have the right to pursue non-economic targets and addresses market failures (namely information asymmetries and negative environmental externalities) without imposing barriers to trade (Beestermöller et al., 2018; Cadot et al., 2018; Disdier et al., 2008). In sum, and according to the WTO (2001a), the agricultural package provides for commitments in the following areas:

- First, the market access issue where non-tariff border measures are replaced by tariffs that provide substantially the same level of protection.
- Second, WTO members are required to reduce the value of direct export subsidies with respect to their level of development.

- Finally, domestic support devices that have a minimal impact on trade are excluded from reduction commitments and are gathered in a "green box". The latter includes specific forms of decoupled subsidies, income support and direct payments under environmental and regional assistance programs. However, amounts of domestic support are defined according to the level of development of countries.

In 2001, multilateral agricultural negotiations resumed within the framework of the Doha development agenda to achieve greater trade liberalization by strengthening market access, eliminating export subsidies, reducing distorting domestic support and dealing with several developing country issues (WTO, 2001b). Although the Doha ministerial elicited an optimistic agreement to launch the agenda, the subsequent conferences of Cancun (2003) and Hong Kong (2005) did not share the same positive fate and failed to deal with agricultural issues (Flentø & Ponte, 2017). However, the WTO ministerial conferences in Bali (2013) and Nairobi (2015) provided direct impetus to multilateral negotiations, particularly in the agricultural field (Pavot & Dufour, 2016) and remained in line with the AoA.

According to Bellmann (2014), the Bali package is an agreement on a small subset of issues being negotiated under the Doha round. Regarding the field of agriculture, the ''mini-package" includes four decisions (WTO, 2013). First, an agreement to negotiate a permanent solution to public stockholding for food security purposes. The same decision states to refrain from challenging breaches of domestic support commitments resulting from developing countries' public stockholding programs for food security. Second, the agreement calls for more transparency in tariff quota administration and for governments not to create trade barriers by how they distribute quotas among importers. The third decision qualifies the land use, land reform, water management, and other poverty-reduction programs for green box support. Finally, the agreement provides a declaration to reduce all forms of export subsidies and to enhance transparency and monitoring.

Due to the difficult negotiations that followed ministerial conferences in Bali, there were fewer expectations for a successful and substantial agreement in Nairobi. Despite the overall lack of consensus, an agreement was reached in 2015. As stated by the ministerial declaration of the WTO (2015), it includes the following provisions regarding agricultural commodities. Firstly, a legally binding agreement that seeks the removal of export subsidies in agriculture by 2020 for developed countries, and by 2023 for developing countries. Secondly, the WTO members agreed to engage constructively in finding a permanent solution that allows developing countries to use public stockholding to ensure food security. Finally, WTO members agreed to continue negotiations on a special safeguard mechanism that would allow developing countries to temporarily raise tariffs on agricultural products in cases of import surges or price falls. In sum, and apart from the decision to eliminate agricultural export subsidies, the Bali and Nairobi packages regarding this sector can be summed up in a series of ''peace clauses" that favor mostly developing countries in addition to the commitment of WTO members to negotiate further market access.

Although the Nairobi outcome has energized the Doha round, the future for the multilateral trading system is questioned by several scholars in the absence of a universal endeavor. Martin and Mercurio (2017) argue that the Nairobi Ministerial has marked the end of the Doha round and suggest that the inability of WTO members to reach a comprehensive agreement is likely to foster plurilateral agreements (e.g. FTA, PTA, etc.) at the expense of the single undertaking and the multilateral level. In turn, the break point according to Wilkinson et al. (2016) is the privileged position of developing countries compared to their developed counterparts.

In this regard, emerging and developing countries have become important players in multilateral trade negotiations after numerous accessions, which reinforced opposition across agricultural negotiations. Indeed, the divide between the North and the South is far from being the only cleavages (WTO, 2017). First, we distinguish the Europe - United States duopoly that has set the main agricultural parameters for the Uruguay Round in conjunction with highly protective countries, namely the group of Ten[1] (G10). The latter brings together mainly net food-importing and industrialized countries that grant significant protection to their agriculture. Essentially defensive, these countries protect their domestic policies by promoting multifunctional and environmentally friendly agriculture.

Second, few industrialized countries (notably Canada, Australia and New Zealand) have escaped this rule and allied themselves to several developing nations such as Argentina, Brazil, Uruguay and Thailand. They jointly putted forward their comparative advantages and formed the CAIRNS group[2] in 1986. This has marked the first step in the aggressive participation of developing countries in agricultural negotiations. The group has been denouncing tariffs and export subsidies of highly protective countries as they have historically distorted trade and negatively impacted their exports.

Third, and contrary to the CAIRNS, the group of Twenty[3] (G20) plays the role of a counterweight to exert the influence of developed countries and assert the rise of emerging economies (Daviron & Voituriez, 2006). Created in 2003 at the WTO ministerial conference in Cancun, the G20 gathers mostly developing net food exporters and endeavors to audit northern countries' proposals to make them favorable to the South.

Cleavages continue to spread within southern countries with the emergence of the group of thirty-three (G33) and the G90 during the Doha round. Their interests are indeed opposed to those of the CAIRNS and G20. In fact, some countries have poorly modernized their subsistence agriculture due to various factors, namely unfavorable natural conditions, low land use, low-productivity workforce and lacking infrastructure. Accordingly, they have increased their customs duties to protect their fragile sector from international competition.

[1] Marked by an economic dependence on the United States and Europe, the G10 is composed of Bulgaria, Korea, Iceland, Israel, Japan, Liechtenstein, Mauritius, Norway, Switzerland and Taiwan.

[2] Composed of South Africa, Guatemala, Argentina, Indonesia, Australia, Malaysia, Bolivia, New Zealand, Brazil, Paraguay, Canada, Philippines, Chile, Thailand, Costa Rica and Uruguay.

[3] Composed of Argentina, Bolivia, Brazil, Chile, China, Cuba, Ecuador, Egypt, Guatemala, India, Indonesia, Mexico, Nigeria, Pakistan, Paraguay, Peru, Philippines, South Africa, Tanzania, Thailand, Uruguay, Venezuela and Zimbabwe

The G33[4] group brings together countries characterized by subsistence-oriented agriculture in addition to nations with the ambition to pursue agricultural policies (e.g. Venezuela and Turkey). The latter are jointly seeking to exempt southern countries from agricultural liberalization. Finally, the G90 is often described as the group of the 90 poorest countries (namely the least developed nations and African, Caribbean and Pacific group) and is considered as the least active in multilateral negotiations due to its large size.

According to Bellmann (2014), coalitions of developing countries have marked the Doha negotiating process of the Bali package. For instance, the G20 has submitted two proposals concerning export subsidies and tariff rate quotas that favor reform in developed countries' trade policies. Meanwhile, the G33 coalition had rallied around the Indian proposal on public food stockholding for food security (Pavot & Dufour, 2016). The latter was controversial and caused negotiations to break down in November 2013 (Efstathopoulos & Kelly, 2014). Eventually, the USA and India have negotiated a bilateral and indefinite ''peace clause" to protect India's food security program from being legally challenged under the WTO until a permanent solution is reached (Flentø & Ponte, 2017).

Regarding environmental issues, they had a low priority over the first four decades of the GATT (1947-1994) but came back with a vengeance in the early 1990s. This is particularly true for agriculture, a sector of great interest in developed and developing countries and usually subject of natural resources' exhaustion. Accordingly, managing depletable resources such as biodiversity, water and soil became more challenging for agriculture and critically important whether for ensuring food security (S. Khan & Hanjra, 2009; Tilman et al., 2002), conserving ecosystem services (Dominati et al., 2010; Ribaudo et al., 2010) or coping with global warming (Battisti & Naylor, 2009). To tackle these issues, several countries have been implementing environmental devices to enhance agricultural productivity in an ecologically sustainable manner (Moon, 2011).

Several studies have addressed the relationship between agricultural trade and the environment. Some of them were interested in the environmental drawbacks of agricultural trade like Duarte et al. (2019) and Fracasso (2014) who examined the determinants of global virtual water trade using the gravity model. Both studies have shown that the virtual water embodied in agricultural goods is affected by the classical economic, institutional and geographic variables. Additionally, national water endowments and the level of pressure on water resources turn out to be determinant for virtual water trade.

A second type of studies has investigated the impact of climate change on agricultural trade. El Hadri et al. (2018) show that natural disasters appear to reduce agricultural exports of about 3% regardless the location. Jones and Olken (2010) showed that agricultural exports from

[4] Composed of Antigua and Barbuda, Guyana, Nicaragua, Sri Lanka, Barbados, Haiti, Nigeria, Suriname, Belize, Honduras, Uganda, Tanzania, Benin, India, Pakistan, Trinidad and Tobago, Botswana, Indonesia, Panama, Turkey, China, Jamaica, Peru, Venezuela, Congo, Kenya, Philippines, Zambia, Korea, Madagascar, Saint Kitts and Nevis, Zimbabwe, Ivory Coast, Mauritius, Saint Lucia, Cuba, Mongolia, Saint Vincent and the Grenadines, Grenada, Mozambique and Senegal.

developing countries to the United States are particularly reduced due to direct impacts of climate shocks on crop yields. In the same vein, Péridy and Brunetto (2013) underlined the double impact of climate change on agricultural trade in MENA countries. Rising temperatures and decreased precipitation not only lower their export capacity but also increase their dependency to cereal and milk imports.

A third category of studies was more interested in the relationship between trade and environmental regulations. From a theoretical perspective, the issue has been a hot topic for economists for some years now. As presented in Figure I. 1, a first school of thought relates to the environmental outcomes of trade openness. In this regard, the "race-to-the-bottom" hypothesis was initially formulated in the context of local competition for investments and jobs within federal states in the USA before 1970. Back then, responsibilities for the environment were decentralized. The theory argues that increased competition for trade and foreign direct investment could lead to lowering environmental standards and regulations (World Bank, 2000; WTO, 1999).

However, few studies have countered this negative link using the terms "race to the top" and "the gains-from-trade hypothesis". For instance, Frankel and Rose (2005) examined the positive impact of globalization on environmental regulation and argued that increased trade could eventually lead to better environmental protection. This finding was supported later on par other scholars, namely Dong et al. (2012), Yao & Zhang (2008) and Tamazian et al. (2009).

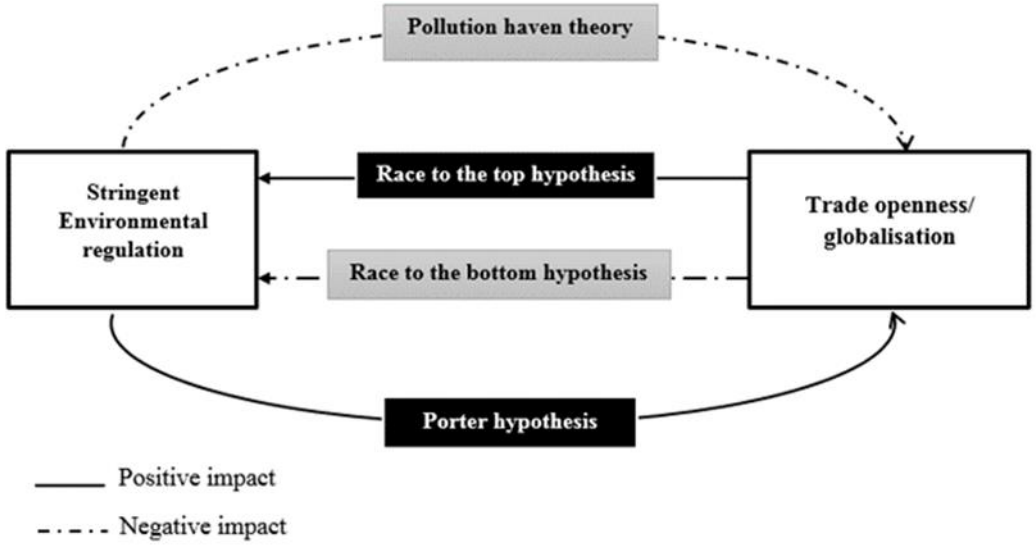
In fact, this hypothesis adds to a growing number of trade theories, from old doctrines to the new trade theory. The latter have highlighted the outcomes of free trade and, accordingly, impacted on policy at many levels. We recall that free trade was first initiated by the absolute advantage theory of Adam Smith to achieve production efficiency at a global level (Smith & Skinner, 1999). He argues that the division of labor in the nascent large-scale industries allows for lowering labor costs, ensuring therefore effective competition across countries. Basic premises of the free trade theory were further developed by Ricardo at the beginning of the 19th century. His theory is based on the comparative advantage, which is both necessary and sufficient to ensure mutually gainful trade across countries (Ricardo, 2001).

Later on, free trade theory moved away from the Ricardian comparative cost doctrine and the technology-based explanation to endowment-based interpretations for nations having similar access to technology (Sen, 2010). The Heckscher-Ohlin, and later Heckscher– Ohlin–Samuelson (HOS) versions laid a foundation for the defense of free trade as Pareto-optimum (Samuelson, 1949). In turn, Linder (1961) provides a demand-based framework for explaining product differentiation and intra-industry trade. In his theory of overlapping demand, he argues that representative demand in the trading countries determines the feasibility of trade between them.

In the framework of new trade theory, Ethier (1984) and Krugman (1981) argue that production achieves a global span in terms of location through countries which are external to the firm but internal to the industry. Thus, relocating production away from economies where

it is not cost-efficient allows for a better cost reduction on a global scale. This argument put forward the potential gains to all trading countries by achieving increasing returns on a global scale (Krugman, 1981), which is considered as an additional incentive for free trade. Finally, Grossman and Helpman (1991) argue how a country's research and development sector can be enhanced by international trade. They show that free trade increases competition and expands the market size in which innovative firms produce.

Figure I. 1. Main theories of environmental economics and trade



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Regarding the environmental aspect, Figure I. 1 shows that the second school of thought relates more to environmental regulations' impact on competitiveness. According to the traditional assumption, known as the "pollution haven" hypothesis, an environmental regulation adds additional constraints on the possible actions of companies and increases thereby their production costs. Eventually, this would affect negatively their competitive position on the international market (Taylor, 2005). This theory suggests that countries tend to reduce their firms' production costs by applying more lenient environmental regulations. Thus, they improve their ability to export despite the possibility of becoming pollution havens. The hypothesis implies a deliberate strategy on the part of host governments to purposely undervalue the environment and attract new investment.

On the other side of this debate, the negative link between environmental regulations and competitiveness was questioned first by Porter (1991) and then by Porter and Van der Linde (1995). Based on what is now known as the "Porter hypothesis", the introduction of well-designed environmental regulations leads, in most cases, to innovation. The latter will ultimately generate a rent to cover the costs of compliance and will eventually allow firms to reach new markets. Put differently, this approach emphasizes the potential synergic effect between environmental regulation and trade competitiveness. Several empirical studies, namely

Jiménez-Parra et al. (2018) and Pautrel (2009) have confirmed the positive link between environmental policies and growth. However, and to the best of our knowledge, few studies regarding the agricultural sector are available. Runge and Nolan (1990) were the first scholars to address the issue by drawing a descriptive analysis of trade distortion effect of environmental and health regulations. They conclude that developing countries may be prevented from selling their agricultural products to richer nations because they fail to reach environmentally acceptable standards.

One year later, Tobey (1991) provided a sketchy evidence on environmental policies' effects on agricultural trade. He performed a simple correlation analysis between the revealed comparative advantage index with the overall pollution content ordinal ranking index of 10 primary crops of the United States. He found that the crops in which the country performs best in world trade are also the most polluting. Diakosavvas (1994) extented the analysis of Tobey (1991) and tested the hypothesis of whether international trade for agriculture is hampered by environmental control policies. His method was based on the Heckscher-Ohlin theorem of comparative advantage to deal with the environment as a productive capital. The author found that trade patterns of polluting commodities have mostly deviated from the Heckscher-Ohlin predictions due to environmental control measures.

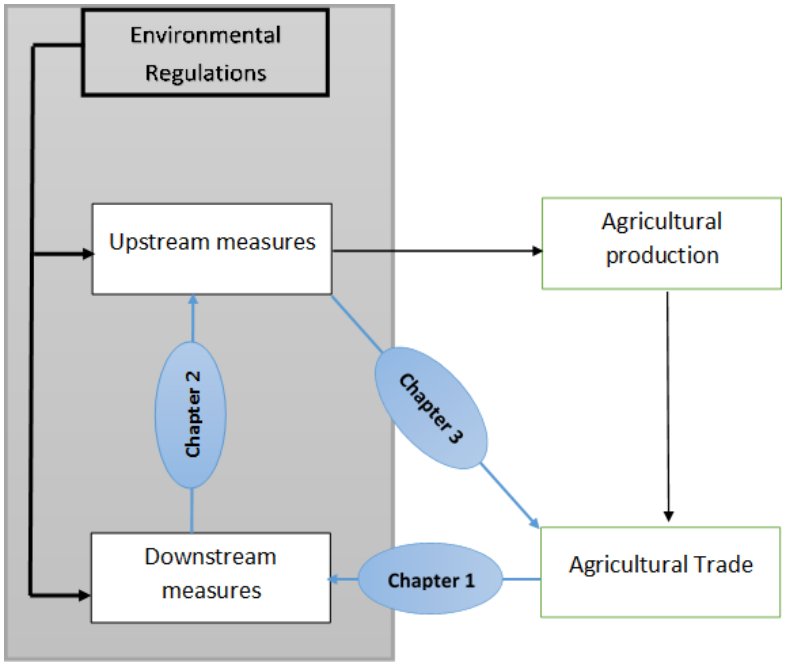
Few years later, Feix et al. (2008) have reignited the debate and employed a cross-section approach of the Heckscher-Ohlin-Vanek model to examine the relation between net exports of agribusiness sectors and the environmental regulation. The latter was proxied by the Environmental Performance Index of Esty et al. (2008) as well as the emissions of greenhouse gases (GHG). Nonetheless, results were not conclusive and varied according to the commodity and exporting countries' origin. More recently, Ramzy and Zaki (2018) showed that stringent environmental regulations affect positively agricultural exports between the European Union and 20 MENA countries during the period 2001-2014. They employed the gravity model and followed the method of Feix et al. (2008) by introducing the Performance Index and total GHG emissions as indicators of environmental regulation.

Given these mixed results, the relationship between rules aimed at liberalizing trade and standards intended to protect the environment has been the source of controversy for many years. In this regard, our work seeks to contribute to this debate. By examining Figure I. 2 that summarizes the structure of the present thesis, we understand that the answer is not that obvious. The scheme shows that trade can be directly or indirectly affected by agri-environmental regulations that impose additional costs to producers. Accordingly, the adequacy to new environmental patterns requires changes of production techniques and final goods.

Additionally, environmental regulations can be supported by trade restrictions in order to become more effective. This is the case of border measures that play a determining role in agricultural trade. Despite the progressive reduction of customs duties resulting from the successive rounds of the GATT and WTO, Bureau and Jean (2013), Liapis (2015) and the WTO (2012) argue that agricultural products are the most concerned by the rise of non-tariff measures (NTMs), particularly in terms of technical barriers to trade (TBT) and sanitary and

phytosanitary (SPS) measures. The reduction of explicit barriers to trade such as quotas and customs duties has thus been accompanied by a multiplication of technical, procedural and regulatory provisions. The latter are governing trade flows and compromizing current and future trade agreement negotiations (Claquin et al., 2017).

Figure I. 2. Structure of the thesis



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Non-tariff measures were in turn the focus of a vast literature to characterize their impact on agricultural trade using traditional gravity models. For instance, Fontagné et al. (2005) reported that the trade-distorting effects of non-tariff barriers (NTB) were important in the food trade. Moreover, they highlighted their negative effects on fresh and processed food products. In turn, Disdier et al. (2008) showed that NTMs constitute obstacles and considerably reduce exports from developing to OECD countries. Nonetheless, NTMs do not affect trade between OECD members according to this study. In addition, Péridy & Ghoneim (2013) have shown that NTMs significantly reduce trade in almost all MENA countries, including sanitary and phytosanitary measures and TBT to a lesser extent. In sum, the above-mentioned studies demonstrate the trade distortion effect of NTMs (or NTBs).

An alternative strand of empirical studies suggests that NTMs expand trade and can act as market-creating "catalysts". Cadot et al. (2018) argue that well-designed SPS and TBT measures have a trade-facilitating effect although they raise prices. They show that technical NTMs can have a demand-enhancing effect and correct pre-existing market failures. In turn, Maertens and Swinnen (2007) conducted two case-studies in Madagascar and Senegal to analyze the local welfare effects of high agricultural standards imposed by developed countries. Their main findings suggest that they can be a catalyst for trade, growth and poverty reduction in developing countries.

Nonetheless, technical NTMs, namely TBT and SPS measures, are environmentally-related according to Fontagné et al. (2005). Despite its significance, this feature was not fully covered by the existing literature and several questions related to their environmental aspect remain asked.

As presented in Figure I. 2, this thesis investigates at different levels the relation between international trade, upstream and downstream environmental regulations using empirical analyses and considering the income heterogeneity of countries. Along this line, this research extends previous findings and highlights that environmental regulations related to the agricultural sector (agri-environmental regulations hereafter) take many forms. The latter are thereby crucial to understand the new trade patterns. With this in mind, several questions arise:

- Have trade growth led to stronger environmentally-related conflict between major supplying countries?
- How can we measure the stringency of agri-environmental policies?
- Is the agri-environmental performance affected by international trade features? If that is the case, did they encourage a "race to the bottom" or a "race to the top" in environmental standards?
- Regarding bilateral trade flows, are agricultural exports affected by environmental regulations? If so, do they support the "Porter hypothesis" or the "pollution haven theory"?
- Finally, does the difference in exporter and importer environmental regulations affect their bilateral trade flows?

We try to answer these questions and contribute to current strands of literature by examining the relationship between trade and environmental regulations after the implementation of the AoA. Thereby, we examine the new patterns of agricultural trade using both upstream and downstream environmental regulations. On the one hand, we extend our analysis beyond the simple quantification of trade volumes and investigate the network structure of technical NTMs. The purpose is to identify the new "hot-spots" of environmentally-related disputes. On the other hand, this research focuses on upstream environmental measures that affect agricultural production. The idea here is to compute their efficiency and explain their variability across-countries. Finally, we explore new environmental determinants of the capacity for exporting crop commodities considering the income heterogeneity of countries.

This thesis is organized around three chapters. Chapter 1 draws a descriptive analysis that will guide the rest of our work. The conducted study identifies the recent international dynamics of crop commodities' trade. Besides, we extend the analysis by including downstream environmental regulations that affect agricultural trade, namely technical NTMs. Then in Chapter 2, we focus on upstream measures and examine the recent greening agricultural reforms that have marked several countries around the word. To that end, we measure the agri-environmental efficiency of a large country sample and investigate its determinants. Finally,

Chapter 3 examines the effects of agri-environmental regulations' stringency and heterogeneity on the intensive margin of trade.

Chapter 1 investigates the new patterns of agricultural trade and deals with one of the most visible and effective facets of the AoA, namely the environmentally-related NTMs. The study addresses more precisely the bilateral specific trade concerns (STCs hereafter) raised at the SPS and TBT committees, and closely tied to agricultural commodities (Horn et al., 2013). To that end, we use the tools of network analysis introduced by Harary (1953) to visualize the evolution of the regulatory distance between WTO members over the period 2003-2013. The second motive is to understand to what extent developing and emerging countries are concerned by environmentally-related trade conflicts.

The concept of interdependence lying within the network analysis is in fact the basic motive behind choosing this tool. To the best of our knowledge, this is the first time that the analysis of bilateral STCs has been expanded to study their global structure using network techniques. Additionally, we compute the centrality measures developed by Bonacich (1987) and Newman (2010) as a way of describing the level of country heterogeneity in bilateral STCs on the one hand, and to identify the new "hotspots" of the environmentally-related conflicts on the other.

Our analyses indicate that agricultural trade has been marked by a strong growth in developing and emerging countries. This increase was less reflected by market share gains in exports to developed nations than by a strong increase in "South-South" flows, which is detrimental to high income suppliers. In addition, the structure of trade has become more complex in 2013 compared to 2003 and is marked by a growing interconnection and lower trade concentration.

Further results show that bilateral STCs can be thought of as networks. The latter confirm the "old" offensive position of industrialized countries, namely Japan, the US and the European Union. An interesting finding is that this effect has been dissipating over time, suggesting that high income countries have left their central positions within the environmentally-related STC network to several emerging and developing agricultural suppliers, namely Peru, Argentina, Brazil and Indonesia. Accordingly, it appears as if trade growth of southern countries has been conducive to rising environmentally-related trade conflicts. Finally, our results reveal new environmentally-related conflictual relation targeting developing and emerging countries on one side and increasing environmental tensions within southern agro-suppliers on the other.

Although suggestive, findings of chapter 1 do not give full account of the environmentally-related implication of the agreement on agriculture. In chapter 2, we focus on its repercussion on upstream agricultural production systems, and more precisely, on agri-environmental policies around the world. To that end, we conduct a large-scaled empirical application to measure the agri-environmental efficiency of 108 countries over the period 2003-2013.

The evaluation is based on a two-step data envelopment analysis model developed by Andersen and Petersen (1993). As a first step, we use time-varying data and undesirable output

to compute the efficiency scores following the method of Seiford and Zhu (2002). We employ in the second step the double bootstrapped truncated regression suggested by Simar and Wilson (2007) to conduct a sensitivity analysis and test the effect of a wide range of variables, in particular international trade features, on the agri-environmental inefficiency. In this model, we consider the income heterogeneity of countries and control for country-specific unobserved heterogeneity.

The findings show that the sector of crops has witnessed globally an increasing trend in average agri-environmental efficiency between 2003 and 2013. An interesting and somewhat expected result is that the agri-environmental performance of developing countries is more sensitive to climatic variables compared to emerging and high-income economies. Moreover, the effect of environmental protection's expenditure is highly detrimental to the agri-environmental inefficiency in low and middle income countries, whereas the effect is weaker in the BRICS and high income economies. An intriguing finding is that agricultural trade openness and the specialization in crop commodities' exports hamper the inefficiency. We confirm by this means the "environmental gains-from-trade" hypothesis.

In addition, our results show that environmentally-related NTMs affect considerably the agri-environmental performance. In fact, technical barriers to trade and sanitary and phytosanitary measures turn out to be levers for enhancing the agri-environmental efficiency of exporters especially in the BRICS and high as well as middle-income countries. This would suggest that the overall increase of environmentally-related NTMs against tariff dismantling in the agricultural sector has aligned developed, emerging and middle income exporting countries with their partners' strict regulations. Accordingly, this has induced a "race to the top" phenomenon in their domestic environmental standards. Nonetheless, low income countries react differently and show a deteriorating agri-environmental performance due to technical NTMs.

In Chapter 3, we deeply examine the question of agricultural trade and the environment using the computed efficiency scores as a proxy of the stringency of environmental policies. On the one hand, the chapter investigates whether the agricultural sector support the "Porter theory" (Porter, 1991) or favor the "pollution haven hypothesis". On the other hand, this research furthers the analysis by determining the trade effect of regulations' heterogeneity, highly determined by the level of development of exporters and importers.

To that end, we employ the theoretically justified gravity model of trade of Anderson and van Wincoop (2003) to examine the impact of environmental policies' stringency on exports, focusing on trade creation and diversion effects. The model is tested on a sample of 108 countries over the 2003-2013 period and using bilateral export data for crop commodities. To obtain unbiased and consistent estimates, we considered the endogeneity bias problem due to omitted variables by controlling for time-varying multilateral resistance terms and country-pair fixed effects following the method of Yang and Martinez-Zarzoso (2014). Additionally, we use a high- dimensional fixed effects Poisson pseudo maximum likelihood (PPML) model of Santos Silva and Tenreyro (2006) to solve the zero-trade issue and the presence of heteroskedasticity.

Results show that the stringency of environmental regulations is determinant for bilateral agricultural exports. However, our findings are sensitive to the level of development of exporting countries. First, the environmental stringency turns out to be trade reducing in the CAIRNS group, supporting thereby the pollution haven hypothesis. This finding suggests that free agricultural trading nations characterized by lenient environmental regulations have gained comparative advantages in pollution-intensive goods and are turned into pollution havens.

By contrast, rigorous agri-environmental policies have a significant trade-enhancing effect on bilateral agricultural exports of highly protective and industrialized countries such as the EU and the USA. Similarly and surprisingly, further results show that low and middle income countries with higher agri-environmental performances export larger volumes of crop commodities, supporting therefore the Porter hypothesis. Our findings suggest that strict environmental regulations can enhance the competitive advantage of developing countries against foreign rivals.

In addition, we note that agricultural commodities react differently to environmental regulations. The sector of fruit and vegetables is more sensitive to this determinant unlike cereals that remain relatively less affected. Finally, our results show that difference in exporter and importer environmental regulations is more relevant to agricultural trade than trade agreements. Overall, the environmental gap between two trade partners is decreasing slightly, but significantly, crop commodities' exports. However, trade effects vary according to the income groups of exporting and importing countries.

To conclude, the relationship between trade and the environment has long been a concern of researchers in economics. The key results emerging from these chapters enable us to clarify the complex relationship between agricultural trade and environmental regulations, especially when we consider the environmentally-related NTM in conjunction with upstream policies. Overall, the present research reveals the positive relationship between agricultural trade and environmental regulations. Although this finding is highly determined by the income heterogeneity of countries, it shows so far promising results related to southern countries.

Finally, we want to point out that our study is limited to crop commodities, excluding thereby livestock products. This choice is in fact purely technical. First, crop commodities share similar production process and have thereby similar environmental impact (this issue is discussed in chapter 2). Accordingly, they are subject to the same agri-environmental measures unlike other products such as live animals, meat and dairy production. The second motivation is the strategic role of these products in both developed and developing countries (this point is discussed in section 3.3.1 in Chapter 3). The present study includes 108 countries that together account for more than 90% of the world's food crops production and covers the period 2003-2013.

1. Chapter 1. The new “hotspots” of the environmentally-related non-tariff measures: New evidence from network analysis

1.1. Introduction

The aim of this first chapter is twofold. First, we investigate the new patterns of agricultural trade over the past years and characterize the recent international dynamics of crop commodities. Nonetheless, the study of international trade needs to be expanded. It should integrate new perspectives other than the quantification of trade volumes, namely technical non-tariff measures (NTMs) that influence international trade as acknowledged by Cadot et al. (2018). This is the central objective of this work.

In fact, the signature of the agreement on agriculture (AoA hereafter) in 1994 is usually considered as a breakpoint in the history of global food trade (Anderson, 2009; Bureau & Jean, 2013). The aim behind the agreement was to open a new era of trade growth and enhance the liberalization of domestic markets. Additionally, several developed countries have restructured their agricultural policies since the mid-1990s and implemented progressively the agenda of trade liberalization. The project sought also to define new rules for fairer competition between exporting countries and better market access. To that end, the World Trade Organization (WTO) implemented a regulatory framework for environmental and food safety concerns in order to achieve these targets.

Therefore, we deal with one of the most visible and effective facets of the agreement on agriculture, namely the environmentally-related non-tariff measures. The study addresses more precisely the bilateral specific trade concerns (STCs) raised at the sanitary and phytosanitary (SPS) and technical barriers to trade (TBT) committees that are closely tied to agricultural commodities (Horn et al., 2013). We thereby employ network techniques to assess the different characteristics of STCs related to crop commodities. The purpose of this descriptive analysis is to provide a global vision of the international agricultural market over time and integrate different groups of countries to capture the extent to which environmental NTMs affect international trade.

Network analysis has rapidly evolved in recent years. Traditionally, scholars explore trade flows data using network techniques at both aggregated (De Benedictis & Tajoli, 2011;

Garlaschelli & Loffredo, 2005; Kali & Reyes, 2007) and sectoral (De Benedictis et al., 2014; De Benedictis & Tajoli, 2010; Puma et al., 2015) levels. Before going into technical details, it is appropriate to answer a preliminary question: why do we want to look at the structure of bilateral STCs using network analysis? First, networks are about relations and the dyad "origin-destination" is the fundamental piece of their information. In other words, the analysis is structured around the relationship between the country of origin and the destination instead of the monads. The specificity of graphs is that the link between both countries is not analyzed in isolation. In fact, their relation is studied by focusing on its structural dimension while taking into account the effect of neighbors. Accordingly, the network (or graph) is constructed by extending the effect of others to the many third parties included in the set of possible STCs' relations.

The implication of this "structural view" is that the environmentally-related conflictual relation between countries cannot be considered independent from the relation between the origin and destination country, as well as between the destination and the third country. The concept of interdependence lying within the network analysis is thereby the basic motive behind choosing this tool in our study. To the best of our knowledge, this is the first time that the analysis of bilateral STCs has been expanded to study their global structure using network analysis.

Starting from the visualization of the network of SPS and TBTs' specific trade concerns, we define and describe its topology in the weighted version. We then calculate and discuss some of the commonly used statistics of network. The graph is calculated using bilateral STCs notified in 2003 and 2013. The data come from the integrated trade intelligence portal (I-TIP) of the World Trade Organization (WTO, 2018). We consider the period 2003–2013 to be in line with chapter 2 in which, the study extends to 2013 due to missing data. In order to visualize the evolution of the regulatory distance between trade partners and understand to what extent developing and emerging countries are concerned by environmentally-related trade conflicts, we compare between two graphs relative to the above-mentioned years. We finally focus on centrality measures as a way of describing the level of country heterogeneity in STCs' networks.

Our findings indicate that agricultural trade has been marked by a strong growth in developing and emerging countries. This increase was less reflected by market share gains in developed importers than by a strong increase in "South-South" flows, which is detrimental to high income suppliers like the US and the EU. In addition, trade structure has become more complex in 2013 compared to 2003 and marked by a growing interconnection and lower trade concentration. Further results show that bilateral STCs can be thought of as networks. The latter confirm the "old" offensive position of industrialized countries, namely Japan, the US and the European Union. An interesting finding is that this effect has been dissipating over time, suggesting that high income countries have left their central positions within the environmentally-related STCs' network to several emerging and developing suppliers, namely Peru, Argentina, Brazil and Indonesia. The latter clearly hold a notable position in the network, mainly as STCs' destinations. Accordingly, it appears as if trade growth of southern countries

has been conducive to rising environmentally-related trade conflicts. Finally, our results reveal new environmentally-related conflictual relation targeting developing and emerging countries on one side and increasingly spreading environmental tensions within southern agro-suppliers on the other.

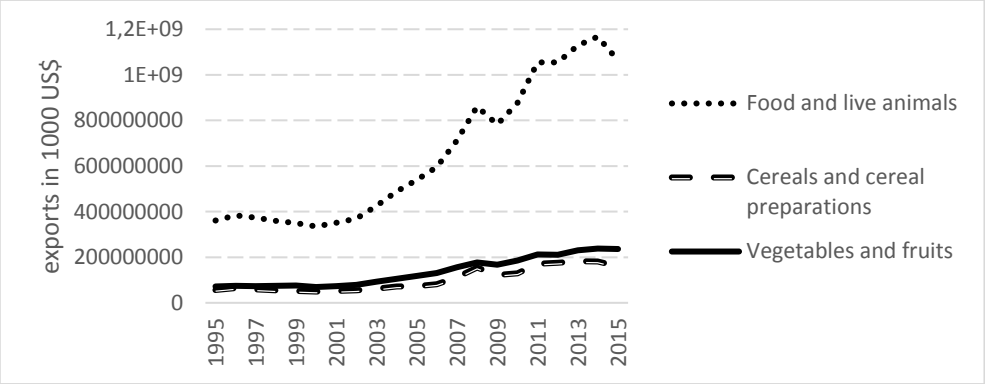
The structure of the chapter is the following. In section 1.2, we analyze the recent international agricultural trade dynamics as well as the environmentally-related non-tariff measures. In section 1.3, we present the used methodology and data. We fully describe the general characteristics of STCs' networks and centrality measures in section 1.4. Finally, section 1.5 closes the chapter with the main conclusions.

1.2. Stylized facts

1.2.1. New agricultural trade patterns

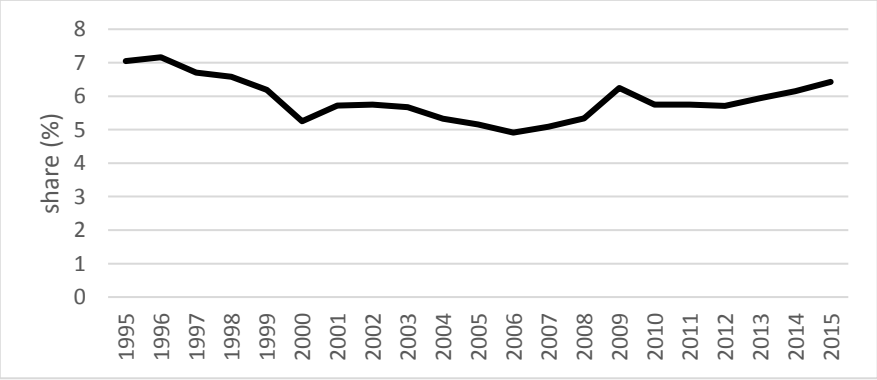
In this section, we investigate the new patterns of agricultural trade over the past years with updated data.

Figure 1. 1. Global agricultural exports from 1995 to 2015



Source: the figure is created by the author using data from UNCTADstat (UNCTAD, 2017)

Figure 1. 2. Relative share of agricultural exports in global world trade



Source: the figure is created by the author using data from UNCTADstat (UNCTAD, 2017)

Along with the exponential growth of food and animal exports depicted in Figure 1. 1, cereal exports weighed in 2013 more than 180 US$ billion, representing almost 3.5 times more than 1995. Moreover, exports of fruit and vegetables recorded the same increase since the signature of the agreement on agriculture. They reached the value of 237 US$ billion in 2014 (compared to only 56 US$ billion in 2005). Despite this increase, the share of agricultural goods in international trade fell from around 7% in 1995 to less than 5% in 2006, then its rises by 1.4 points after the economic crisis of 2009 as Figure 1. 2 shows.

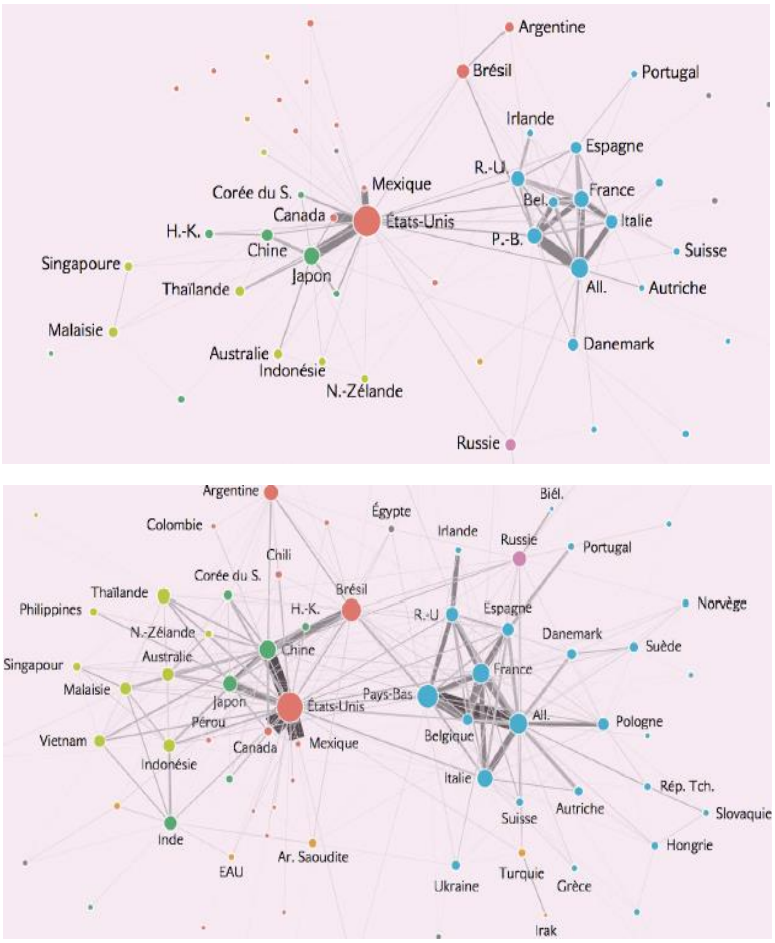
According to Serrano and Pinilla (2012), the relatively slow growth is due to three factors, namely the high degree of protectionism, the low demand elasticity for these products and their small share in intra-industrial trade. Nevertheless, the recorded increase in agricultural products' exchange, both in volume and diversity is a remarkable element that needs further investigation.

Figure 1. 3 shows that international agricultural trade has been witnessing, for more than seventeen years, a gradual shift in the center of gravity of trade from North to South, and from Europe and North America to Asia and Latin America. In 1995, the number of major countries and flows is limited. Even if international trade involved a large number of countries back then, its central structure was relatively defined by the triad Europe-North America-Japan that concentrated most of the flows.

On the other hand, the structure of trade has become more complex in 2013. Indeed, the number of countries and flows that matter has greatly increased to cover all continents. This phase is marked by a growing interconnection and lower trade concentration. A second heavy pattern noticed in trade networks of Figure 1. 3 is the explosion of international trade in an ever-increasing number of flows. In the mid-1990s, only one in four countries traded agricultural products with half of the rest of the world. In 2013, this proportion grew to 43% for exports and 46% for imports according to Claquin et al. (2017), leading to the dispersion of agricultural flows.

This is the case of two major importers namely Japan and Algeria where we can see clearly in Figure A1. 1 in the Appendix of chapter 1 (A1) a significant increase in the number of their suppliers between 2000 and 2013. New entrants were introduced to the Algerian market, namely Brazil, Ecuador, India, New Zeeland, Indonesia and Vietnam. The significant increase in flows from South America and Asia to North Africa is clearly detrimental to European exports, whose supremacy is threatened in the long term. According to the same figure, Japan has been opening up to new exporters. The country's suppliers switched from the American continent to Southeast Asian countries. The latter are therefore increasingly asserting themselves as major suppliers for many regions of the world.

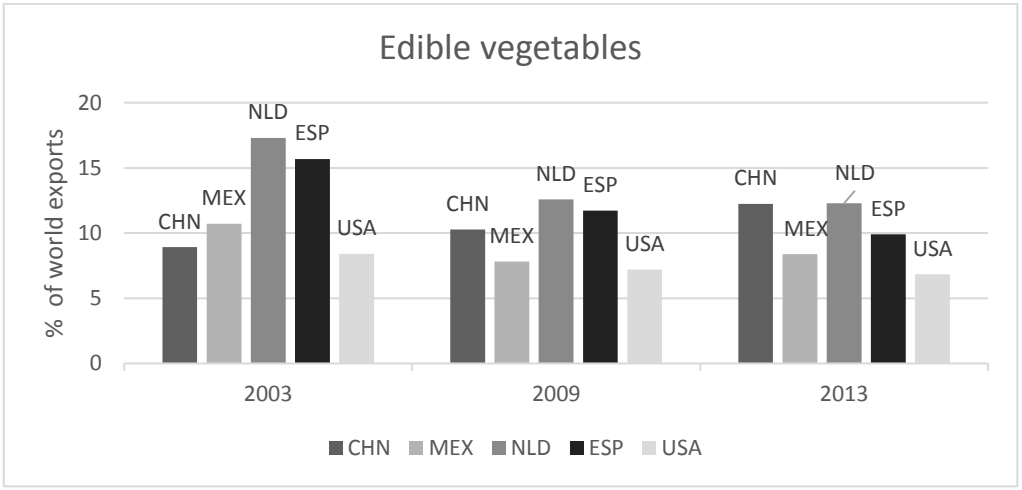
Figure 1. 3. Geography of international agricultural trade in 1995 (top) and 2013 (bottom)

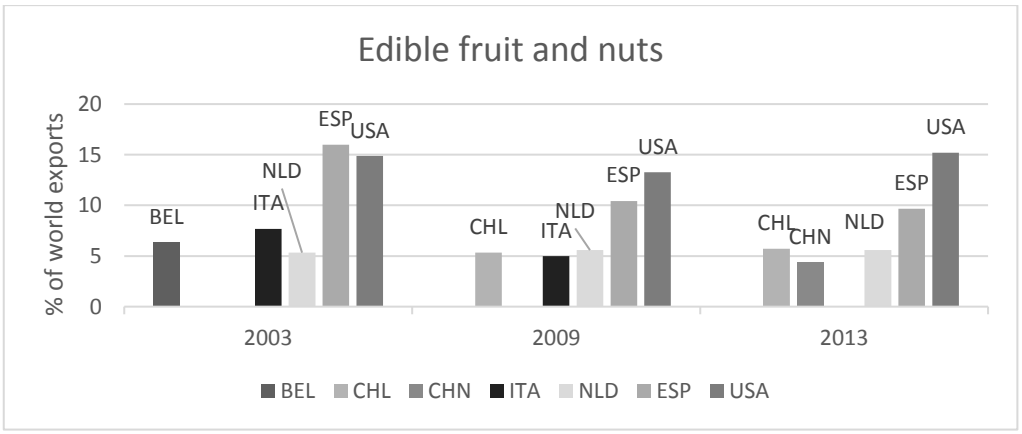


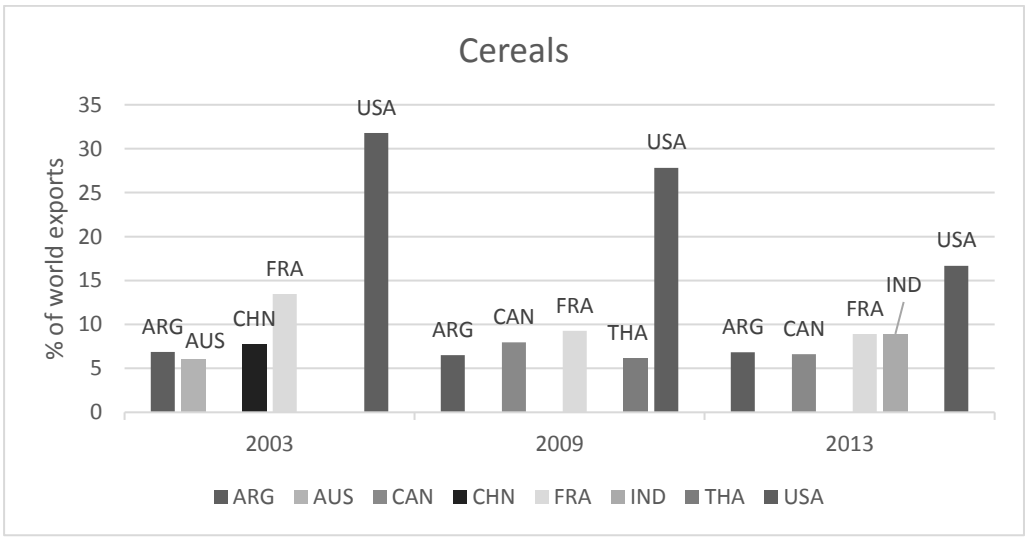
Source: Claquin et al. (2017). Links represent trade volumes in billions of US$ at constant 2012-2013 prices

Focusing on the sector of crop commodities, Figure 1. 4 provides the top five suppliers and their evolution between 2003 and 2013. At the product level, we can observe interesting patterns. First, we note that the country composition of top five exporters of edible vegetables remain unchanged over this period. Among these suppliers, we have two Member States of the EU (i.e. Spain and Netherlands), the US as well as two developing countries, namely China and Mexico. Nevertheless, while Chinese exports have reached 12.23% of global exports in 2013 (against 10,2% in 2009 and 8% in 2003), the share of edible vegetables' exports from the US and the two European countries fell from 8.4% and 32.97% in 2003 to 6.8% and 22.17% in 2013, respectively.

Figure 1. 4. Top five crop commodities' exporters







Source: the figure is created by the author using data from UNCTADstat (UNCTAD, 2017). The following countries are displayed on histograms: ARG (Argentina), AUS (Australia), BEL (Belgium), CAN (Canada), CHL (Chile), CHN (China), ESP (Spain), FRA (France), IND (India), ITA (Italy), MEX (Mexico), NLD (Netherlands), THA (Thailand), and USA (Unites States of America).

Second, we note that the primacy of the United States-Europe duo on the export side of edible fruit and nuts in 2003 (respectively 14.8% and 35% of global exports) has been declining since 2009. As Figure 1. 4 shows, their market shares have reached 15% and 16.2% in 2013, respectively. Interestingly, we note the presence of southern countries among the top five list starting from 2009, namely Chile and China. The share of fruit exports from developing countries grew from 5.3% in 2003 to 10% in 2013.

Other basic products, namely cereals are mainly exported by the USA according to Figure 1. 4. However, the country's share of global exports lost weight and fell from 31% in 2003 to 16% ten years later. Similarly, the share of cereal exports from France fell from 13% to 8% during the same period. This can be explained by the increasing weight of other exporters from emerging and developing countries that grew from 14.4% in 2003 to 16% in 2013. The figure shows that the post-World War II American leadership had first given way to a USA – Europe "duopoly" and is currently challenged by southern countries, at the forefront of which are China, Argentina, Chile and Mexico as new major crop commodities' suppliers. According to Gaigné et al. (2020), the absence of productivity gains, the lack of a competitive edge, and the high costs of access to foreign markets are the major factors behind northern countries' slack, like France, in competitiveness.

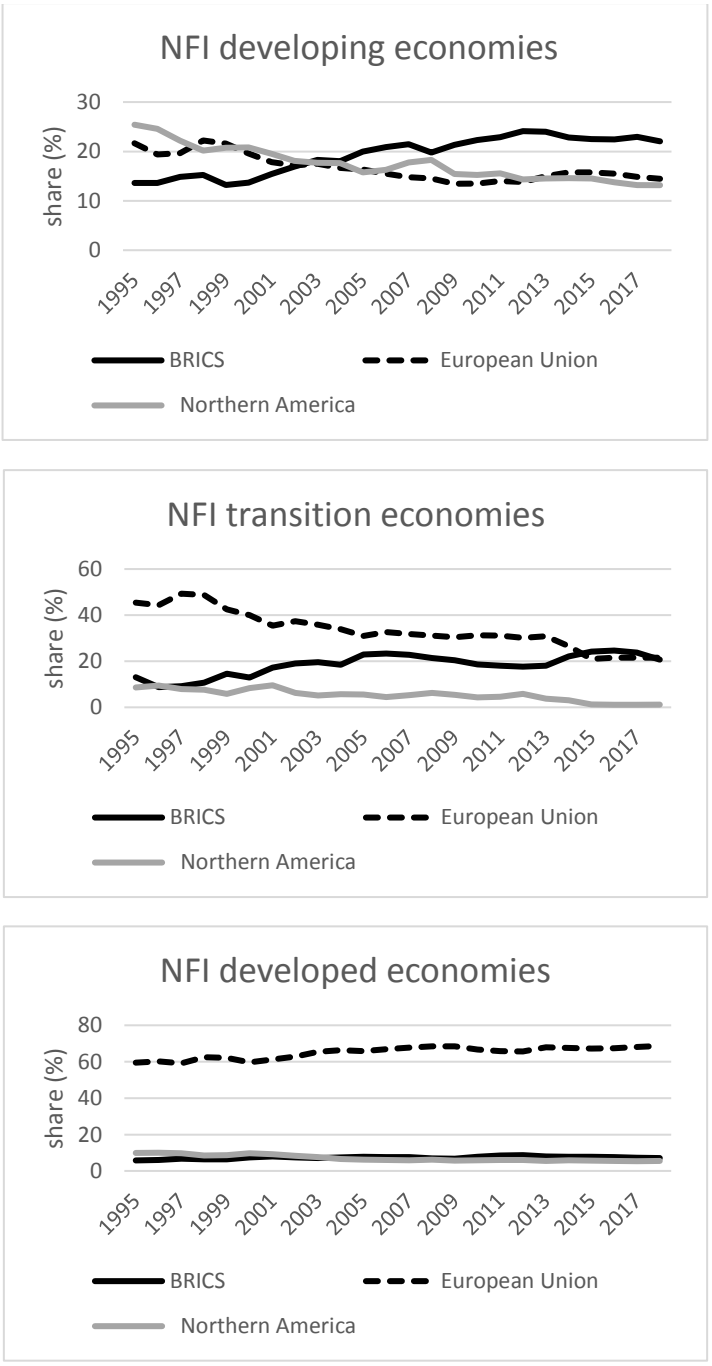
Trade networks reported in Figure 1. 3 outline, however, the supremacy of European exports to developed net food-importing (hereafter NFI) countries. This observation is supported by Figure 1. 5. In fact, food supplies of developed NFI are primarily from the EU (67% in 2013) and, to a lesser extent, from North America. The latter's share has also decreased from 10% in 1995 to 5.4% in 2013. Meanwhile, the BRICS exports grew from 5.7% in the mid-1990s to 8% in 2013. Figure A1. 2 in the Appendix of chapter 1 (A1) provides a visual explanation and shows that international agricultural trade of the EU remains mainly intra-continental and is largely dominated by intra-European flows over the period 2000 and 2013.

On the other hand, emerging countries have been affirming themselves in the international market since 1995 as Figure 1. 6 shows. Indeed, and while the share of European exports had decreased by 15 % between 1995 and 2015, the BRICS have doubled their market share. The latter grew from 7.7% in 1995 to 14% in 2014, whereas the share of North American countries has fallen by more than 12 points since the mid-1990s. In addition, Figure A1. 2 in the Appendix of chapter 1 (A1) shows that trade flows from the BRICS to southern countries have significantly increased over the period 2000 and 2013. By contrast, emerging countries' exports to the north have sharply declined during the same period.

The leadership of emerging countries is most acute in developing markets. As reported in Figure 1. 5, the UE and North America covered in 1995 respectively 22% and 25% of the imports of developing NFI markets. However, both rates have fallen to 14% within 20 years. On the other hand, we note that the BRICS exports to developing NFI countries have significantly increased, going from 13% in 1995 to 24% in 2013. According to the same figure, we note that emerging NFI countries have recorded the same pattern. The EU covered almost

half of their agricultural market in the 1990s (45.5% in 1995). The rate has decreased to 30% in 2013, whereas the share of the BRIC grew from 13% to 18.11% over the same period.

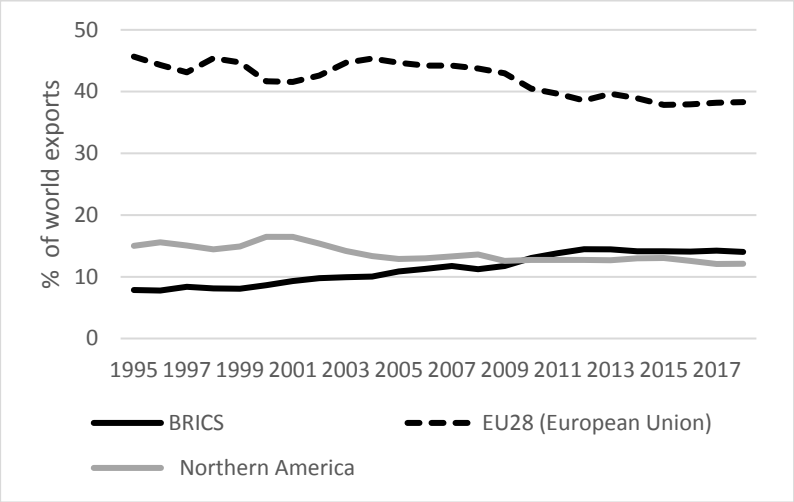
Figure 1. 5. Market shares of the BRICS, North America and the EU in NFI countries



Source: the figure is created by the author using data from UNCTADstat (UNCTAD, 2017).
The y-axis displays the share of each group (BRICS, EU and North America) in total agricultural imports of NFI countries. The latter are classified according to their income group (developing, transition and developed). List of NFI countries is presented in Table A1. 7 in the Appendix of chapter 1 (A1). Data is extended to 2017 to confirm the tendency beyond the period studied 1995-2013.

To sum up, agricultural trade has been marked by a strong growth in developing and emerging countries. This increase was less reflected by market share gains in exports to developed nations than by a very strong increase in "South-South" flows. Both of Figure 1. 5 and Figure 1. 6 confirm the tendency beyond 2013 and until 2017. Anderson and Strutt (2012) predict a further doubling of this share by 2030.

Figure 1. 6. Evolution of crop commodities' exports of the BRICS, North America and the EU

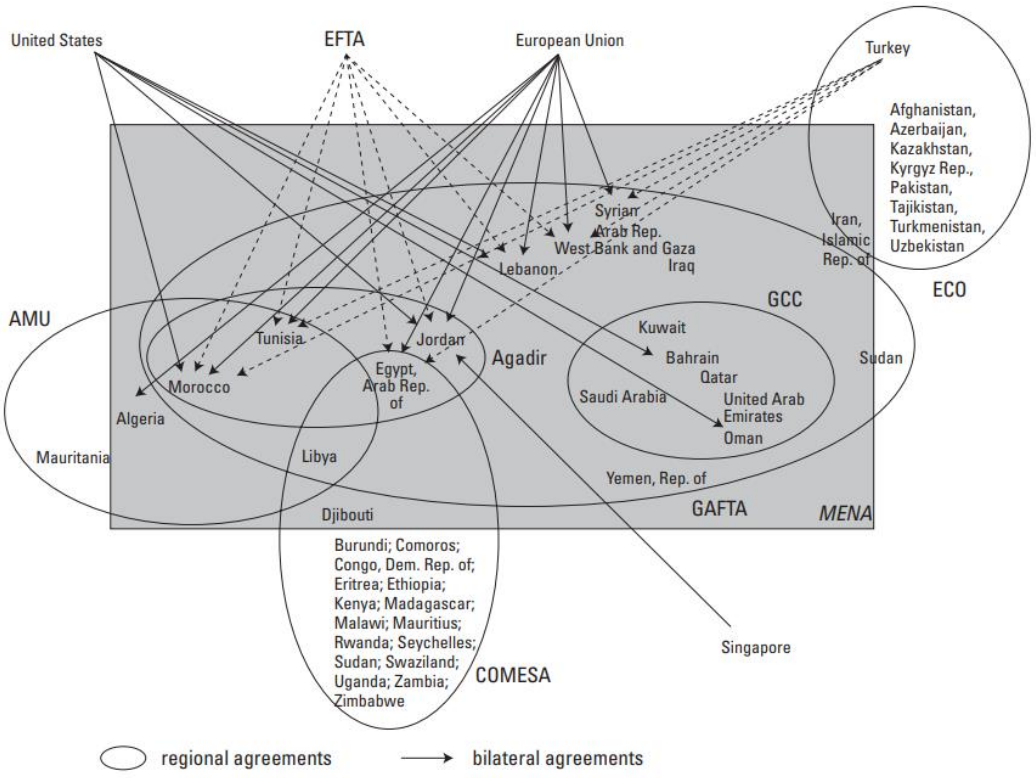


Source: the figure is created by the author using data from UNCTADstat (UNCTAD, 2017). Data is extended to 2017 to confirm the tendency beyond the period studied 1995-2013.

If intercontinental trade has grown strongly in volume, its progress seems to be durably hampered by the importance of the associated costs and the rise of preferential free trade agreements, often regional (Bureau & Jean, 2013). Realistically, some exceptions to this general principle may apply. Let's take the example of Middle East and North African (MENA) countries. The latter have been experiencing a structural imbalanced supply of agricultural products exacerbated by political destabilizations and their dependency on oil prices (Ianchovichina et al., 2014).

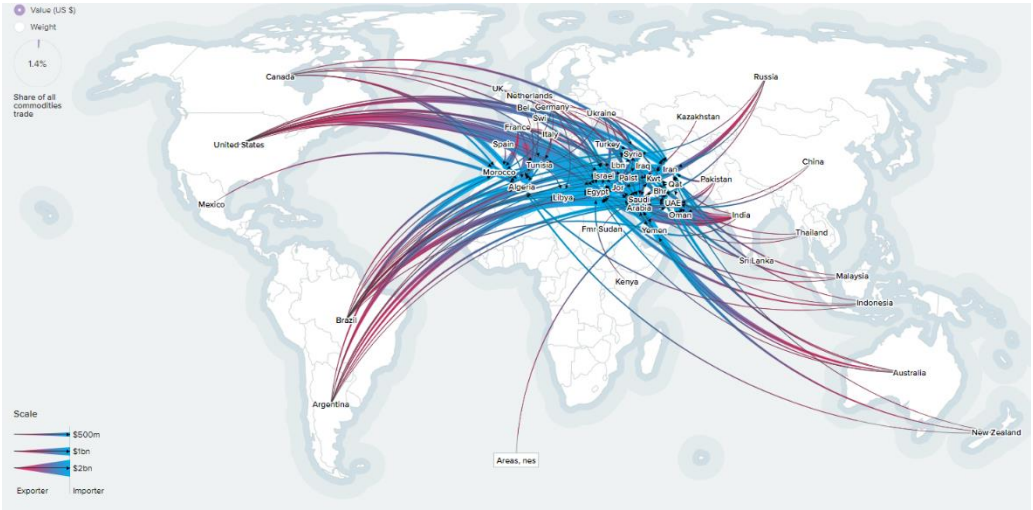
Figure 1. 7 identifies regional and preferential trade agreements signed in the past five decades by MENA countries. Besides the intra-region arrangements, others are concluded with outside partners notably the European Union and the United States of America. If we compare this network with their main agricultural suppliers' map (reported in Figure 1. 8), we notice a significant gap between the two networks. Put differently, market shares of traditional European and American suppliers are eroded by new entrants, namely the BRICS, South-East Asia and Oceania without necessarily concluding new trade agreements.

Figure 1. 7. Network of MENA trade agreements



Source: World Bank (2008). Only major agreements are reproduced, namely Agadir Agreement for the Establishment of a Free Trade Zone between Arabic Mediterranean Nations (Agadir), Arab Maghreb Union (AMU), the Common Market for Eastern and Southern Africa (COMESA), the Economic Cooperation Organization (ECO), European Free Trade Association (EFTA), Greater Arab Free Trade Agreement (GAFTA) and Gulf Cooperation Council (GCC).

Figure 1. 8. Main agricultural suppliers of MENA countries in 2013



Source: calculated from resourcetrade.earth (Chatham House, 2017).

Accordingly, investigating trade flows with updated data is as pertinent as ever. Nonetheless, we believe that it does not fully depict the new patterns of international trade. In the next section, we investigate the environmentally-related implications of the agreement on agriculture to be more accurate and offer an appropriate holistic view with regard to agricultural trade.

1.2.2. Environmental implications of the agreement on agriculture

The WTO rules, intended primarily to deepen international trade, are increasingly influencing environmental, health and social areas of public policy, although they do not come directly under the commercial sphere. The question of the interaction between the WTO and other specialized agencies arises frequently. For instance, the development of international standards within the Codex Alimentarius must reconcile the objectives of trade facilitation and consumer protection with regard to food safety.

In their study, Disdier et al. (2007) mention the example of Russia that has imposed sanitary and phytosanitary (SPS) measures on US meat and poultry imports in 2002 due to the eventual presence of avian influenza in the United States. This decision was countered by the exporting country according to which, the ban was not scientifically defensible and was discriminatory.

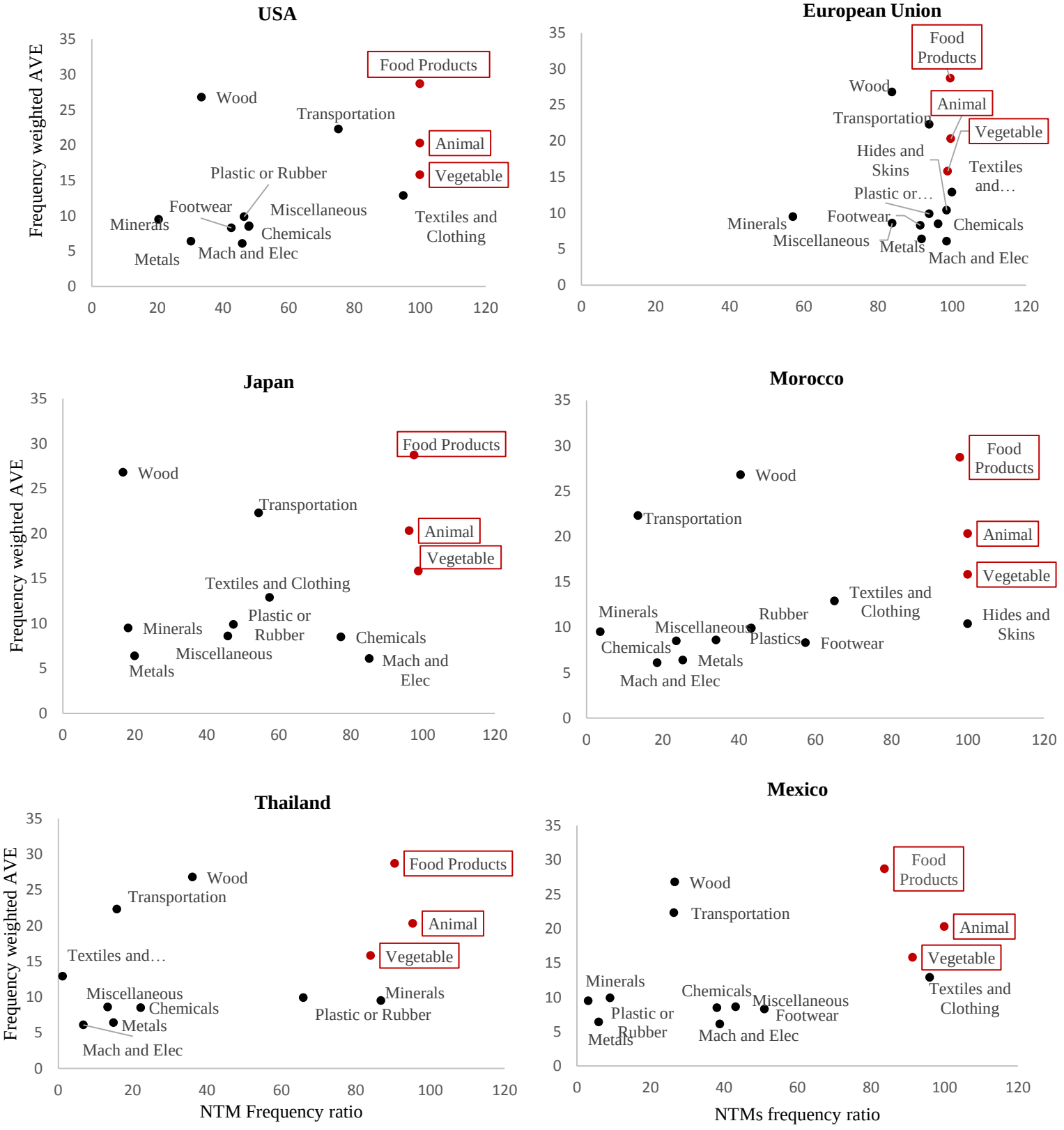
Within this context, restrictions on agricultural imports can be considered as trade barriers when commodities are not produced locally. However, these measures can be justified as a tool to correct negative externalities. In fact, some goods are, by their nature, slightly subject to NTMs, whereas agricultural commodities are highly regulated because of consumers and environmental protection standards (Cadot et al., 2018).

Figure 1. 9 shows the distribution of the main harmonized system sections according to their NTMs frequency ratio and their ad valorem equivalents [5] (AVE) of NTMs. Interestingly, agricultural and food sectors such as animal, vegetable and food products are positioned in the top right dial in Figure 1. 9 of all countries. Indeed, this positioning is reserved for the sectors that are likely to be most constrained by NTMs. Surprisingly, this behavior is common not only to highly protective countries, namely the USA, EU and Japan, but also to free agricultural trading nations (such as Thailand) and developing countries like Mexico and Morocco.

In this regard, analyzing NTMs is clearly crucial to address the question of agricultural trade. In the following paragraphs, we argue the importance and the structure of technical non-tariff measures related to agricultural products, and more specifically to crop commodities. But first, what do technical NTMs mean?

[5] The ad valorem equivalent (AVE) of an NTM is the conventional approach to estimate their trade-restricting effect (Looi Kee et al., 2009). AVE represents the proportional increase in the domestic price of the products subject to these measures, relative to a counterfactual where they are absent.

Figure 1. 9. Most constrained sectors by NTMs in a selection of countries



Source: the figure is created by the author using data from WITS TradeStat Database (World Bank, 2018) and Cadot et al. (2018). The figure displays the breakdown of the harmonized system sections according to their NTMs' frequency ratio (abscissa axis) and AVE of NTMs (ordinate axis). The displayed sectors are food products, minerals, chemicals, transportation, metals, animal, vegetable, hides and skins, wood, plastic and rubber, textiles and clothing, machines and electronic, miscellaneous and footwear.

UNCTAD (2019, page v) defines NTMs as "policy measures, other than customs tariffs, that can potentially have an economic effect on international trade in goods, changing quantities traded, or prices or both". Most measures are applied as requirements for the importation of products, despite their origin. Nonetheless, some measures are only applied to selected countries, and not to all (UNCTAD, 2018). Two types of NTMs may be distinguished. First, "non-technical" including quantitative restrictions, anti-dumping duties, countervailing duties and so on.

The second type is of a "technical" nature, generally imposed to address market failures such as information asymmetries or negative externalities (Cadot et al., 2018). It includes primarily sanitary and phytosanitary measures (SPS) and technical barriers to trade (TBT) that became in the last years prevalent and more widespread to pursue non-economic targets without imposing barriers to trade. In fact, when a country imposes environmental regulations on its producers, it is tempting to impose them also on imported products to avoid distortions of competition.

In order to understand such a pattern shared by such different countries in Figure 1. 9, we need to go back to April 15th, 1994 when the Marrakesh agreement was signed and marked the end of the Uruguay round of multilateral trade negotiations (1986-1994). Simultaneously, three major sub-agreements were reached and revolutionized the agricultural sector (WTO, 2001a).

- First, the agreement on agriculture which stipulates that, inter alia, tariffs on agricultural products are to be reduced by an average of 36 % in the case of developed countries (over a 6-year period) and 24 % in the case of developing countries (to be undertaken over 10 years). However, least-developed countries are not required to reduce their tariffs. Contrary to the Bali and Nairobi packages reached in 2013 and 2015, respectively, the AoA provides a wide framework for the long-term reform of agricultural trade.
- Second, the agreement on sanitary and phytosanitary measures related to food safety, animal and plant health regulations. It entered into force with the establishment of the World Trade Organization on January 1995 and recognizes that governments have the right to take SPS measures as long as they are applied to protect human, animal or plant life and health without any discrimination among countries. As a result, the use of SPS measures is largely limited to agricultural sectors and more than 60% of food-related products are found to be affected by at least one form of these measure (Cadot et al., 2018; Horn et al., 2013).
- Third, the agreement on technical barriers to trade that extended the TBT agreement of Tokyo Round (1974-1979). It covers by contrast technical requirements resulting from

food safety, animal and plant health measures including pesticide residue limits, inspection requirements and labelling that are not covered by the SPS agreement.

In sum, technical NTMs were reintroduced by the WTO after being removed during the GATT to internalize negative externalities and pursue non-economic targets. Hereafter in this thesis, we assume that all the previously cited technical NTMs, namely SPS and TBT measures are environmentally-related.

Table 1. 1. Notifications of technical-NTMs from 1995 to 2013

	SPS			**TBT**		
	1995	**2003**	**2013**	**1995**	**2003**	**2013**
USA	1300	1607	3003	1247	1695	2430
	(32.6%)	*(22%)*	*(12.6%)*	*(27.7%)*	*(20.8%)*	*(12%)*
Australia	7	49	58	30	166	685
	(0.1%)	*(0.6%)*	*(0.2%)*	*(0.6%)*	*(2%)*	*(3.4%)*
Brazil	22	134	529	33	117	493
	(0.5%)	*(1.8%)*	*(2.2%)*	*(0.7%)*	*(1.4%)*	*(2.4%)*
China	22	209	1047	92	443	3248
	(0.8%)	*(2.8%)*	*(4.4%)*	*(2%)*	*(5.4%)*	*(16.1%)*
India	36	48	2301	278	412	1415
	(0.9%)	*(0.6%)*	*(9.7%)*	*(6.1%)*	*(5%)*	*(7%)*
World	3988	7281	23735	4548	8120	20140
	(100%)	*(100%)*	*(100%)*	*(100%)*	*(100%)*	*(100%)*
Total number of notifying countries	77	87	91	77	85	91

Source: the table is created by the author. Cumulative number of NTMs' notification is extracted from the I-TIP database (WTO, 2018). Country share (in %) of global SPS and TBT notifications is reported in parentheses.

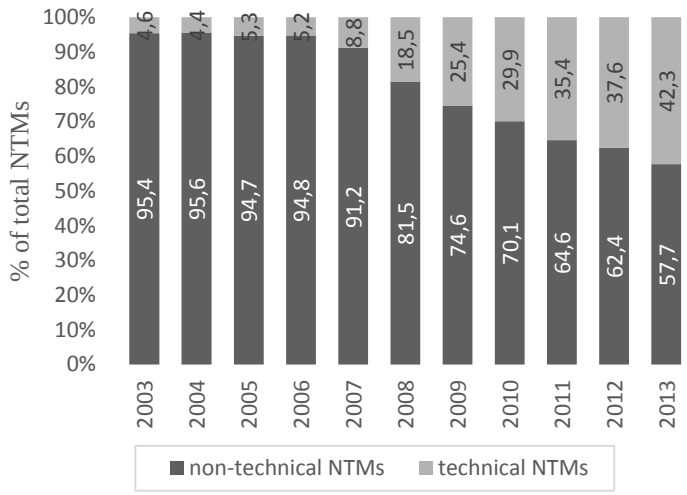
Table 1. 1 shows that notifications of technical NTMs grew vigorously in 20 years. Overall, SPS measures increased from 3 988 in the mid-1990s to 23 735 notifications in 2013. TBT measures also surged and went from 4 548 notifications to 20 140 during the same period. In addition, we note the increasing number of notifying countries (accounting for 77 in 1995 and 90 countries in 2013) during these years.

At the country level, we can also observe interesting patterns whether in absolute or in percentage (values in parentheses) terms. Firstly, we note that industrialized countries behave differently. In 2013, Australia made 58 notifications in the framework of the SPS agreement and 685 under the TBT agreement, accounting for about 0.2% and 3.4% of total notifications respectively. On the other hand, the American SPS and TBT notifications' shares accounted for 12.6% and 12%, respectively during the same year. However, the country has gradually lost its SPS and TBT relative shares as they accounted for 32.6% and 27.7%, respectively in 1995.

In parallel, the number of notifications from developing countries is rising steadily. In Brazil, it grew from 22 in 1995 to 529 SPS notifications in 2013. In turn, Chinese notifications under the SPS agreement increased from 22 to 1 047 measures during these years. Similarly, TBT notifications show increasing growth. In the mid-1990s, they accounted for 33 measures in Brazil (representing 0.7% of global TBT notifications) and 92 measures in China (accounting for 2%). In 2013, they reached 493 notifications in Brazil and 3 248 measures in China, representing 2.4% and 16.12% of total notifications, respectively.

Additionally, Indian SPS notifications grew vigorously. According to Table 1. 1, they increased from 0.9% of global notifications in 1995 to 9.7% in 2013. In sum, the absolute growth in technical NTMs' notifications that international trade has been witnessing since the signature of the SPS and TBT agreements is due to the increasing number of notifying countries along with their exploding notifications. Interestingly, notifications from developing countries recorded a notable growth (in relative terms) compared to highly protective countries like the United States (Beestermöller et al., 2018; Fontagné & Mimouni, 2001).

Figure 1. 10. Global NTMs restrictions applied on vegetable products from 2003 to 2013



Source: the figure is created by the author. Cumulative number of NTMs' notification is extracted from the I-TIP database (WTO, 2018).

In Figure 1. 10 and Figure 1. 11, we limit our analysis to "vegetable products" [6] under the section II (HS07). Figure 1. 10 shows that the share of technical measures (of total NTMs) applied on crop commodities grew from 4.6% in 2003 to 42% in 2013. This escalating trend was first noticed in 2008 when the cumulative number of SPS and TBT restrictions had doubled

[6] Section II (HS07) corresponds to "vegetable products" including live trees and other plants, bulbs, roots and the like, cut flowers and ornamental foliage, edible vegetables and certain roots and tubers, edible fruit and nuts, peel of citrus fruit or melons, coffee, tea, mate and spices, cereals, products of the milling industry, oil seeds and oleaginous and vegetable plaiting materials.

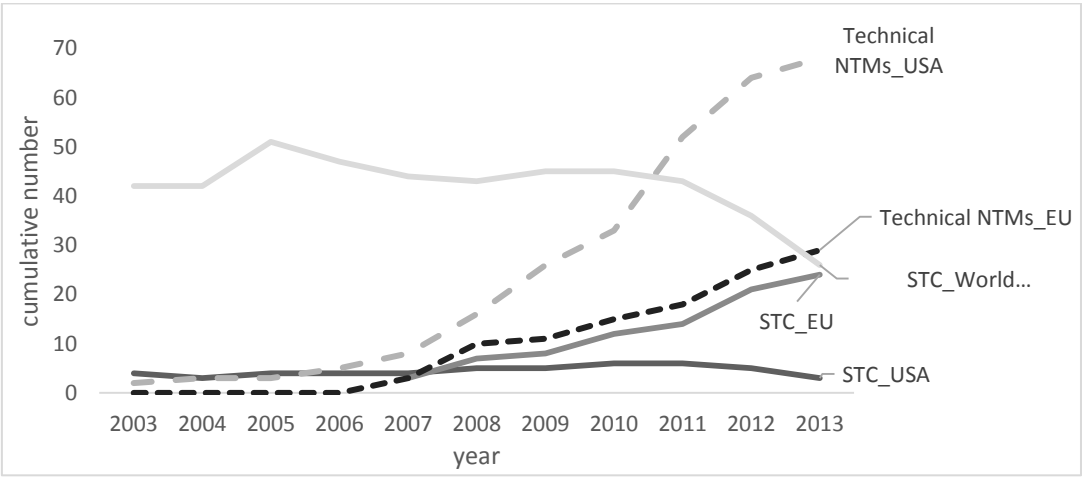
in one year. By contrast, the share of non-technical NTMs decreased by 53 points within ten years.

We recall that the GATT authorized environmental measures as long as they are neither discriminatory nor protectionist according to its article XX. On the other hand, the principle of national treatment (article iii of the GATT) states that each country must reserve for imported goods the same fate as for similar national goods (GATT, 1986). However, "likeness" is an indeterminate concept, and a growing number of disputes has been relating to the question of whether two products resulting from different production methods are to be considered as "similar". The relationship between trade-liberalizing rules and standards intended to protect the environment and food safety has been the source of controversy, particularly between trade partners (e.g. the previously described dispute between the US and Russia). Consequently, a significant number of specific trade concerns (STCs) is addressed by the SPS and TBT committees.

Holzer (2019) and Orefice (2017) define STCs as means of addressing disputes between countries about the conformity of national measures in the SPS and TBT areas with the agreements. WTO members can initiate STCs concerning both notified and unnotified measures. As a matter of fact, a country may raise the matter in the committee if he endures a measure that was not notified by his partner.

Even though TBT and SPS agreements affect both industrial and agricultural products, we notice that trade in agricultural goods emerges as the single most important area where STCs are raised. According to Horn et al. (2013), only 6% of trade concerns raised at the SPS committee affect non-agricultural commodities. In addition, 30% of trade concerns within the TBT agreement affect agricultural commodities.

Figure 1. 11. NTMs and STCs imposed on vegetable products by the EU and USA



Source: the figure is created by the author. Data is collected from the I-TIP database (WTO, 2018). Curves display global trend as well as in the EU and USA.

Figure 1. 11 illustrates the cumulative number of STCs that were raised in the SPS and TBT committees from 2003 to 2013. We notice that the number of imposed STCs by WTO members (outside the EU and USA) varied considerably. First, STCs notifications grew from 42 measures in 2003 to 51 in 2005, then recorded a significant decrease from 2006 to 2008. Thereafter, notifications have risen again during the sub-prime crisis. In 2012, STCs' cumulative number fell from 36 notifications in 2012 to 26 in 2013.

In turn, specific trade concerns imposed by the EU reached their first peak in 2010 (12 measures) then increased steadily to reach over 24 measures in 2013. Meanwhile, the yearly number of STCs imposed by the US ranges between 3 to 4 over the period 2003-2007. Thereafter, two additional measures were recorded between 2008 and 2012.

Figure 1. 11 traces also the evolution of notified technical-NTMs imposed by the EU and the US. The comparison with the previous findings shows that the rise in STCs between 2008 and 2013 cannot be attributed to a falling number of SPS and TBT notifications (technical NTMs) since they have steadily increased throughout the same period. It does not seem to be randomness the fact that the period 2008-2011 saw more imposed measures than any year thereafter. In its world trade report, the WTO (2012) highlights the fact that non-tariff measures had increased after the "trade collapse" that followed the financial crisis of 2008. Consequently, this may discredit the legitimacy of technical NTMs based on environmental and food safety concerns.

Representing the structural view of environmentally-related NTMs may clear the picture that we have drown so far. However, their multilateral nature prevents us from employing network techniques. Therefore, we rely on the bilateral aspect of STCs and use network analysis. The aim of the rest of the chapter is to reveal new environment-related conflictual relation between developed and developing countries to complement the findings of section 1.2. In the next section, we start by presenting the basic theoretical tools of the network analysis as well as the used methodology and data.

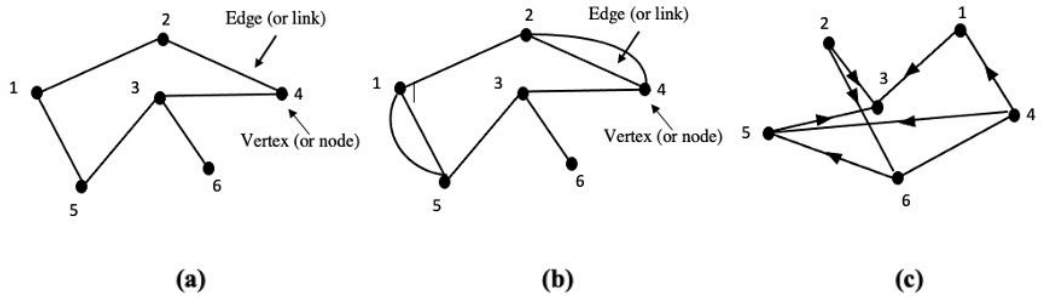
1.3. Network analysis

1.3.1. Basic theoretical tools

Most of basic theoretical tools and fundamental quantitative foundations of networks analysis (called graph in the mathematical literature) come from graph theory. The latter was developed by Harary (1953) and represents the branch of mathematics that deals with networks. In its simplest form, a network is a collection of points, referred to as nodes or vertices. They are joined together in pairs by lines called edges or links (Figure 1. 12). Indeed, several aspects of these systems are worthy of study, namely their components nature, the character of their connections and their interactions' pattern.

Network visualization is usually the first step in analyzing the structure of a graph. This tool is demonstrated to reveal important structural features that are usually difficult to pick out of the raw data. Furthermore, network theory has developed a large tool chest of measures and metrics that can help us understand what our network data are telling us, even in cases where useful visualization is impossible. Our study aims to show that bilateral STCs can be thought of as networks which may lead to useful insights.

Figure 1. 12. Structure of networks



Source: the figure is adapted from Newman (2010) and shows a simple graph (a), a multigraph (b) and a directed graph (c).

Following the common notation in the mathematical literature, we denote by N the number of nodes in a network with integer labels 1 . . . N (as shown in Figure 1. 12) and by M the number of edges. If we denote a link between vertices o and d by (o, d) where $o \in [1 \ldots N]$ and $d \in [1 \ldots N]$, then the complete network can be specified by giving the value of N and a list of all edges.

According to these characteristics, several types of networks may be distinguished. First, simple networks that have at most a single edge between any pair of vertices (Figure 1. 12, part (a)). In this case, the adjacency matrix A of a simple graph is the matrix with elements A_{od}. Formally,

$$A_{od} = \begin{cases} 1 \text{ if there is a link between nodes o and d} \\ 0 \text{ otherwise} \end{cases} \quad (1.1)$$

In other cases, there can be more than one edge between the same pair of vertices as shown in Figure 1. 12, part (b). We refer to those links collectively as a multiedge and to the network as a multigraph. Multiedges can also be represented using an adjacency matrix by setting the corresponding matrix element A_{od} equal to the multiplicity of the edge. For example, a double edge between nodes o and d is represented by $A_{od} = A_{do} = 2$.

Additionally, part c of Figure 1. 12 defines the directed network. In the latter, each edge has a direction (called directed edges), pointing from one node to another. In this case, links can be represented by lines with arrows on them. The elements of an adjacency matrix of a directed network can be written as:

$$A_{od} = \begin{cases} 1 \text{ if there is an edge from d to o} \\ 0 \text{ otherwise} \end{cases} \quad (1.2)$$

Besides, connections in a social network might have weights representing frequency of contact between nodes. Weighted networks can be represented by giving the elements of the adjacency matrix values equal to the weights of the corresponding connections. In the next sub-section, we look at measures and metrics for quantifying network structure.

1.3.2. Metrics for quantifying network structure

Several important ideas in this area come from social sciences and the discipline of social network analysis. Once the network's structure is defined, we can calculate from it a variety of useful measures. For instance, we can compute metrics at both network (e.g. density) and node (e.g. centrality) levels to capture particular features of the graph topology (Borgatti, 2005).

Measures of centrality are useful to identify the most important or central vertices in a networked system. Thus, it seems reasonable to suppose that countries that have connections to many others might have more influence on agricultural trade than those who have fewer connections. There is a wide variety of mathematical measures of vertex centrality that focus on different concepts and definitions of what it means to be central in a network. In this chapter, we limit our analysis to the most suitable measures to our study, namely the degree centrality and the eigenvector centrality.

Degree centrality or the degree of a vertex is the number of edges attached to it. In many cases, vertices with the highest degrees are those with the most connections and play important roles in the functioning of the network system (Newman, 2010). Therefore, degree can be a useful guide to focus our attention on the system's most crucial elements. In our case, the degree of a country represents the number of its trade partners within the STC network. We denote the degree of vertex o by k_o. For an undirected graph of N vertices, the degree is a single number that can be written in terms of the adjacency matrix as:

$$k_o = \sum_{d=1}^{N} A_{od} \quad (1.3)$$

In undirected networks, every edge has two ends. Therefore, and for a total M edges, there are 2M ends. Additionally, the number of edges' ends is equal to the sum of degrees of all the vertices. Formally,

$$2M = \sum_{o=1}^{N} k_o \quad (1.4)$$

If we denote the mean degree of a vertex by c, then:

$$c = \frac{1}{N} \sum_{o=1}^{N} k_o \quad (1.5)$$

By combining Eq. (1.4) and Eq. (1.5), we conclude that:

$$c = \frac{2M}{N} \tag{1.6}$$

In directed networks, vertex degrees are more complicated since each node has two different degrees. First, the in-degree which is the number of ingoing edges connected to a vertex. Second, the out-degree corresponding to the number of edges that point outward from the node. In and out-degrees can be written in terms of the adjacency matrix as follows:

$$k_o^{in} = \sum_{d=1}^{N} A_{od} \qquad k_d^{out} = \sum_{o=1}^{N} A_{od} \tag{1.7}$$

Moreover, the number of edges should fit the following condition:

$$M = \sum_{o=1}^{N} k_o^{in} = \sum_{d=1}^{N} k_d^{out} = \sum_{od}^{N} A_{od} \tag{1.8}$$

According to Eq. (1.8), the number of edges (M) in a directed network must be equal to the total number of ingoing ends of links at all nodes, or equivalently to the total number of outgoing ends of links. Thus, the mean in-degree (denoted c_{in}) is equal to the mean out-degree (denoted c_{out}). In other words:

$$c_{in} = \frac{1}{N}\sum_{o=1}^{N} k_o^{in} = c_{out} = \frac{1}{N}\sum_{d=1}^{N} k_d^{out} = \sum_{od}^{N} A_{od} = c \tag{1.9}$$

By combining Eq. (1.8) and Eq. (1.9) we get:

$$c = \frac{M}{N}$$

(1.10)

Furthermore, we can compute other metrics at the network level, namely the density. In a simple graph, the maximum possible number of links is defined as:

$$\frac{N}{2} = \frac{1}{2}N(N-1) \tag{1.11}$$

The density of a network, denoted ρ, is the ratio between the number of realized links and the number of maximum links possible (Newman, 2010). ρ is defined as the fraction of these links that are actually present. In other words, and according to Eq. (1.10) and Eq.(1.11), we get:

$$\rho = \frac{M}{(\frac{N}{2})} = \frac{2M}{N(N-1)} = \frac{2c}{N-1} \tag{1.12}$$

The density lies strictly in the range [0, 1]. A network is said to be dense when ρ tends to a constant as the number of nodes approaches infinity (N→∞). In this case, the fraction of non-zero elements in the adjacency matrix remains constant as the graph becomes large.

Furthermore, it is common to investigate the occurrence of "loops of length two" in directed networks. A loop occurs when directed edges are running in both directions between a pair of vertices. The frequency of these loops is measured by the reciprocity which tells us how likely it is that node d, pointed out by node o, also points back at o. Put differently, the link from o to d is reciprocated if there is a directed edge from o to d and a link from d to o. The reciprocity, denoted r, is defined by the following equation:

$$r = \frac{1}{M}\sum_{od} A_{od}A_{do} \tag{1.13}$$

Where M is the total number of directed links in the graph. A_{od} and A_{do} are elements of the adjacency matrix. Returning to node-level metrics, we can think of degree centrality as awarding one "centrality point" for every graph neighbor a node has. But not all neighbors are equivalent. We shall thereby complete this measure by the eigenvector centrality, one of the extensions of the degree centrality (De Benedictis et al., 2014).

In many circumstances, the importance of a node in a graph is enhanced by having connections to other "important" nodes. In other words, eigenvector centrality gives each node a score that is proportional to the sum of the scores of its neighbors. According to Bonacich (1987), the eigenvector centrality of the o^{th} node in a directed network is written as follows:

$$c_o^{eign} = k_1^{-1}\sum_{d} A_{od}x_d \tag{1.14}$$

Where c_o^{eign} measures the centrality of each vertex o and A_{od} is an element of the adjacency matrix. Thus, the entity $\sum_{d} A_{od}x_d$ represents the sum of the centralities of o′s neighbors. Finally, k_1 is the largest of the eigenvalues denoted k_o.

The adjacency matrix of directed networks is in general asymmetric. Thereby, it has two sets of eigenvectors: the left (out)-eigenvectors and the right (in)-eigenvectors. According to part c of Figure 1. 12, the vertex 2 is connected to the rest of the network but has only outgoing edges and no incoming ones. Such a vertex will always have in-eigenvector centrality zero because there are no terms in the sum in Eq. (1.14). In addition, the same figure shows that vertex 6 has one ingoing edge that originates from vertex 2. Thereby, node 6 also has in-eigenvector centrality equal to zero because the one term in its sum in Eq. (1.14) is zero.

Taking this argument further, we see that a vertex may be pointed to by others that themselves are pointed to by many more, and so on through many generations. Nonetheless, if the progression ends up at a vertex or vertices that have in-degree zero, the final value of the

centrality will still be zero. In mathematical terms, only vertices that are in a strongly connected component of two or more vertices can have non-zero eigenvector centrality.

1.3.3. Data

We rely on the bilateral aspect of specific trade concerns (STCs) raised in meetings of the SPS and TBT committees to explore their structure using network analysis. In fact, the most frequent type of concerns is purely bilateral in nature according to Horn et al. (2013). However, if two countries are concerned about a same measure undertaken by a third WTO member, we count each one of them having a 'bilateral STC' with the third member. The basic idea behind this approach is to use specific trade concerns to visualize bilateral relational problems and the extent of environmentally-related conflicts between trade partners. We employ bilateral-level data including the countries that were subject of STCs from at least one trade partner in 2003 and 2013. We recall that this study covers this time period to ensure the consistency with the next chapter and to be able to draw coherent general conclusions in section 4.

The country to which the measure applies is denoted d (destination). We denote the trade partner that is imposing the measure by o (origin). Each country is represented by a node in the network, labeled with the respective ISO3 code. Since we account for notifications' cumulative number, there are as many directed links as STCs imposed on the country d by each origin. The list of countries, ISO3 codes and respective geographical regions is reported in Table A1. 1 in the Appendix of chapter 1 (A1).

STCs' data is gathered from the integrated trade intelligence portal I-TIP (WTO, 2018) under the section II (HS07) corresponding to vegetable products. Thereby, STC_{od} is the key variable to elaborate the classical visual representation of networks (or sociograms). The definitions and sources of used variables are reported in Table 1. 2.

In addition, we assign weights to the ties among countries instead of describing the network topology in its binary[7] version. More specifically, we use directed weighted networks as presented in Figure 1. 14 and Figure 1. 15.

In addition to the network characteristics described in section 1.3.1, we add the edge value function, denoted as L. It presents some relevant characteristics including the strength of the link between the origin and destination country. In other words, the elements L_{od} act as dyadic weights on the graph. Similarly, we denote by V the node value function which includes all relevant characteristics of countries such as their ISO3 code and geographical regions.

To define and describe the topology of the graph, we compute two commonly used metrics. First, we measure the normalized weighted version of in-degree (c_{in}) and out-degree (c_{out}) centralities (also called strength centralities) to compare between the networks of 2003 and

[7] called also unweighted version that depicts the presence or not of a trade concern between o and d, whereas the weighted network considers the cumulative number of STCs.

2013. Degree centralities are defined by Eq.(1.15) and Eq.(1.16), where total weights of the links connected to the country is normalized by the factor (N-1) (De Benedictis et al., 2014).

$$c_{in} = \frac{\sum_{d\#o}^{N} L_{do}}{(N-1)} \tag{1.15}$$

$$c_{out} = \frac{\sum_{d\#o}^{N} L_{od}}{(N-1)} \tag{1.16}$$

Despite the relevance of this indicator, the weighted centrality is essentially a local measure. Indeed, it only considers the direct links of a country that represent its nearest neighborhood. The limit of this method is that it neglects the node's position in the structure of the network. To fill the gap, we use global centrality measures, namely the in-eigenvector (c_{in}^{eigen}) and out-eigenvector (c_{out}^{eigen}).

The next step is to explore the characteristics of the WTO members according to their graph position. Considering the findings of section 1.2, did STCs' network change over the period 2003-2013 in conjunction with the expansion and the multipolarity in the trade of agricultural commodities? What is the position of developing and emerging countries? Have southern countries become in the center of the environmentally-related conflicts in addition to their trade growth?

We note that the small sample size of the surveyed countries prevents us from using network metrics into traditional econometric analysis. To answer these questions, we compute instead the correlation scores between the degree centralities and some international trade features, namely the exporters' degree of openness to trade (denoted DOT_d), their agricultural revealed comparative advantage indicator (denoted RCA_d) and the agricultural value-added (denoted VA_agri_d) in both years 2003 and 2013. The used variables and data are described in Table 1. 2.

Agricultural trade openness degree (expressed in %) is computed based on FAOSTAT data (FAO, 2018). The indicator is calculated by dividing the aggregate value (in US$) of imports and exports of agricultural commodities by the agricultural gross domestic product, the whole multiplied by 50. The variable RCA_d, introduced by Balassa (1965) reports the share of the agricultural sector in a country's total gross exports with respect to the world average of the same sector in global exports. RCA data are extracted from the world integrated trade solution (WITS) portal of the World Bank (World Bank, 2018). The value added (VA_agri_d) data have been taken from the FAOSTAT database (FAO, 2018).

Table 1. 2. Data and sources

Variable	Definition	Source
STC_{od}	Cumulative number of specific trade concerns related to crop commodities imposed by the importer (or origin) o on the exporting country (or destination) d.	WTO's integrated trade intelligence portal (I-TIP) (WTO, 2018)
C_{in} , C_{out}	in-degree and out-degree centralities	author's compilation
C_{in}^{eigen}, C_{out}^{eigen}	in-degree and out-degree eigenvector centralities	author's compilation
DOT_{d}	Degree of openness to trade of the exporter d	author's compilation
RCA_{d}	Revealed comparative advantage indicator of the exporter d in the agricultural sector	WITS data portal (World Bank, 2018)
VA_agri_{d}	Agricultural value-added of the exporter d (in % of GDP)	FAOSTAT (FAO, 2018)
$Protectionist_{o}$ $Protectionist_{d}$	Binary variable that takes the value 1 if the country is the USA, a member of the G10 or a member of the EU, and 0 otherwise	author's compilation based on the WTO (2017) classification
$CAIRNS\_G20_{o}$ $CAIRNS\_G20_{d}$	Binary variable that takes the value 1 if the country is a member of the CAIRNS or the G20, and 0 otherwise	author's compilation based on the WTO (2017) classification
$G90\_G33_{o}$ $G90\ \_G33_{d}$	Binary variable that takes the value 1 if the country is a member of the G90 or the G33, and 0 otherwise	author's compilation based on the WTO (2017) classification

Source: the table is created by the author.

Finally, we add the following dummy variables based on the classification of the WTO (2017) to identify the potential correlation between degree centralities and countries' coalitions during multilateral agricultural negotiations. In fact, and as discussed in the general Introduction, emerging and developing countries had become important players in the WTO Uruguay and Doha cycles after numerous accessions, which reinforced opposition across agricultural negotiations. Henceforth, the North- South divide is far from being the only main opposition. First, we distinguish the Europe - US duopoly in conjunction with the highly protective countries, i.e. the group of Ten (G10), that defend their agricultural policies by promoting multifunctional and environmentally friendly agriculture. Therefore, we add the variable $Protectionist_{o/d}$ that takes the value 1 if the country o (or d) is the USA, a G10 or an EU member, and 0 otherwise.

On the other hand, few industrialized countries notably Canada, Australia and New Zealand formed the CAIRNS group in 1986 in conjunction with some developing countries like Argentina, Brazil, Uruguay and Thailand. The group marked the first step in the aggressive participation of developed countries in agricultural negotiations. This coalition accuses highly protective countries of hampering market access and distorting international trade by their export subsidies.

In the same vein, the G20 (created in 2003) represents a counterweight to developed countries to exert their influence and assert the rise of emerging nations through trade negotiations. The group is dedicated to audit northern countries' proposals and make them favorable to the South. We combine both of these coalitions under the variable $CAIRNS\_G20_{o/d}$ that takes the value 1 if the country is a member of the CAIRNS or the group of twenty, and 0 otherwise.

Finally, we introduce the variable $G90\_G33_{o/d}$ that takes the value 1 if the country (o or d) is a member of the G90 or the group of Thirty-three, and 0 otherwise. Indeed, the G33 brings together countries with the ambition to pursue agricultural policies (such as Venezuela and Turkey) as well as developing countries with subsistence agriculture.

In turn, the G90 represents the least active coalition in negotiations due to its large size. It gathers the group of the ninety poorest countries, namely the least developed countries and African, Caribbean and Pacific group. Contrary to the CAIRNS and G20, the G33 aims to exempt southern countries from agricultural liberalization and have increased their customs duties to protect their fragile sector from international competition.

1.4. Results and discussion

1.4.1. Structural characteristics of STCs' networks

Developed by Cartwright and Harary (1977), the sociogram in modern social network analysis is the classical visual representation of graphs. In the latter, individuals (countries in this study) are represented by nodes. Additionally, their STCs' relationship to one another is represented by arcs. Table 1. 3 reports the main characteristics of the calculated networks of 2003 and 2013.

First, we note that total numbers of countries and links change year by year. According to Table 1. 3, a set of 42 STC links is recorded among 31 WTO members in 2003. Links are directed going from the importer o to the exporting country d. In 2013, the number of countries increased to 37. Besides, the graph shows a link-dimension of 48, corresponding to an overall increase of 14.3% in 10 years. The same table shows that the lowest edge value is 0 (i.e. no

edge present) and the highest edge value (i.e. the number of edges present between a couple of countries) is 4 in 2003 and 3 in 2013.

Table 1. 3. Global characteristics of STCs' networks

	2003	2013
Nodes	31	37
Arcs	42	48
Minimum value	0	0
Maximum value	4	3
Density	0.0451	0.036
Indegree centralization	0.228	0.134
Outdegree centralization	0.332	0.277

Source: the table is created by the author.

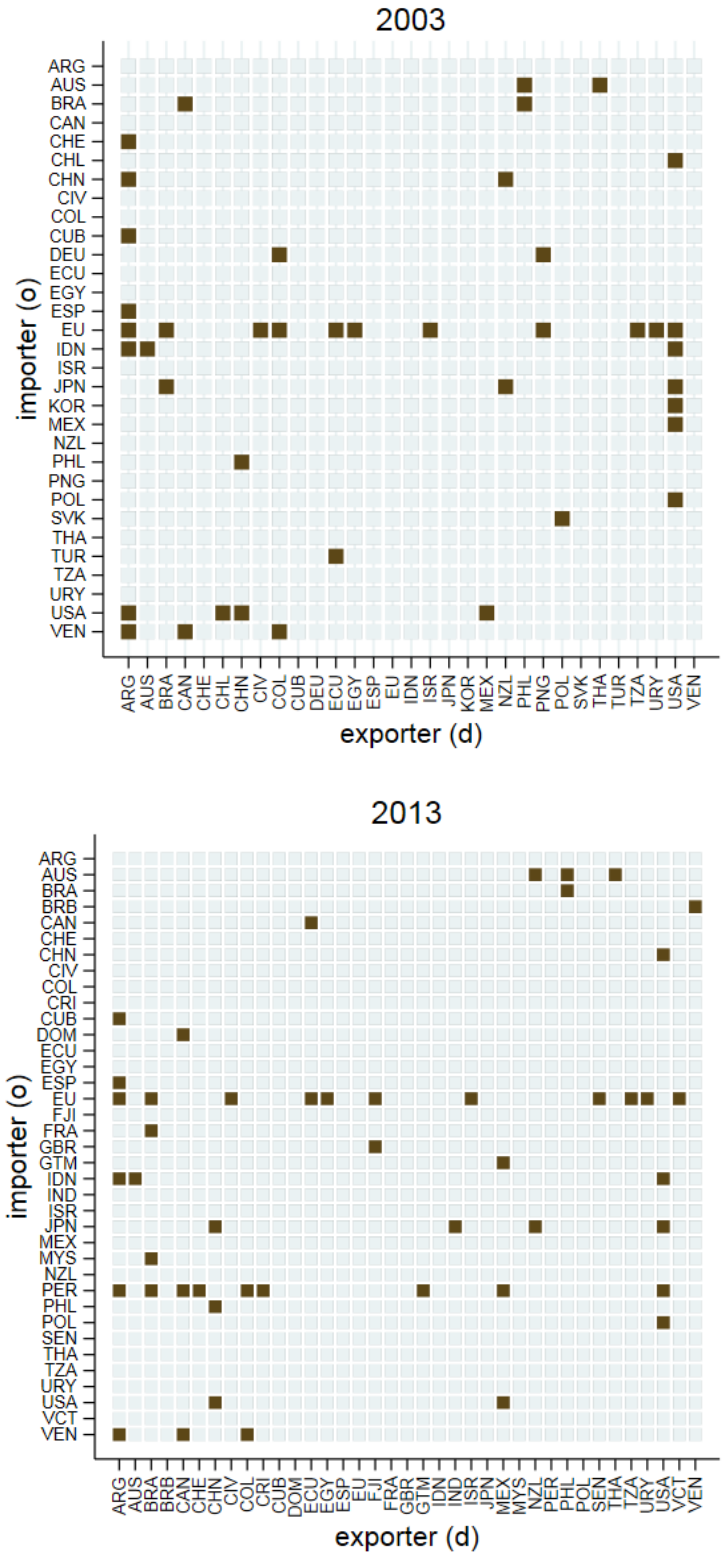
Furthermore, the network is characterized by an average dimensionality over this period. As Table 1. 3 shows, STCs' links correspond to a density of 0.036 in 2013. This would suggest that by taking two countries at random, the probability of an existing STC link among them is of 3.6%. However, this value fell from 4.5% in 2003, showing a slight decrease within 10 years. This can be explained by the number of countries that grew by 19 points between 2003 and 2013.

Overall, Table 1. 3 shows that the likelihood for a country to endure a specific trade concern, measured by the in-degree centralization, decreased from 22.8% in 2003 to 13.4% in 2013. Similarly, the likelihood for a country to direct (or impose) an environmentally related trade concern to others (i.e. outdegree centralization) fell from 33.2% in 2003 to 27.7% in 2013.

So far, global characteristics do not show a strong difference between the two graphs. These indicators hide most likely strong heterogeneity across countries. To resolve the issue, we use as a first step the correlation matrices plots presented by Figure 1. 13. The latter depicts the most active countries raising STCs in the SPS and TBT committees in 2003 (top) and 2013 (bottom).

Both matrices show a high degree of overlap. According to Figure 1. 13, the most active WTO members in 2003 are mostly similar to those of 2013. Argentina (ARG) and the United States (USA) dominate, each accounting for over 6 raised STCs in both years. Interestingly, emerging and developing countries like Brazil (BRA), China (CHN), Mexico (MEX) and Côte d'Ivoire (CIV) have joined this list in 2013.

Figure 1. 13. STCs correlation matrix plots in 2003 and 2013



Source: the figure is created by the author. A_{od} is the element (o, d) in the STC matrix A. d is the column-indicator corresponding to exporting countries that are raising STC matters. o is the row-indicator corresponding to importing countries that are imposing STCs.

On the other hand, most of the raised measures were originated from high income countries such as the European Union (EU) and Japan (JPN) that have imposed 12 and 6 measures, respectively. In addition, STCs imposed by the United States range between 3 and 4 over the same period. But a striking feature is the presence of developing countries in 2013. Figure 1. 13 shows that Peru (PER) and Venezuela (VEN), to name only a few, imposed 9 and 3 specific trade concerns, respectively. In sum, these findings highlight the significant presence of southern countries within the environmentally-related disputes as imposers and notifying countries. Their presence is even more important in 2013 compared to 2003.

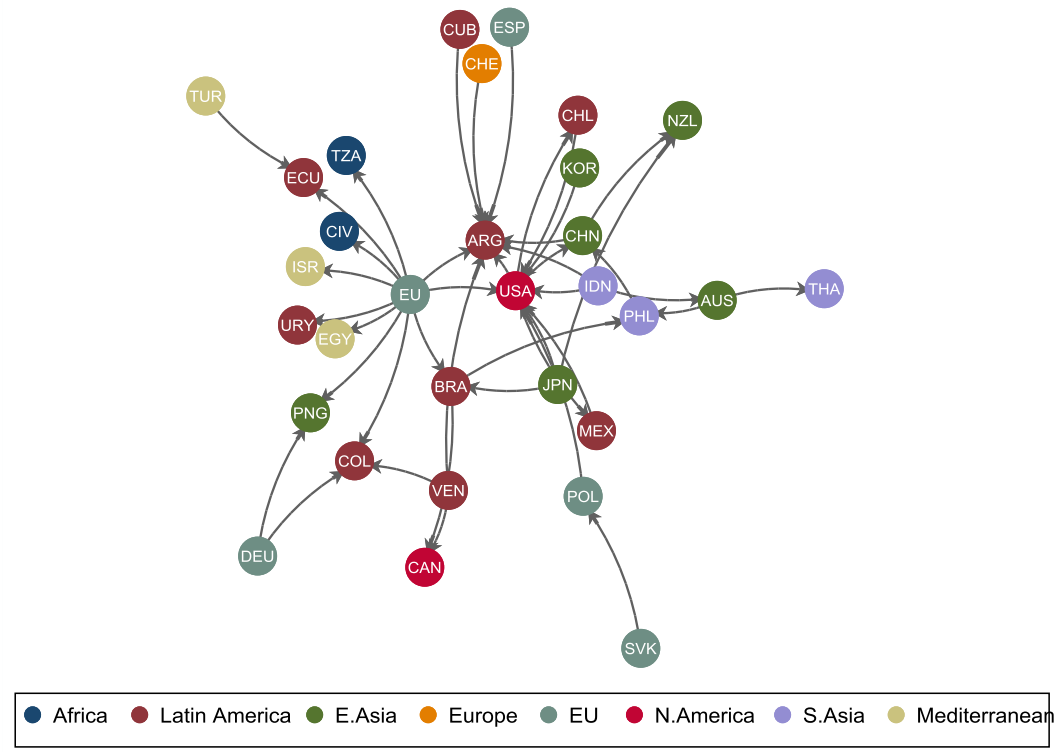
In a second step, Figure 1. 14 and Figure 1. 15 show the visualizations of the STCs' directed networks in 2003 and 2013, respectively. Each country is represented by a node labeled with the respective ISO3 country code. The entire list of countries, ISO3 codes and respective geographical regions is reported in Table A1. 1 in the Appendix of Chapter 1.

Besides, the colors depict geographical regions. First, grey nodes correspond to the member states of the European Union. We note that Spain (ESP), Germany (DEU), United Kingdom (GBR), Slovak Republic (SVK) and Poland (POL) have a "double identity" in networks. In addition to STCs imposed under the aegis of the European Union (EU), these member states had imposed additional STCs on their partners. For instance, Figure 1. 14 shows that Germany (DEU) has imposed two extra STCs on crop commodities coming from Colombia (COL) and Papua New Guinea (PNG). Second, Central and South American countries are in brown. Third, South Asian countries are in purple, whereas Russia and other European countries (outside the EU) are in orange. Oceania and East Asian countries are in green while North American countries are in red. Finally, Southern and Eastern Mediterranean countries are in yellow, whereas African countries are in blue.

Sociograms in Figure 1. 14 and Figure 1. 15 are obtained by relaxing the geographical constraint on the position of countries, following the method of Fruchterman and Reingold (1991). This technique allows us to account for interactions while setting the relative position of each country in the STC system and visualize dyadic data using network analysis techniques. Consequently, countries which are not connected tend to be placed far apart, whereas connected countries tend to stay close.

On the other hand, the position of each country depends not only on its bilateral links but also on the indirect effect of others. In fact, sociograms allow to give to every country a position with respect to the other countries in the entire STC system. By this means, we can visualize the effect of the relationship between trade partners as well as the structure of the network itself. The latter should reveal some patterns that are difficult to see using other approaches.

Figure 1. 14. Network of specific trade concerns, 2003



Source: the figure is created by the author. Although they are marked in grey, Slovak Republic (SVK) and Poland (POL) are not members of the EU in 2003.

We note that Figure 1. 14 and Figure 1. 15 show connected graphs that are composed of one component. By construction, there is no isolated vertices in the directed networks. However, the global STC system seems to be characterized by disparate levels of interconnectivity across and within geographical regions. Indeed, the most connected regions turn out to be European, East Asian as well as North and South American countries. However, African, Southern and Eastern Mediterranean countries are largely disconnected.

We recall that in theory, disconnected countries tend to be placed far apart while connected countries tend to stay close. In our study, we employ the term « connected » in a pejorative sense. That is to say, the observed proximity reflects the environmentally-related regulatory distance between the country raising the STC matter (i.e. the exporter d) and the one imposing it (i.e. the importing country).

In Figure 1. 14, highly connected nodes, namely the United States of America (USA), the European Union (EU), Argentina (ARG), Brazil (BRA), Japan (JPN) and China (CHN) are placed in the center of the network. On the other hand, less connected countries are placed at the edges of the graph like Canada (CAN), Turkey (TUR), Israel (ISR), Cuba (CUB), Thailand (THA) and Uruguay (URY).

The structure of the network is both core-periphery and multipolar, with a leading role played by the main developed (European economies and the United States) and developing (i.e. Argentina (ARG), Colombia (COL)) agricultural suppliers. Surprisingly, Turkey (TUR), Thailand (THA) and New Zealand (NZL) hold peripheral positions despite being important agricultural producers. On their side, the emerging economies of China (CHN), India (IDN) and Brazil (BRA) also hold a notable position in Figure 1. 14.

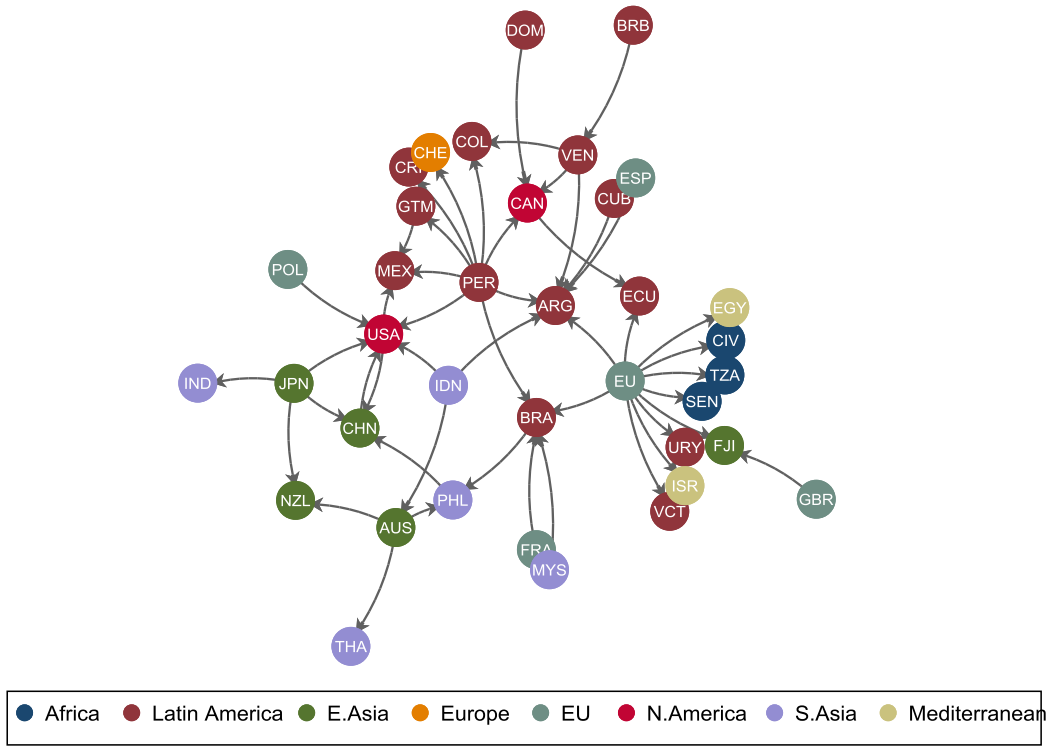
Additionally, the graph highlights the offensive side of the European Union whose norms have targeted Latin American (including Ecuador (ECU), Brazil (BRA), Colombia (COL), Uruguay (URY)), African (Tanzania (TZA), Côte d'Ivoire (CIV)) and Mediterranean (Egypt (EGY) and Israel (ISR)) countries as well as the United States. The network shows also that before their integration into the European Union, Poland (POL) has notified one measure imposed by Slovak Republic (SVK) in 2003. Similarly, Japan (JPN) shows the same offensive behavior against the United States (USA), Mexico (MEX), Brazil (BRA), and New Zealand (NZL). Figure 1. 14 shows also that Latin American and the US are the major destinations of STCs in 2003. However, we must make clear that being the target of an STC is not necessarily incriminating.

In sum, the drawn distinction between weakly and strongly connected countries reveals the hotspots of environmentally-related notifications at a global scale. Eight years after the establishment of the SPS, TBT and the agricultural agreements, STC network confirms the "old" offensive position of industrialized countries, namely Japan, the US and the European Union. More importantly, the network introduces new tensions that target developing agricultural producers. In fact, emerging agro-exporting countries such as Brazil, Argentina, and China clearly hold a notable position in the network, mainly as STCs' destinations. In addition, the network outlines the offensive position of some southern countries. For instance, Brazil (BRA) imposed several STCs on Canada (CAN) and Argentina (ARG). The latter was also subject of STCs from developing countries like Cuba (CUB) and China (CHN).

Contrary to the network of 2003, we notice that ten years later, countries sharing the same continental color tend to be close together. Figure 1. 15 shows that most of Latin American countries are on the upper center except for Brazil (BRA), Uruguay (URY) and Saint Vincent and the Grenadines (VCT). Oceania and Asian countries are mostly situated on the bottom left side. As for the bottom right of the graph, it is occupied by African countries. Additionally, the core countries of the 2013 network are more numerous.

Interestingly, several peripheral countries identified in 2003 had moved to the center. Henceforth, most of core countries are developing and emerging economies, namely Peru (PER), Argentina (ARG), Brazil (BRA) and Indonesia (IDN). This finding suggests that strong environmentally-related tensions were created within Asian and Latin American countries in 2013.

Figure 1. 15. Network of specific trade concerns, 2013



Source: the figure is created by the author.

Indeed, Figure 1. 15 shows that most of the STCs imposed by Peru (PER) target vegetable products coming from Latin American countries like Argentina (ARG), Mexico (MEX), Colombia (COL) and Guatemala (GTM). Another offensive position is revealed by Indonesia (IDN) against Argentina (ARG), Australia (AUS) and the United States. On the other hand, Brazil (BRA), Mexico (MEX) and Argentina (ARG) have raised several STCs at the SPS and TBT committees originating mostly from other developing and emerging countries such as Guatemala (GTM), Malaysia (MYS), Peru (PER) and Venezuela (VEN).

As noticed in 2003, peripheral positions are still held by African and Mediterranean countries, namely Côte d'Ivoire (CIV), Tanzania (TZA), Senegal (SEN), Egypt (EGY) and Israel (ISR). This would suggest that these countries are whether the least targeted by STCs or the least active at the SPS and TBT committees. Meanwhile, several high income countries appear far from the network center in 2013. Among them, traditionally offensive countries like the United States, Japan (JPN) and the European Union. Nonetheless, and despite its peripheral position, the EU kept its offensive behavior against African and weakly connected countries. Likewise, STCs imposed by Japan (JPN) were raised by several, yet weakly connected nodes which explains its position far from the center.

The position of the United States is somehow peculiar being not located right at the center of the network despite its direct links with Mexico (MEX), Peru (PER), Poland (POL), Indonesia (IDN), China (CHN) and Japan (JPN) in 2013. By contrast, Indonesia (IDN) is right

at the center of the network, being linked only to the United States, Argentina (ARG) and Australia (AUS). In this regard, central positions could reflect both an effective pivotal role and, conversely, a condition of strong dependence on major players. Therefore, we present in the next section the computed degree and eigenvalues centralities for better analyses.

1.4.2. Characteristics of countries and centralities' measures

Besides visualizing the structural characteristics and the evolution of the STCs' network, we focus on how and how much each country is relatively positioned in the overall graph. To that end, we must consider STCs disputes with all countries inside and outside the geographical region of the node. As highlighted in section 1.3.2, network analysis provides some indicators to assess the importance of a node centrality, while controlling for several aspects of its position. In this section, we will focus on the degree and eigenvalue centralities as they are the most suitable for our data. Results are reported in Table A1. 2 in the Appendix of chapter 1 (A1).

Focusing on the weighted in-degree centralities (defined in Eq. (1.15)), results of 2003 and 2013 are reported in columns (2) and (6) of Table A1. 2, respectively. Results show that high in-strength values were mostly recorded by developing agro-exporters namely Argentina (c_{in_2003}=9, c_{in_2013}= 6), Brazil (c_{in_2003}=2, c_{in_2013}= 4), China (c_{in_2003}=2, c_{in_2013}= 4), Ecuador (c_{in_2003}=2, c_{in_2013}= 3), Colombia (c_{in_2003}=3, c_{in_2013}= 2), Philippines (c_{in_2003}=2, c_{in_2013}= 2) and Mexico (c_{in_2003}=1, c_{in_2013}= 3). This list is extended to include few high income economies, namely the United States (c_{in_2003}=10, c_{in_2013}= 8), Canada (c_{in_2003}=2, c_{in_2013}= 3) and New Zealand (c_{in_2003}=2, c_{in_2013}= 2).

Meanwhile, Australia, Israel (c_{in_2003}=1, c_{in_2013}= 1) as well as African countries have recorded average in-degree values. On the other hand, the lowest in-degree centralities are recorded by Costa Rica (c_{in_2003}=0, c_{in_2013}= 1) and Chile (c_{in_2003}=1, c_{in_2013}= 0). In turn, Barbados, and the European Union recorded zero in-strength values in both years.

We conduct an elementary analysis to investigate the attributes of central countries. To that end, we compute the correlation scores between the in-degree centralities and a set of variables. The latter are mostly related to the agricultural sector's weight in their economy and their trade coalition during agricultural multilateral negotiations.

Firstly, we introduce the exporter's (d) degree of openness to trade (denoted DOT_d), its revealed comparative advantage indicator (denoted RCA_d) and its agricultural value-added (denoted VA_agri_d) in 2003 and 2013. Secondly, we add three dummy variables based on the classification of the WTO (2017), namely $Protectionist_d$ (that takes the value 1 if the country d is the USA, a member of the G10 or the EU, and 0 otherwise), the variable $CAIRNS\_G20_d$ (that takes the value 1 if the country is a member of the CAIRNS or the G20, and 0 otherwise).

Finally, the variable $G90\_G33_d$ takes the value 1 if the country is a member of the G90 or the G33, and 0 otherwise.

Table 1. 4. Correlation scores of the in-degree centrality

	c_{in_2003}	c_{in_2013}
$Protectionist_d$	0.2877	0.2482
$CAIRNS\_G20_d$	-0.2903	-0.0659
$G90\_G33_d$	-0,1223	-0,2002
VA_agri_d	-0.2122	-0.3359
RCA_d	0.2347	0.0554
DOT_d	-0.3095	-0.4026

Source: the table is created by the author. It reports the correlation scores between the in-degree centrality of 2003 (c_{in_2003}) and 2013 (c_{in_2013}) and a selection of variables. Full correlation matrices are presented in Table A1. 3 and Table A1. 4 in the Appendix of chapter 1 (A1).

Results are summarized in Table 1. 4, whereas full correlation matrices of 2003 and 2013 are reported in Table A1. 3 and Table A1. 4 in the appendix of Chapter 1, respectively. The correlation between in-degree centralities and the variable $Protectionist_d$ is positive and moderately important, ranging between 28% and 24% during these years. This would suggest that the G10 members as well as the EU and the USA are the most active at the SPS and TBT committees. Put differently, they are the most active at raising STC matters imposed by their trade partners. This seems quite intuitive given the offensive position of the USA highlighted by Figure 1. 14 and Figure 1. 15. The country has recorded the highest in-degree centralities in both years (c_{in_2003}=10, c_{in_2013}= 8). Nonetheless, the correlation score decreased by 0.4 point within a 10-year period.

Conversely, results show negative correlation between in-degree centralities and the variable $CAIRNS\_G20_d$. Further results show a weak and negative correlation between in-degree centralities and the variable $G90\_G33_d$. This would suggest that the least developed countries are the least active at raising environmentally-related disputes at the SPS and TBT committees.

In addition, the correlation between the variable RCA_d and in-degree centralities fell from 23% in 2003 to 5% in 2013. Accordingly, the effect of the agricultural comparative advantage is waning over time. On the other hand, Table 1. 4 shows a negative correlation with the variable VA_agri_d, ranging between 21 and 33% over this period. In other words, countries with high agricultural value-added are less likely to be affected by STCs, which explains the low in-degree centralities of African and the least developed countries. Similarly, the variable DOT_d records a negative correlation over the same time-period. This would indicate that countries characterized by high degree of openness to agricultural trade raise the least their STC matters, or simply are the least affected by these measures.

Considering out-degree centralities, they measure the number of arcs exiting from origin countries as defined in Eq. (1.16). Results of 2003 (c_{out_2003}) and 2013 (c_{out_2013}) are reported in columns (1) and (5) of Table A1. 2 in the Appendix of chapter 1 (A1), respectively.

Our findings show that the highest out-degree centralities were mainly recorded by high income countries, namely the European Union (c_{out_2003}=c_{out_2013}= 12), Australia (c_{out_2003}=2, c_{out_2013}= 3), Japan (c_{out_2003}=c_{out_2013}= 6), and the United States (c_{out_2003}=4, c_{out_2013}= 3). Interestingly, some developing countries join the previous list, namely Peru (c_{out_2003}=0, c_{out_2013}= 9), Indonesia (c_{out_2003}=3, c_{out_2013}= 4) and Venezuela (c_{out_2003}=3, c_{out_2013}= 3). We note that out-strength centralities of Canada (CAN), Dominican Republic (DOM), Guatemala (GTM), Malaysia (MYS) and Philippines (PHL) have increased in 2013. By contrast, out-degrees of Brazil (BRA), Chile (CHL), China (CHN), Korea (KOR) and Turkey (TUR) have decreased over the period 2003-2013. On the other hand, our results show that several CAIRNS members and African countries have recorded out-strength centralities equal to zero in both years, namely Argentina (ARG), Costa Rica (CRI), New Zealand (NZL), Thailand (THA), Uruguay (URY) Côte d'Ivoire (CIV) and Tanzania (TZA).

In addition, we investigate the potential relationship between out-degree centralities and countries' coalitions during agricultural negotiations. Table 1. 5 reports the correlation scores between centrality measures and the following dummy variables. Fist, $Protectionist_o$ that takes the value 1 if the importer (o) is the USA, a member of the G10 or the EU, and 0 otherwise. The variable $CAIRNS\_G20_o$ takes the value 1 if the country belongs to the CAIRNS or the G20, and 0 otherwise. Finally, $G90\_G33_o$ takes the value 1 if the country is a member of the G90 or the G33, and 0 otherwise.

Table 1. 5. Correlation scores of the out-degree centrality

	c_{out_2003}	c_{out_2013}
$Protectionist_o$	0.5273	0.3996
$CAIRNS\_G20_o$	-0.4890	-0.2005
$G90\_G33_o$	-0.1430	-0.2407

Source: the table is created by the author. The complete correlation matrix of the out-degree centrality of 2003 (c_{out_2003}) is presented by the Table A1. 5 in the Appendix of chapter 1 (A1). The correlation matrix of the out-degree centrality of 2013 (c_{out_2013}) is presented by the Table A1. 6

Table 1. 5 shows a strong and positive correlation with the variable $Protectionist_o$. Nonetheless, it fell from 52% in 2003 to 39% in 2013. This finding suggests that the US, countries of the G10 and the EU are the major imposers of STCs related to vegetable products. Another possible explanation is that the imposed STCs by this group are the most raised at the SPS and TBT committees. Either way, our results reveal a highly conflictual situation at the multilateral scale that is, surprisingly, dissipating over time.

In addition, Table 1. 5 shows a weak and negative correlation between out-degree centralities and $G90\_G33_o$ indicating that few notified STCs originate from the least developed countries. Further results show that centrality measures of 2003 are negatively and highly correlated with the variable $CAIRNS\_G20_o$. However, the computed scores decreased from 48% to 20% within 10 years. This would suggest that CAIRNS and G20 members were less likely to impose environmentally-related STCs especially in 2003. However, this negative relationship is waning over the period of study.

The weighted centrality is essentially a local measure. It considers the direct links of a country corresponding to its nearest neighborhood. However, the measure neglects the country's position in the structure of the network. Let's take the example of Brazil (BRA) and Australia (AUS): both countries have by construction the same out-degree in 2003 (c_{out_2003} = 2) according to Table A1. 2 in the appendix of Chapter 1. However, they attain very different positions in the network presented in Figure 1. 14. In addition, the European Union (EU) and Turkey (TUR) have the same in-degree in 2003 (c_{in_2003} = 0) according to the same table. Nonetheless, Turkey is situated at the periphery of Figure 1. 14, whereas the EU is in the center of the graph. Their positions are in fact dependent on other countries' locations. Indeed, Turkey is linked to a peripheral country (i.e. Ecuador), whereas the EU is linked to central countries, namely the United States, Argentina (ARG) and Brazil (BRA). Using a global centrality measure in addition to the local one will thereby reveal the effect of other countries. The eigenvector centrality measures, defined in Eq. (1.14), are reported in Table A1. 2 in the Appendix of chapter 1 (A1).

Focusing on the in-eigenvector (c_{in}^{eigen}) centralities, columns (4) and (8) show the results of 2003 and 2013, respectively. Surprisingly, few countries have recorded nonzero values. That is to say, only the following countries have recorded increasing in-eigenvector values during this period. First China (CHN) where the index grew from 0.24 in 2003 to 0.75 in 2013. Similarly, the index of Mexico (MEX) increased from 0.37 in 2003 to 0.48 in 2013. In addition, the United States recorded a slight increased going from 0.53 in 2003 to 0.58 in 2013. On the other hand, results show that several developed countries have recorded decreasing in-eigenvector centralities. For instance, the value of Switzerland (CHE) fell from 0.58 in 2003 to zero in 2013. Likewise, in-eigenvector centralities of Spain (ESP), Korea (KOR) and Poland (POL) dropped to zero in 2013.

Regarding the out-eigenvector (c_{out}^{eigen}) centrality, the results of 2003 and 2013 are presented in columns (3) and (7), respectively of Table A1. 2 in the Appendix of chapter 1 (A1). Surprisingly, the out-eigenvector centrality of the European Union fell from 0.9 in 2003 to zero in 2013. Similarly, African countries have recorded zero out-eigenvector centralities in 2013. In fact, countries characterized by high eigenvector centralities are mostly connected to many other countries which are, in turn, connected to many others. If we go back to Figure 1. 15, we note that the EU imposes STCs on peripheral and weakly connected countries. Conversely, the largest out-eigenvector values are recorded by Brazil ($c_{out,2003}^{eigen} = 1.2e^{-16}$, $c_{out,2013}^{eigen} = 1.13$), China (

$c^{eigen}_{out,2003}$ =6.5e^{-17}, $c^{eigen}_{out,2013}$ = 2.7), Indonesia ($c^{eigen}_{out,2003}$ =0, $c^{eigen}_{out,2013}$ = 0.44), Peru ($c^{eigen}_{out,2003}$ =0, $c^{eigen}_{out,2013}$ = 0.17), Philippines ($c^{eigen}_{out,2003}$ =5.4e^{-17}, $c^{eigen}_{out,2013}$ = 0.19) as well as the United States ($c^{eigen}_{out,2003}$ =0.28, $c^{eigen}_{out,2013}$ = 0.38) and Japan ($c^{eigen}_{out,2003}$ =0, $c^{eigen}_{out,2013}$ = 0.6). This sub-network, characterized by a high-density, is obviously outnumbered by developing countries and reveals the new "hot-spot" of environmentally-related tensions. This would suggest that high income countries have indeed left their central positions within the STC network to several emerging and developing agricultural suppliers.

1.5. Conclusion

The aim of this chapter is to provide a descriptive analysis that will guide the rest of the thesis. The study deals with the new patterns of agricultural trade and identifies the recent international dynamics of crop commodities. More importantly, our analysis extends beyond the simple quantification of trade volumes and includes downstream environmental regulations that affect agricultural trade, namely technical NTMs.

Our findings indicate that international agricultural trade has been witnessing a gradual shift in the center of gravity from North to South, and from Europe and North America to Asia and Latin America. In fact, agricultural trade has been marked by a strong growth in developing and emerging countries. This increase was nonetheless less reflected by market share gains in exports to developed nations than by a very strong increase in "South-South" flows, which is detrimental to high income suppliers like the US and the EU. In addition, the structure of trade has become more complex in 2013 compared to 2003. Indeed, the number of countries and flows that matter has greatly increased to cover all continents. This phase is marked thereby by a growing interconnection and lower trade concentration.

Furthermore, our analysis shows that crop commodities are highly regulated by technical NTMs that turn out to be environmentally-related. This behavior is common not only to highly protective countries, but also to free agricultural trading nations and developing countries. Interestingly, notifications from developing countries recorded a notable growth (in relative terms) compared to high income countries like the United States. Accordingly, analyzing NTMs is clearly crucial to address the question of agricultural trade.

The structural view of bilateral specific trade concerns using the network analysis led to new and useful insights. First, and despite the limited number of countries involved in the graph, the overall country size as well as SPS and TBT notifications grew significantly over the period 2003-2013. Surprisingly, our findings highlight the significant presence of southern countries within the environmentally-related disputes as imposers and notifying countries. Their presence has even gained importance in 2013 compared to 2003.

Second, the structure of STC networks has significantly evolved within a ten-year period. In 2003, the global STC system seems to be characterized by disparate levels of interconnectivity across and within geographical regions, whereas the network of 2013 is marked by the rapprochement between countries belonging to the same region. In fact, the term « rapprochement » is used in a pejorative sense since the proximity in our study reflects the environmentally-related tensions between importers and their trade partners. This would indicate that regional disputes over agricultural products have increased, especially within Latin American and Asian countries.

Third, the drawn distinction between weakly and strongly connected countries reveals the hotspots of environmentally-related disputes and their evolution over this period. Interestingly, African and southern Mediterranean countries kept their peripheral positions throughout the time period. This would suggest that these countries are whether the least targeted by STCs or the least active at the SPS and TBT committees.

On the other hand, the network confirms the "old" offensive position of industrialized countries, namely Japan, the US and the European Union. An interesting finding is that this effect has been dissipating over time. This indicates that high income countries have left their central positions to several emerging and developing agricultural suppliers, namely Peru, Argentina, Brazil and Indonesia. The latter clearly hold a notable position in the network, mainly as STCs' destinations.

In sum, the network analysis introduces new environmental tensions that target developing agricultural producers on one side and outlines the offensive position of some southern countries on the other. For instance, Brazil imposed several STCs on Canada and Argentina, whereas the latter was subject of STCs from developing countries like Cuba and China.

Finally, global centrality measures reveal a highly dense sub-network composed of Brazil, China, Indonesia, Peru, Philippines as well as the United States and Japan. The identified group is outnumbered by southern countries. This would support the environmentally-related conflicts that affect heavily the network of developing and emerging agro-suppliers.

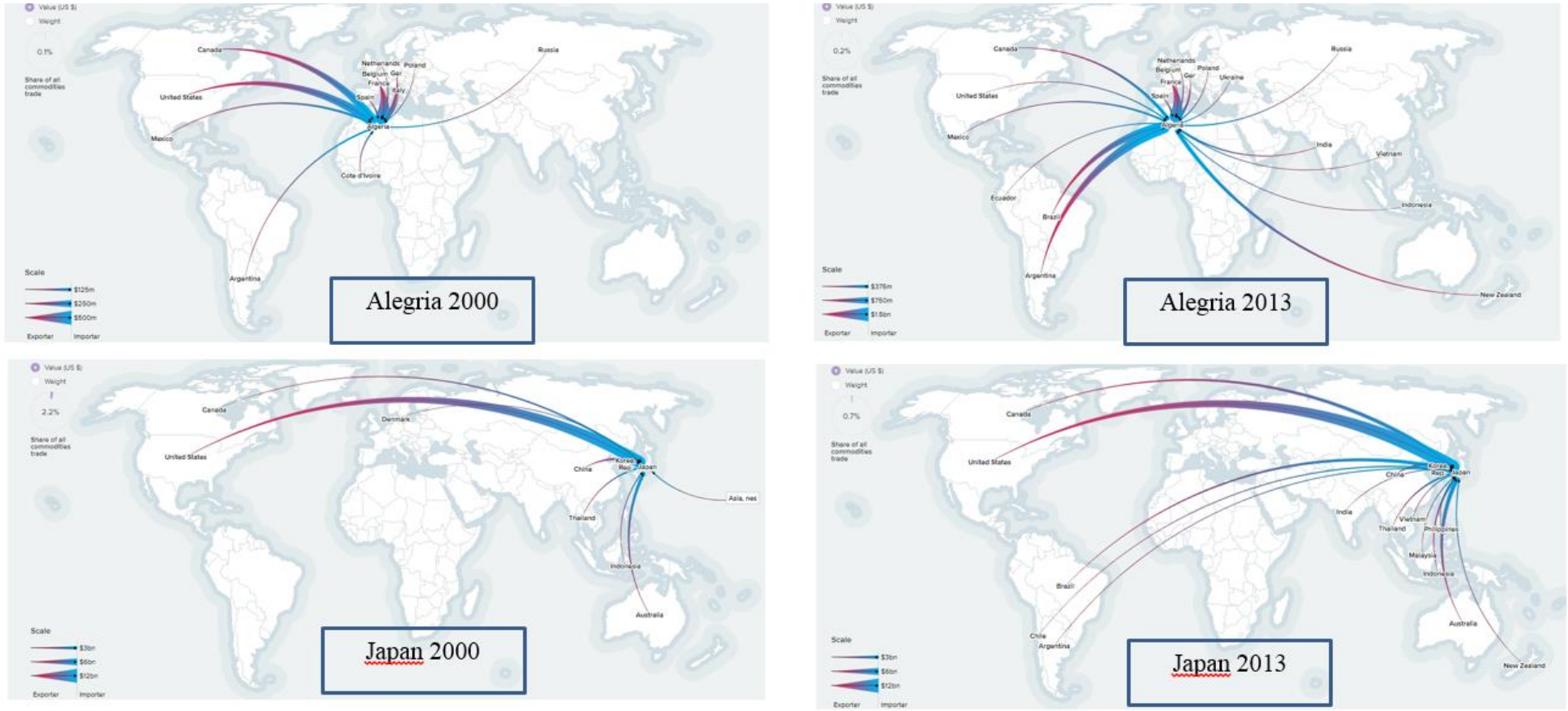
To conclude, these findings do not purport to show the exact extent of environmentally-related trade conflicts, but we believe that bilateral STCs can be thought of as networks. Additionally, it appears as if trade growth of southern countries has been conducive to rising environmentally-related trade conflicts. While Latin American and Southeast Asian countries are increasingly asserting themselves as major suppliers for many regions of the world, our findings reveal new environmentally-related conflictual relation targeting developing and emerging countries on one side and increasingly spreading within southern agro-producers on the other.

Unfortunately, the present analysis does not go beyond 2003-2013. We opted for this time period to be in line with chapter 2 in which, the study extends to 2013 due to missing data. Nonetheless, we consider over fifteen years after the implementation of the agreement of agriculture. During these years, transcendental changes took place regarding trade of crop commodities, agricultural policies and significant environmental concerns.

Although suggestive, this study does not give full account of the environmentally-related implication of the agreement on agriculture. In the next chapter, we will focus on its repercussion on upstream agricultural production systems, and more precisely, on agri-environmental policies around the world.

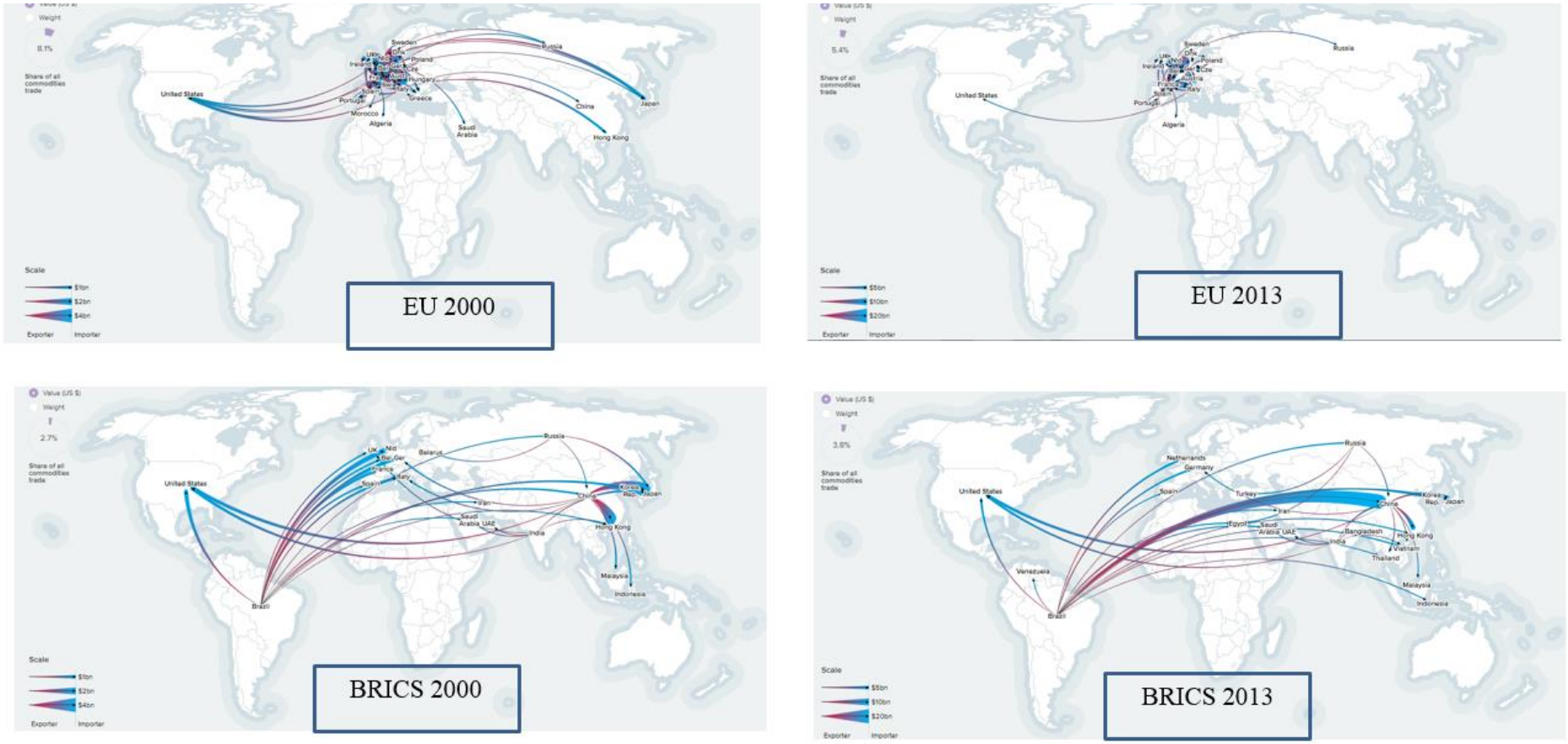
1.6. Appendix of chapter 1 (A1)

Figure A1. 1. Evolution of the main agricultural suppliers of Algeria and Japan in 2000 and 2013



Source: calculated from resourcetrade.earth (Chatham House, 2017).

Figure A1. 2. Leading destinations for European and emerging countries' agricultural exports



Source: calculated from resourcetrade.earth (Chatham House, 2017)

Table A1. 1. List of countries included in the sample

Country (group of countries)	Region	ISO 3	Negotiating coalition in agriculture
European Union	European Union	EU	European Union, United States of America and G10
Cuba	Central and South America	CUB	CAIRNS and G20
Indonesia	South Asia	IDN	CAIRNS and G20
Switzerland	Europe outside EU and Russia	CHE	European Union, United States of America and G10
Peru	Central and South America	PER	CAIRNS and G20
Venezuela, Bolivarian Republic of	Central and South America	VEN	CAIRNS and G20
Spain	European Union	ESP	European Union, United States of America and G10
China	East Asia and Oceania	CHN	CAIRNS and G20
United States of America	North America	USA	European Union, United States of America and G10
France	European Union	FRA	European Union, United States of America and G10
Malaysia	South Asia	MYS	CAIRNS and G20
Japan	East Asia and Oceania	JPN	European Union, United States of America and G10
Dominican Republic	Central and South America	DOM	G90 and G33
Brazil	Central and South America	BRA	CAIRNS and G20
Philippines	South Asia	PHL	CAIRNS and G20
Germany	European Union	DEU	European Union, United States of America and G10
Turkey	Southern and Eastern Mediterranean countries	TUR	G90 and G33
Canada	North America	CAN	CAIRNS and G20
United Kingdom	European Union	GBR	European Union, United States of America and G10
Guatemala	Central and South America	GTM	CAIRNS and G20
Australia	East Asia and Oceania	AUS	CAIRNS and G20
Slovak Republic	European Union	SVK	European Union, United States of America and G10
Mexico	Central and South America	MEX	CAIRNS and G20
Korea, Republic of	East Asia and Oceania	KOR	European Union, United States of America and G10
Poland	European Union	POL	European Union, United States of America and G10
Chile	Central and South America	CHL	CAIRNS and G20
Barbados	Central and South America	BRB	G90 and G33
Argentina	Central and South America	ARG	CAIRNS and G20
Côte d'Ivoire	East, West, Central and Southern Africa	CIV	G90 and G33
Colombia	Central and South America	COL	CAIRNS and G20
Costa Rica	Central and South America	CRI	CAIRNS and G20

Ecuador	Central and South America	ECU	CAIRNS and G20
Egypt	Southern and Eastern Mediterranean countries	EGY	CAIRNS and G20
Fiji	East Asia and Oceania	FJI	G90 and G33
India	South Asia	IND	CAIRNS and G20
Israel	Southern and Eastern Mediterranean countries	ISR	European Union, United States of America and G10
New Zealand	East Asia and Oceania	NZL	CAIRNS and G20
Papua New Guinea	East Asia and Oceania	PNG	G90 and G33
Senegal	East, West, Central and Southern Africa	SEN	G90 and G33
Thailand	South Asia	THA	CAIRNS and G20
Tanzania	East, West, Central and Southern Africa	TZA	CAIRNS and G20
Uruguay	Central and South America	URY	CAIRNS and G20
Saint Vincent and the Grenadines	Central and South America	VCT	G90 and G33

Source: the table is created by the author.

Table A1. 2. Weighted centrality measures of 2003 and 2013

ISO3	Country	c_{out_2003}	c_{in_2003}	$c^{eigen}_{out,2003}$	$c^{eigen}_{in,2003}$	c_{out_2013}	c_{in_2013}	$c^{eigen}_{out,2013}$	$c^{eigen}_{in,2013}$
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ARG	Argentina	0	9	1.6e-16	0	0	6	0	0
AUS	Australia	2	1	4.0e-17	0	3	1	.134786	0
BRA	Brazil	2	2	1.2e-16	0	1	4	.134786	0
BRB	Barbados	0	0	0	0	1	0	9.4e-17	0
CAN	Canada	0	2	4.4e-17	0	1	3	1.4e-16	0
CHE	Switzerland	1	0	0	.58851	0	1	0	0
CHL	Chile	1	1	.20203	.487538	0	0	0	0
CHN	China	2	2	6.5e-17	.58851	1	4	.269572	.755929
CIV	Côte d'Ivoire	0	1	8.6e-34	0	0	1	0	0
COL	Colombia	0	3	1.4e-34	0	0	2	0	0
CRI	Costa Rica	0	0	0	0	0	1	0	0
CUB	Cuba	1	0	0	.58851	1	0	1.3e-16	0
DEU	Germany	2	0	0	0	0	0	0	0
DOM	Dominican Republic	0	0	0	0	1	0	2.6e-16	0
ECU	Ecuador	0	2	0	0	0	3	0	0
EGY	Egypt	0	1	0	0	0	1	0	0
ESP	Spain	1	0	0	.58851	1	0	1.9e-16	0
EU	European Union	12	0	.095308	0	12	0	0	0
FJI	Fiji	0	0	0	0	0	2	0	0
FRA	France	0	0	0	0	1	0	.095308	0
GBR	United Kingdom	0	0	0	0	1	0	0	0
GTM	Guatemala	0	0	0	0	1	1	0	0
IDN	Indonesia	3	0	0	0	4	0	.443835	0
IND	India	0	0	0	0	0	1	0	0
ISR	Israel	0	1	0	0	0	1	0	0

JPN	Japan	6	0	0	0	6	0	.618099	0
KOR	Korea, Republic of	1	0	0	.487538	0	0	0	0
MEX	Mexico	1	1	.20203	.377964	0	3	0	.487538
MYS	Malaysia	0	0	0	0	1	0	.095308	0
NZL	New Zealand	0	2	0	0	0	2	0	0
PER	Peru	0	0	0	0	9	0	.174264	0
PHL	Philippines	1	2	5.4e-17	.344741	1	2	.190616	0
PNG	Papua New Guinea	0	2	0	0	0	0	0	0
POL	Poland	1	1	.20203	.487538	1	0	.269572	0
SEN	Senegal	0	0	0	0	0	1	0	0
SVK	Slovak Republic	1	0	0	0	0	0	0	0
THA	Thailand	0	1	0	0	0	1	0	0
TUR	Turkey	1	0	0	0	0	0	0	0
TZA	Tanzania	0	1	0	0	0	1	0	0
URY	Uruguay	0	1	0	0	0	1	0	0
USA	United States	4	10	.285714	.534522	3	8	.381232	.58851
VCT	Saint Vincent & G	0	0	0	0	0	1	0	0
VEN	Venezuela	3	0	0	.02158	3	1	1.0e-17	0

Source: the table is created by the author. Columns (1) and (5) report the out-degrees of 2003 (c_{out_2003}) and 2013 (c_{out_2013}), respectively. In-degrees of 2003 (c_{in_2003}) and 2013 (c_{in_2013}) are presented in columns (2) and (6), respectively. The out-eigenvectors ($c^{eigen}_{out,2003}$ and $c^{eigen}_{out,2013}$) are reported in columns (3) and (7), whereas in-eigenvectors values ($c^{eigen}_{in,2003}$ and $c^{eigen}_{in,2013}$) are presented in columns (4) and (8).

Table A1. 3. In-degree correlation matrix, 2003

	c_{in_2003}	$Protectionist_d$	$CAIRNS\_G20_d$	$G90\_G33_d$	VA_agri_d	RCA_d	DOT_d
c_{in_2003}	**1**						
$Protectionist_d$	**0.2877**	1					
$CAIRNS\_G20_d$	**-0.1903**	-0,9333	1				
$G90\_G33_d$	**-0,1223**	-0,0863	-0,2774	1			
VA_agri_d	**-0.2122**	-0,5534	0,341	0,5344	1		
RCA_d	**0.2347**	-0,4574	0,4433	-0,006	0,3351	1	
DOT_d	**-0.3095**	-0,1352	0,0571	0,2033	0,1754	-0,415	1

Source: The table is created by the author.

Table A1. 4. In-degree correlation matrix, 2013

	c_{in_2013}	$Protectionist_d$	$CAIRNS\_G20_d$	$G90\_G33_d$	VA_agri_d	RCA_d	DOT_d
c_{in_2013}	**1.0000**						
$Protectionist_d$	**0.2482**	1.0000					
$CAIRNS\_G20_d$	**-0.0659**	-0.7348	1.0000				
$G90\_G33_d$	**-0,2002**	-0.1195	-0.5855	1.0000			
VA_agri_d	**-0.3359**	-0.4123	0.0739	0.3847	1.0000		
RCA_d	**0.0554**	-0.3183	0.2298	0.0440	0.2541	1.0000	
DOT_d	**-0.4026**	0.1256	-0.2751	0.2527	0.0984	-0.1810	1.0000

Source: the table is created by the author.

Table A1. 5. Out-degree correlation matrix, 2003

	c_{out_2003}	$Protectionist_o$	$CAIRNS\_G20_o$	$G90\_G33_o$
c_{out_2003}	**1.000**			
$Protectionist_o$	**0.527**	1.0000		
$CAIRNS\_G20_o$	**-0.489**	-0.9501	1.0000	
$G90\_G33_o$	**-0.143**	-0.1991	-0.1164	1.0000

Source: the table is created by the author.

Table A1. 6. Out-degree correlation matrix, 2013

	c_{out_2013}	$Protectionist_o$	$CAIRNS\_G20_o$	$G90\_G33_o$
c_{out_2013}	**1.0000**			
$Protectionist_o$	**0.3996**	1.0000		
$CAIRNS\_G20_o$	**-0.2005**	-0.9195	1.0000	
$G90\_G33_o$	**-0.2407**	-0.1839	-0.2174	1.0000

Source: the table is created by the author.

Table A1. 7. List of net food-importing countries

Income Group	Countries
Net food-importing developing economies	Afghanistan, Algeria, Angola, Anguilla, Antigua and Barbuda, Aruba, Bahamas, Bahrain, Bangladesh, Barbados, Benin, Bhutan, Bonaire, Sint Eustatius and Saba, Botswana, British Virgin Islands, Brunei Darussalam, Burkina Faso, Burundi, Cabo Verde, Cambodia, Cameroon, Cayman Islands, Central African Republic, Chad, China, China, Hong Kong SAR, China, Macao SAR, China, Taiwan Province of, Colombia, Comoros, Congo, Cook Islands, Côte d'Ivoire, Cuba, Dem. Rep. of the Congo, Djibouti, Dominica, Dominican Republic, Egypt, El Salvador, Equatorial Guinea, Eritrea, Ethiopia, Fiji, French Polynesia, Gabon, Gambia, Ghana, Grenada, Guam, Guinea, Haiti, Iran (Islamic Republic of) , Iraq, Jamaica, Jordan, Kenya, Kiribati, Korea, Dem. People's Rep. of, Korea, Republic of, Kuwait, Lao People's Dem. Rep. , Lebanon, Lesotho, Liberia, Libya, Madagascar, Maldives, Mali, Mauritius, Mongolia, Montserrat, Mozambique, Nauru, Nepal, New Caledonia, Niger, Nigeria, Niue, Northern Mariana Islands, Oman, Pakistan, Palau, Philippines, Qatar, Rwanda, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Samoa, Sao Tome and Principe, Saudi Arabia, Senegal, Sierra Leone, Singapore, Sint Maarten (Dutch part) , Solomon Islands, Somalia, Sri Lanka, State of Palestine, Sudan, Sudan (...2011) , Suriname, Syrian Arab Republic, Timor-Leste, Togo, Tonga, Trinidad and Tobago, Tunisia, Turks and Caicos Islands, Tuvalu, United Arab Emirates, Vanuatu, Venezuela (Bolivarian Rep. of) , Wallis and Futuna Islands, Yemen and Zimbabwe
Net food-importing transition economies	Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Georgia, Kazakhstan, Kyrgyzstan, Montenegro, North Macedonia, Russian Federation, Tajikistan and Uzbekistan
Net food-importing developed economies	Andorra, Austria, Bermuda, Croatia, Cyprus, Czechia, Estonia, Finland, France, Germany, Gibraltar, Greece, Israel, Italy, Japan, Luxembourg, Malta, Portugal, Romania, Saint Pierre and Miquelon, Slovakia, Slovenia, Sweden, Switzerland, Liechtenstein and the United Kingdom

Source: the table is created by the author based on the income group classification of UNCTADSTAT (UNCTAD, 2016).

2. Chapter 2. Computing the agri-environmental efficiency using Data Envelopment Analysis and exploring its determinants

2.1. Introduction

Although they had a low priority during the first four decades of the GATT (1947-1994), environmental issues came back with a vengeance in the early 1990s, especially with regard to agricultural products. The latter are usually subject of natural resources' exhaustion and human health risks.

In this regard, and as highlighted in Chapter 1, technical NTMs were reintroduced within the framework of the Marrakesh agreement along with the genesis of the agreement on agriculture to correct information asymmetries and negative environmental externalities (Beestermöller et al., 2018; Cadot et al., 2018; Disdier et al., 2008). Meanwhile, environmental side effects have become increasingly integrated into several agricultural policies whether in free agricultural trading nations (like the BRICS and CAIRNS group), countries pursuing agricultural protectionist policies (namely the European Union and the United States of America) or developing countries. Accordingly, enhancing agricultural productivity in an ecologically sustainable manner became an urgent target for several governments for the past years by implementing devices for environmental regulation (Moon, 2011).

The debate here started by focusing on what a stringent agri-environmental policy implies in the first place. How can we measure its efficiency and how can we explain the inefficiency? Does international trade affect the agri-environmental performance? If so, does trade openness provide an "environmental gain"?

A second aspect intimately linked to agricultural trade needs also to be considered, namely technical barriers to trade (TBT) and sanitary and phytosanitary (SPS) measures, denoted as environmentally-related NTMs by Fontagné et al. (2005). Besides their trade-restrictive impact (so far unveiled by several scholars), did they astonishingly impact the agri-environmental regulations of exporting countries? If so, did they encourage a "race to the bottom" or a "race to the top" in domestic agri-environmental standards? Potential environmental-enhancing feature of such measures merits further study.

This work belongs to a narrow branch of cross-country efficiency literature and is the first to be interested in the agri-environmental efficiency assessment concerning crop commodities. The latter are considered as one of the most important agricultural sectors for several developed and developing countries and are highly regulated in international trade because of their sensitivity and perishability.

Data envelopment analysis (DEA) has gained great popularity in environmental modeling in recent years thanks to its nonparametric frontier approach which does not assume a particular functional form (Daraio & Simar, 2007). Few cross-country studies had applied this technique and are worth mentioning. For instance, Kuosmanen (2013) examines the environmentally oriented efficiency of a panel of 13 OECD countries over the time period 1990-2004. Results indicate large differences across high income countries and within EU members. In turn, Vlontzos et al. (2014) attempted to evaluate the energy and environmental efficiency of the primary sectors of the EU member states in the 2001–2008 time period. The main findings suggest that countries with strong environmental protection standards (such as Germany, Sweden, or Austria) appear to be less energy and environmentally efficient compared with countries like Denmark, Belgium, Spain, France or Ireland. Moreover, several eastern European countries achieve low efficiency scores, which can be explained by their low technology level.

Nevertheless, and to the best of our knowledge, there are no previous empirical attempts targeting explicitly the impact of international trade (or any other determinants) on the agri-environmental efficiency. To overcome this lack of information and to answer the previously asked questions, our study suggests a larger-scaled empirical application in order to measure the agri-environmental efficiency of 108 countries (accounting for more than 90% of global crop production) over the period 2003-2013.

The evaluation is based on a two-step super-efficiency DEA model developed by Andersen and Petersen (1993) and based on the fundamental work of Farrell (1957). First, we use time-varying data and undesirable output to compute the efficiency scores following the method of Seiford and Zhu (2002). We employ in the second step the double bootstrapped truncated regression suggested by Simar and Wilson (2007) to conduct a sensitivity analysis and test the effect of a wide range of variables on the agri-environmental inefficiency. In this model, we consider the income heterogeneity of countries and control for country-specific unobserved heterogeneity.

Our results suggest that the sector of food crops has witnessed globally an increasing trend in average agri-environmental efficiency between 2003 and 2013. An interesting and somewhat expected result is that the agri-environmental inefficiency of developing countries is more sensitive to climatic variables compared to emerging and high-income economies. Moreover, the effect of environmental protection's expenditure is highly detrimental to the agri-environmental inefficiency in low and middle income countries, whereas the effect is weaker in the BRICS and high income economies.

An intriguing finding is that agricultural trade openness and the specialization in crop commodities' exports hamper the inefficiency. We confirm by this means the "environmental gains-from-trade" hypothesis. In addition, our results show that environmentally-related NTMs affect considerably the agri-environmental performance. In fact, technical barriers to trade and sanitary and phytosanitary measures turn out to be levers for enhancing the agri-environmental efficiency of exporters especially in the BRICS and high as well as middle-income countries. This would suggest that the overall increase of environmentally-related NTMs against tariff dismantling in the agricultural sector has aligned developed, emerging and middle income exporting countries with their partners' strict regulations. Accordingly, this has induced a "race to the top" phenomenon in their domestic environmental standards. Nonetheless, low income countries react differently and show a deteriorating agri-environmental performance due to environmentally-related NTMs.

The structure of the chapter is the following. First, and since most countries have largely restructured their agricultural policies after the signature of the AoA, we discuss in section 2.2, the recent greening agricultural reforms that have marked several countries around the word. Second, we try to compute the efficiency of these policies. We describe the DEA model and explain the second stage in section 2.3. Section 2.4 is dedicated to the description of the used variables. The results are reported in section 2.5. We draw in the last section clear conclusions on these issues and discuss their policy implications.

2.2. The "greening" of agricultural policies: A brief overview

Managing sustainably depletable resources such as biodiversity, water and soil became more challenging for agriculture and critically important whether for ensuring food security (S. Khan & Hanjra, 2009; Tilman et al., 2002) or conserving ecosystem services (Dominati et al., 2010; Ribaudo et al., 2010) while coping with global warming (Battisti & Naylor, 2009). Accordingly, several governments have implemented devices for environmental regulation to cope with these challenges (Moon, 2011). By definition, environmental policies are institutional instruments set up to encourage polluters to behave less polluting. We distinguish typically two categories: (i) institutional regulatory measures aimed at constraining the behavior of polluters under penalty of administrative or judicial sanctions; (ii) economic instruments (namely eco-taxes, subsidies, emission permit …) to change the polluter's economic environment via price signals and encourage voluntary adoption of less polluting behaviors. Other measures more difficult to classify exist such as information instruments as well as voluntary and negotiated agreements.

2.2.1. Agri-environmental measures in developed countries

The environmental drawbacks of intensive agriculture have contributed to move agricultural policies toward greater sustainability in several developed countries. In principle, two

production models are identified. First, the market-protected agriculture based on the approach of multifunctionality (Bjørkhaug & Richards, 2008). In this regard, one of the main mechanisms for achieving agri-environmental policy goals is the provision of financial incentives in return for the production of environmental public goods (Burton & Paragahawewa, 2011).

In Europe, this approach took place in the mid-1980s when positive environmental side effects formed an integral part of the EU's Common Agricultural Policy[8]. Starting by the set-aside policy introduced in 1992 by the MacSharry reform, after which farms had to take land out of production in order to be eligible for the direct income payments (Bureau & Thoyer, 2014). Thus, and combined with the 29% reduction in intervention prices, this measure was expected to make farming more extensive. Besides, agri-environment measures introduced by the same reform have committed the member-states to compensate producers for voluntarily and environmentally friendly farming practices.

Moreover, the 1999 reform [9] and the "Agenda 2000" have introduced voluntary cross compliance that made the direct income payments conditional on meeting a number of basic environmental and animal husbandry conditions (Anderson, 2009). On the other hand, the subsequent 2003 reform made cross compliance and modulation compulsory, whereas the CAP Health Check in 2008 raised the modulation percentage, expanding thereby the amount of money shifting towards rural development. Finally, the 2013 reform introduced the "greening" criteria, which made the payment of 30 % of the direct income payments dependent on compliance with specific environmental requirements.

Similarly, the agricultural policy of Switzerland is based on Article 104 of the federal constitution, which calls for agricultural production that considers simultaneously the requirements of sustainable development and market economy principles. Farmers are not only seen as producers of food, but also as contributing to food security, the conservation of natural resources, and the upkeep of the rural landscape.

The main feature of the agricultural policy in 2011 is the noticeable progress in relation to ecology and efforts to protect and promote biodiversity at the expanse of producers support and export subsidies (OCDE, 2011). In this regard, the general eligibility criteria for direct payments include a set of ecological standards. Additionally, Switzerland has established the ecological direct payments to encourage voluntary environmental contributions. They go beyond the scope of minimum environmental eligibility criteria for direct payments to reach other areas, namely the extensive use of pastures and meadows, extensive cereal and rapeseed farming, organic farming methods, water protection and the sustainable use of natural resources (OECD, 2017).

[8] The CAP is based on two pillars. The first one (Pillar I) funds market price and income support on an annual basis and is fully financed from the EU budget when the second pillar (Pillar II) funds one-off and multi-annual rural development measures on a programmed basis and is co-financed by the EU budget with Member States.

[9] The same reform also merged agri-environment measures together with other (non-environmental) measures in the CAP's Pillar II, introducing a Rural Development policy next to the existing market and price policy of Pillar I.

In the United States, environmental payments have been incorporated into the Conservation Titles of the Farm Bills. Compared to the EU, American agri-environmental programs are more targeted and focus mainly on reducing farmers' negative externalities (Baylis et al., 2008). In 2002, the Farm Bill introduced the Grassland Reserve and the Conservation Security Programs. In the same year, new operations were declared eligible for funds under the Environmental Quality Incentives Program, namely stricter regulations on nutrient management from large livestock operations. Five years later, agricultural conservation programs of the US accounted for about 16% of the 33.8 billion US$ spent on natural resources' protection. In 2008, the Farm Act provided additional 8 billion US$ for conservation programs and expanded the coverage of lands that may be brought into reserve programs.

By contrast, the market-oriented and liberalistic agriculture is reluctant to provide financial rewards to farmers for environmental management except for short-term incentives. This approach reflects the Australian and other CAIRNS group nations' rejection of 'multifunctionality' due to its inconsistency with the WTO rules and its potential 'non-tariff barrier' disguised effect (Potter & Burney, 2002).

In Australia, voluntary measures in relation to the environment are preferred over regulatory ones to promote participatory and 'self-regulation of individuals' approaches (Higgins & Lockie, 2001). Following the introduction of water reforms and transferable water rights, the federal government implemented several devices, namely natural resource management programs, the rural adjustment scheme, the property management planning, and the national drought policy. These environmental devices were designed in economically rational ways to reward "good" farmers while offering exit support to those without a long-term sustainable future (Botterill, 2003).

2.2.2. Agri-environmental measures in developing countries

The following descriptions of environmental devices adopted by southern countries are mostly gathered from the WTO's environmental database (WTO, 2019).

China has introduced the Green for Grain program on a pilot basis in 1999 to encourage afforestation, reverse ecological degradation and soil erosion, and reduce over-cultivation of sensitive land. The five-year plan of 2011-2015 reaffirms China's commitments in earlier plans to build a socialist new countryside agriculture through strengthened support, more benefits to farmers, and the promotion of modernization to improve their living standards. In addition, a series of tax policies was implemented by the country to promote energy conservation and environmental protection. China used also input subsidies to promote fertilizers that have harmless environmental effects.

More developing countries tried to popularize the use of natural fertilizers like Nepal who subsidized the equipment for producing organic fertilizers. In turn, Vietnam invested around 570 million US$ to expand an environmentally-friendly fertilizer factory. In the same vein, Indonesia has subsidized the use of organic fertilizers. Additionally, Bangladesh has implemented in 2010 a program to distribute organic fertilizers to more than 9 million farmers around the country (Maetz et al., 2011).

In Vietnam, the ministry for agriculture and rural development is also responsible for environmental and water management. In 2005, the law on environment protection (number 52/2005/QH11) was adopted by the Vietnamese government. It provides statutory provisions on several activities, measures and resources used for the purpose of environmental protection. They apply to regulatory bodies, public agencies, organizations as well as to households.

In the same vein, Philippines has lunched in 2010 the national convergence initiative which is a joint project of three departments (i.e. environment and natural resources, agriculture, and agrarian reform). The project was implemented in line with the goal of optimizing the government's efforts in environmental sustainability and to honor the country's commitment in the Millennium Development Goals. In the same year, Philippines has adopted the organic agriculture act to promote the organic farming using fiscal incentives. Moreover, Philippines lunched in 2009 the climate change act to integrate climate change into the formulation of government policies. Additionally, prohibited and regulated exports include endangered wildlife species, live animals, and naturally growing timber to fulfil international agreements and conventions like CITES[10].

In the framework of CITES, Peru has imposed some trade restrictions based on health and environmental grounds. For instance, the country bans the export of wild species, skins and leather articles made from wild animals. On the other hand, Peru’s standardization and sanitary policies aim at protecting human, animal and plant health while technical regulations and SPS measures are based on international standards. Additionally, Peru had set in 2008 the national water authority to promote the sustainable development of water resources. And five years later, the national agrarian health service was initiated in the country to represent the national authority for agricultural health, seeds and organic farming.

On its part, the Costa Rican government had enacted in 2013 numerous laws and decrees concerning various aspects of the agricultural sector, namely the law for fostering organic farming. Moreover, the country has implemented taxes and financial incentives to promote organic farming activities. The incentives include exemptions from taxes on sales of organic products.

Additionally, the Costa Rican ministry of agriculture and livestock had initiated the state phytosanitary service that oversees the sanitary protection of vegetable products. On the other

[10] the Convention on International Trade in Endangered Species of Wild Fauna and Flora, also known as the Washington Convention

hand, exports of several commodities, namely coffee and bulk sugar are subject to authorization for public health and environmental reasons, whereas the exportation of wood logs is prohibited. In Uruguay, the agricultural strategy for the period 2011-2015 aimed at enhancing agricultural and agro-industrial competitiveness in a sustainable manner. The strategy promotes the rational management of renewable natural resources and the conservation of biological diversity to mitigate climate change.

In Brazil, support schemes for farmers are relatively low compared with other OECD countries. However, the country maintains several domestic support measures, namely preferential credit lines and price support mechanisms. On the other hand, the country lunched in 2010 its low carbon agriculture program (Programa ABC) to reduce greenhouse gas emissions and to support the recovery of forests.

The objectives of the program are the following: firstly, promote the reduction of deforestation, especially in the Amazon biome, through the expansion of crop, livestock and agroforestry activities in degraded areas or in process of recovery. Secondly, stimulate the adoption of sustainable production systems that gives priority to recovery of degraded pastures, direct planting, adoption of integrated crop-livestock systems, planting of forests and substitution of nitrogen fertilizer use for the biological fixation of this input in the process of crop production. Finally, to encourage the use of vegetable residues.

Additionally, the government has launched the Plan for low carbon emissions in agriculture (Plano ABC), which comprises a credit line organized under the ABC program. In order to implement this program, the government provides credits to enable interested producers to make investments according to the program objectives. The Brazilian development bank also offers the Produsa, which is a credit line for degraded soil, pasture recovery and the use of sustainable practices. A second credit line is the Propflora, used for commercial forestation and forest preservation in areas of legal reserve.

In Mexico, the agricultural policy was reorganized over the period 2007-2012 and introduced environmental goals to reverse the ecosystems' deterioration. On the other hand, the country has set up the natural resources sustainability program to promote the sustainable management of natural resources and to develop integrated systems as well as sustainable agricultural practices. The program introduced a new production structure including the production of bioenergy inputs, the use of alternative energy sources, as well as the conservation and sustainable use of the soil, water and vegetation. Besides, Mexico carried on the direct support to farmers' program (PROCAMPO) lunched in 1994. The latter provides direct payments to farmers maintaining agricultural activities or environmental protection programs under the authority of the environment and natural resources' secretariat.

As for the African continent, three Central African Economic and Monetary Community (CEMAC) countries[11] have finalized in 2011 voluntary partnership agreements in the

[11] Cameroon, the Congo, Central African Republic

framework of the European forest, law enforcement, governance and trade initiative. The agreements aim at supporting, with expertise and guidance, the sustainable development of the forestry industry. The CEMAC countries have also harmonized their pesticides registration procedures in March 2006 to ensure their rational use. In addition, Benin, Burkina Faso and Mali adopted a common environmental improvement policy in 2008 with the following objectives: (i) to cope with the deterioration and reduction of natural resources, (ii) maintaining biodiversity, (iii) harmonize their environmental standards and technical regulations (iv) and promote the sustainable management of natural resources, renewable energy sources and the management of environmental problems. In turn, the West African Economic and Monetary Union (WAEMU) has adopted in 2007 a framework for animal health and food safety to align their sanitary measures on international directives, namely the Codex Alimentarius and the international plant protection convention.

Furthermore, Côte d'Ivoire has created a ministry for the environment and sustainable development and signed several international treaties, namely the Vienna convention for the protection of the ozone layer, the convention on international trade in endangered species of wild fauna and flora, the Bamako convention on the ban of the import into Africa and the control of transboundary movement and management of hazardous wastes within Africa. On the other hand, the Beninese organization for the promotion of organic agriculture has been promoting sustainable development by focusing on making the best use of local resources and developing sustainable agricultural systems. For instance, a growing number of pineapple-producing organizations in Benin are turning since 2013 towards the export of organic and fair-trade products.

Additionally, most of the southern and eastern Mediterranean countries show an engagement towards multilateral environmental agreements concerning biodiversity conservation, namely the convention on the international trade in endangered species of wild fauna and flora in 1975 and the international treaty on plant genetic resources for food and agriculture in 2001.

On national scale, the Albanian national strategy for development and integration (2007-2013) targets environmental protection and rational use of natural resources. In addition, the agricultural policy aims at increasing the country’s competitiveness and the productivity while guaranteeing sustainable development in the agricultural and agro-industry sectors.

Additionally, Israel's accession to the OECD was a catalyst for important reforms concerning chemical management, environmental protection and green growth strategy. The government has also a strong regulatory role in several areas, namely self-sufficiency, export expansion, rural development, preservation of the environment as well as promoting water conservation and efficient irrigation techniques.

Finally, we cite the agricultural law of Turkey that has set up environmental payments to support farmers. This complementary instrument targets soil erosion and the overuse of water resources. Moreover, Turkey has adopted the biosafety law and an additional regulation

concerning genetic modified organisms in 2010 to regulate the country's agricultural biotechnology.

In sum, the above-mentioned descriptions highlight the asymmetrical agri-environmental instruments and policies between southern and northern countries. Our analysis shows that environmental drawbacks of intensive agriculture in Western countries have contributed to move their agricultural policies toward a multifunctionality-based agriculture and to greater environmental sustainability. However, two production models are present, namely the market-oriented, liberalistic agriculture and the market-protected one.

By contrast, emerging and developing countries show uneven environmental regulations that turn out to be mostly regulatory, except for some middle income countries like Brazil and Mexico. In the next section, we argue the efficiency of these devices and investigate the determinants of the agri-environmental performance of a panel of 108 countries over the period 2003-2013.

2.3. Theory foundations and methodology

2.3.1. First stage: Data Envelopment Analysis

Built upon the earlier work of Farrell (1957), data envelopment analysis is a well-established methodology to evaluate relative efficiencies of a set of comparable entities by some specific mathematical programming models. The DEA is a nonparametric approach that does not require any prior assumptions on the underlying functional relationships between inputs and outputs (Seiford & Thrall, 1990) nor specific requirements for a priori weights.

Introduced by Charnes et al. (1978), the radial CCR (Charnes, Cooper, Rhodes) is one of the basic DEA models built on the assumption of constant returns to scale (CRS) of activities that allows to evaluate overall efficiencies of a set of entities under study. The latter are called decision making units (DMUs) and are responsible for converting inputs into outputs. The main result of the model is the breakdown of these production units into efficient and inefficient DMUs.

Suppose there are n DMU: $DMU_1 \ldots DMU_j, \ldots DMU_n$ (j=1,…,n) that are converting m input items x_{ij} (i=1…m) into s output items y_{rj} (r=1…s). The input data matrix X (mxn) and the output data matrix Y (sxn) can be arranged as follows:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ . & . & \cdots & . \\ . & . & \cdots & . \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \tag{2.1}$$

$$Y = \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & y_{2n} \\ . & . & \cdots & . \\ . & . & \cdots & . \\ y_{s1} & y_{s2} & \cdots & y_{sn} \end{bmatrix} \tag{2.2}$$

The production possibility set representing the set of observed feasible activities is denoted P_0 and can be written as follows:

$$P_0 = \{(x, y) \mid x \geq X\lambda, y \leq Y\lambda, \lambda \geq 0\} \tag{2.3}$$

Where λ is a semipositive vector in $\mathbb{R}^n$. We further assume that DMU_n consumes $x_{mn} \geq 0$ of input m to produce $y_{sn} \geq 0$ of output s and each DMU has at least one positive input and one positive output (Cooper et al., 2011; Färe et al., 1994). According to Charnes et al. (1978), the radial CCR optimization model allows to compute the efficiency of a DMU, denoted DMU_o (o = 1…n) that can be estimated by the ratio of its virtual output (weighted combination of outputs) to its virtual input (weighted combination of inputs). To avoid the arbitrariness in assigning the weights for inputs and outputs, the radial CCR model can determine the optimal weights for DMU_o by maximizing its ratio of virtual output to virtual input while keeping ratios for all the DMUs not more than one. This problem which evaluates DMU_o can be further transformed into an equivalent ‘‘output maximization’’ linear programming problem, called the output-oriented[12] model. Formally,

[12] This version of the CCR model aims to maximize outputs without requiring more of any of the observed input values. However, the input-oriented model attempts to minimize inputs while satisfying at least the given output levels.

$$
\begin{aligned}
\max_{u,v} \quad & \theta = \sum_{r=1}^{s} u_r y_{ro} \\
\text{s.t.} \quad & \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0 \\
& j = 1, \ldots, n \\
& \sum_{i=1}^{m} v_i x_{io} = 1 \\
& u_r, v_i \ge 0 \\
& i = 1, \ldots, m \\
& r = 1, \ldots, s
\end{aligned}
\tag{2.4}
$$

Model (2.4) is known as the CCR in multiplier form. The efficiency scores of DMU_1 to DMU_n can be derived by solving n such models in order to obtain values for the input weights denoted v_i (i=1…m) and the output "weights" u_r (r=1…s). The aim is to obtain weights v_i and u_r that maximize the ratio of the DMU being evaluated. By virtue of the constraints, the optimal values of $\theta = \theta^*$ is at most 1. If $\theta^* = 1$, then DMU_o is CCR-efficient and there exists at least one optimal (v*, u*) with $v^* \ge 0$ and $u^* \ge 0$. If $\theta^* < 1$, DMU_o is thus CCR-inefficient.

Nevertheless, efficient units obtained by original CCR-DEA models cannot be differentiated among themselves and thus, cannot rank efficient units. DEA models were extended by Andersen and Petersen (1993) to a new area called super-efficiency (SE) to rank efficient DMUs. SE model takes the form of a radial CCR-DEA model to avoid the possibility of non-solution that is usually associated with the convexity constraint in the Variable Returns to Scale (VRS) models (i.e. BCC model[13]).

Although DEA super-efficiency approach is widely applied in several research fields such as development economics (Martić & Savić, 2001) and energy studies (Khodabakhshi et al., 2010), agricultural economics' studies are not that numerous and are mainly conducted on micro-level to our best knowledge. Han et al. (2014) are among the few scholars who used a super-efficiency DEA model to analyze the efficiency of agricultural informatization in Hunan province in China from 2009 to 2013. The SE model was also used by Mathur and Ramnath (2018) to measure the efficiency of food grains production in India for the two time periods 1960-1990 and 1991-2014. The conducted analysis identified the years in which grains' production was most efficient. Additionally, Wongchai et al. (2012) used the super-efficiency model to measure the paddy rice technical efficiency in 76 provinces in the period 2001 - 2011 in Thailand.

[13] Which refers to the DEA-model of Banker, Charnes and Cooper (Banker et al., 1984).

The output-oriented version of the super-efficiency measure can be written as:

$$\text{[SuperRadial-O-C]} \quad \frac{1}{\phi^{super*}} = \min \frac{1}{\phi_o^{super}}$$

$$\text{subject to} \quad x_{io} = \sum_{\substack{j=1 \\ j\neq 0}}^{n} \lambda_j x_{ij} + s_i^-, i = 1,...,m$$

$$\phi_o^{super} y_{ro} = \sum_{\substack{j=1 \\ j\neq 0}}^{n} \lambda_j y_{rj} - s_r^+, r = 1,...,s \qquad (2.5)$$

$$\phi_o^{super}, \lambda_j (j \neq 0) \geq 0$$

$$s^- \geq 0 \ , \ s^+ \geq 0$$

Where ϕ_o^{super} is the maximum possible proportional outputs that a country DMU_o can produce in comparison to other countries. The Variable s_i^- represents input decrement for evaluating each country. s_i^+ shows the r^{th} output amount that can be further produced. λ_j is a non-negative variable to construct a convex combination of other countries to compare with the country under evaluation. The data associated with the DMU_o being evaluated is therefore omitted from the production possibility set. However, solutions will always exist as long as input items (x_{ij}) and output items (y_{rj}) are positive.

In this chapter, we employ the super-efficiency data envelopment analysis (DEA-SE hereafter) model developed by Andersen and Petersen (1993) and based on the fundamental work of Farrell (1957) to compute the agri-environmental efficiency (AEE) scores. Our study deals with crop production of 108 countries over the period 2003-2013.

Indeed, agricultural production managed by n countries (that represent our DMUs) can be modelled as the transformation of m input items namely, land, labor, and fertilizers. The latter are transformed into s output items denoted by vector y_{rj} (r=1,…,s). The latter may contain economic and desirable outputs (denoted y^d) such as vegetable production, environmental services [14] (e.g. landscape management) as well as undesirable outputs (denoted y^{ud}) such as pollution. Therefore, if inefficiency exists in the production, undesirable pollutants should be reduced to improve the efficiency. Put differently, undesirable and desirable outputs should be treated differently when we evaluate the production performance of agriculture.

Many methods have been proposed to incorporate undesirable outputs into DEA models (Scheel, 2001). They are mostly based on data translation and the utilization of traditional DEA models (Seiford & Zhu, 2002). Additionally, the method shows two advantages. Firstly, the

[14] We are forced to exclude this variable due to data limitations.

weaker conditions remain satisfied since all the selected inputs and outputs are positive elements. This allows us to adopt the CCR radial SE model of Andersen and Petersen (1993). Secondly, the use of CCR model avoids the possibility of non-solution that is associated with the convexity constraint in the variable returns to scale models (BCC model). By introducing the undesirable output y^{ud}, the production technology can be written as follows:

$$P = \left\{ (x, y^{d}, y^{ud}) : x \text{ produces } (y^{d}, y^{ud}) \mid x \geq X\lambda, y^{d} \leq Y\lambda, \frac{1}{y^{ud}} \leq Y\lambda, \lambda \geq 0 \right\} \quad (2.6)$$

where λ is a semipositive vector in $\mathbb{R}^{n}$, $X_{(m \times n)}$ and $Y_{(s \times n)}$ are the input and output data matrices, respectively. According to Färe et al. (1989), P undergoes two assumptions:

- First, weak disposability which requires that reduction of the undesirable output is costly in terms of the proportional reduction of desirable output, i.e. if $(x, y^{d}, y^{ud} \in P)$ and $0 \leq \theta \leq 1$ then $(x, \theta y^{d}, \theta y^{ud}) \in P$
- Second, null-jointness: if $(x, \theta y^{d}, \theta y^{ud}) \in P$ and $y^{d} = 0$, then $y^{ud} = 0$. That is to say that the only way to produce zero amount of y^{ud} is by stopping the production of y^{d}.

Following the method of Seiford and Zhu (2002), and in order to simultaneously increase the desirable output while decreasing the undesirable one, we apply a linear monotone decreasing transformation to the undesirable output. We then use the adapted variable as an output item. Moreover, this method preserves the convexity and linearity relations of DEA model. In sum, the adopted DEA model assumes an increase in the desirable output and a reduction in the undesirable output given constant quantities of input items.

We recall that the aim of this chapter is to evaluate the agri-environmental efficiency change over time. To that end, we employ the window analysis approach, originally introduced by Klopp (1985) and developed by Charnes et al. (1984). The latter is based on radial approach and can be used with time-varying data. The main idea is to capture the temporal impact on agri-environmental efficiencies and see its short-run evolution from one "window" to another (Yue, 1992). The analysis provides trends of efficiency and the rank of each country according to its effectiveness.

Thereby, results allow for analyses of trends of the overall agri-environmental efficiency related to the sector of vegetable products of our country sample (Tulkens & Vanden Eeckaut, 1995). Accordingly, if we add the time dimension t $(1 \leq t \leq T)$ to the above radial-CCR model, the vector forms of Eq. (2.1) and Eq. (2.2) can be written as:

$$x_n^t = \begin{bmatrix} x_n^{1t} \\ . \\ . \\ . \\ x_n^{mt} \end{bmatrix} \tag{2.7}$$

$$y_n^t = \begin{bmatrix} y_n^{1t} \\ . \\ . \\ . \\ y_n^{st} \end{bmatrix} \tag{2.8}$$

If a window with $n \times w$ observations is denoted starting at time period *t*, and is characterized by a window width (i.e. the number of years in a window) denoted as w $(1 \le w \le T - t)$, then matrices of inputs and outputs can be written as follows:

$$X = \begin{bmatrix} x_{11}^t & x_{12}^t & \dots & x_{1n}^t \\ x_{21}^{t+1} & x_{22}^{t+1} & \dots & x_{2n}^{t+1} \\ . & . & \dots & . \\ . & . & \dots & . \\ x_{m1}^{t+w} & x_{m2}^{t+w} & \dots & x_{mn}^{t+w} \end{bmatrix} \tag{2.9}$$

$$Y = \begin{bmatrix} y_{11}^t & y_{12}^t & \dots & y_{1n}^t \\ y_{21}^{t+1} & y_{22}^{t+1} & \dots & y_{2n}^{t+1} \\ . & . & \dots & . \\ . & . & \dots & . \\ y_{s1}^{t+w} & y_{s2}^{t+w} & \dots & y_{sn}^{t+w} \end{bmatrix} \tag{2.10}$$

Accordingly, results of DEA window analysis are produced by substituting inputs and outputs of DMU_n^t into Eq. (2.5). The radial super efficiency output oriented model of DEA window problem for DMU_n and for the t^{th} window is given thereby by solving the following linear program:

[SuperRadial-O-C] $$\frac{1}{\phi^{super*,t}} = \min \frac{1}{\phi_o^{super,t}}$$

subject to

$$x_{io}^{t} = \sum_{\substack{j=1 \\ j\neq 0}}^{n} \lambda_j^t x_{ij}^t + s_i^{(-,t)}, i = 1,...,m$$

$$\phi_o^{super,t} y_{ro}^{t} = \sum_{\substack{j=1 \\ j\neq 0}}^{n} \lambda_j^t y_{rj}^t - s_r^{(+,t)}, r = 1,...,s \qquad (2.11)$$

$$\phi_o^{super}, \lambda_j (j \neq 0) \geq 0$$

$$s^{-} \geq 0 \ , \ s^{+} \geq 0$$

Model (2.11) is applied for every window to estimate the technical efficiency for each DMU. By this approach, the super efficiency is analyzed sequentially with a certain window width using time-varying data. Additionally, windows are based on moving average method that is one DMU is coming and one DMU leaves the system. Nonetheless, in the absence of a specific theories that underpin the definition of the window size, our study utilizes a three-year window following the work of Charnes et al. (1994), Halkos and Tzeremes (2009), Wang et al. (2013) as well as Zhang et al. (2011).

We choose a narrow window width ($w = 3$) to yield the best balance of informativeness and stability of the efficiency measure. According to Table A2. 2 in the Appendix of chapter 2 (A2), the second window incorporates years 2003, 2004 and 2005. From the 3rd to the 10th window, when a new period is introduced, the earliest one is dropped. Thus, year 2003 is dropped in window 3, whereas year 2006 is added to the window. Subsequently in window 4, years 2005, 2006 and 2007 will be assessed. This analysis is performed until window 10 that incorporates years 2011, 2012 and 2013. Due to the lack of data in years 2002 and 2014, we apply a two-year window size for the first and last window. As DEA window analysis treats a DMU as different entity in each year, a three-year window width with 11 time periods and a large sample of DMUs would considerably increase the number of observations of the sample, providing thereby a greater degree of freedom.

In sum, this study employs a time-varying dataset of 108 countries to address changes in agri-environmental efficiency over the period 2003–2013. Inefficient DMUs are assigned an index of efficiency less than 1 that could be interpreted as the proportional increase in output vector that is required to make a DMU efficient. On the other hand, efficient DMUs have an index equal to or greater than 1. In the rest of this work, AEE_{jt} and $\widehat{AEI}_{jt}$respectively denote the computed DEA super-efficiency scores and the estimated inefficiency scores of the j^{th} country in year t.

2.3.2. Second stage: Truncated regression

The aim of the second stage is to explore the contextual factors that are likely to affect inefficiency scores ($\widehat{AEI}_{jt}$) computed in the first stage. To that end, we use a set of environmental variables and test the below regression specification.

$$\begin{cases} \hat{AEI}_{jt} = \beta_0 + \beta Z_{jt} + \varepsilon_{jt} \quad j = 1,\ldots,n \; ; \; t = 1,\ldots,T \\ \hat{AEI}_{jt} \geq 1 \end{cases} \tag{2.12}$$

Where the regressand ($\hat{AEI}_{jt}$) is the truncated variable representing the agri-environmental inefficiency. β_0 is the constant term and β represents the corresponding estimators of variables Z_{jt}. The latter are a vector of observation and time-specific variables that are likely to affect the agri-environmental inefficiency. ε_{jt} is the statistical noise which distribution is restricted by the following condition:

$$\varepsilon_{jt} \geq 1 - \beta_0 - \beta Z_{jt} \quad j = 1,...n; \; t = 1...T \tag{2.13}$$

It is a common practice in the DEA literature to directly regress the estimated efficiency scores with environmental variables using Tobit, simple OLS, GMM or GLS censored estimators. According to Simar and Wilson (2007), this approach leads to clear regression misspecifications, biased results and high probability of endogeneity. They introduce instead a double-bootstrapped truncated regression framework, which copes with the above-mentioned issues and provides bias-corrected efficiency scores.

Econometrically speaking, the authors show that the left-truncated method is a 'safer' approach for several reasons. First, from a truncated normal distribution, errors that fall below are not observed, unlike in censored models such as the Tobit. Second, Simar and Wilson (2007) employ an extra parametric bootstrap (see steps 3 and 4 in algorithm two, page 7) in order to produce improved estimates in terms of statistical significance and bias. Besides, the usefulness of such technique in energy and environmental DEA-modeling has been empirically demonstrated by several scholars, namely Hawdon (2003) and Sanhueza et al. (2004). In this regard, we use the truncated maximum-likelihood method developed by Simar and Wilson (1999, 2007) to estimate Eq. (2.12).

2.4. Data

2.4.1. First stage: Data Envelopment Analysis

As reported in Table 2. 1, all inputs and outputs data are extracted from the FAOSTAT database (FAO, 2018), except for agricultural labor provided by the World Bank data portal (World Bank, 2019c).

Table 2. 1. DEA input and output components

Variable	Definition	Data sources	Mean	Std. Dev.	Min	Max
y_{jt}^{d}	agricultural production	FAO (2018)	4.73e+07	1.65e+08	193	1.79e+09
y_{jt}^{ud}	Emissions (CO_{2eq}) from N_2O	FAO (2018)	17925.3	44871.09	25.03	375673
x_{1jt}	Agricultural land	FAO (2018)	13011.95	28796.95	9.2	174364
x_{2jt}	Agricultural labor	World Bank (2019c)	8183.709	35069.67	1.669	334976
x_{3jt}	Pesticides imports	FAO (2018)	5941833	3.11e+07	2.483	3.00e+08
x_{4jt}	Fertilizers	FAO (2018)	174.8553	281.8457	0.0004	2718.69

Source: the table is created by the author to describe inputs and outputs used in the setup of DEA model.

The economic output (y_{jt}^{d}) is an aggregate variable of crop commodities' production[15] expressed in tons at country-level. Additionally, the agricultural output is associated with the production of the undesirable pollution denoted y_{jt}^{ud}. The latter is an aggregated emission of the nitrous oxide (N_2O) greenhouse gas expressed in CO_2 equivalents. Total agricultural N_2O emissions are in gigagrams and include sub-domains such as: manure management, synthetic fertilizers, manure applied to soils and pastures, crop residues, burning-crop residues and burning-savanna.

In fact, and according to Baumert et al. (2005) and Viard et al. (2013), nitrous oxide is a greenhouse gas that mainly originates from soils and agricultural activities and is closely tied to the production of food crops. On the other hand, livestock production (or animal agriculture) is a large source of methane emissions because of enteric fermentation by ruminant livestock (Baumert et al., 2005). That is to say, agricultural products are responsible for different kinds

[15] Crop statistics in the database of FAOSTAT cover the following categories: live trees and other plants, bulbs, roots and the like, cut flowers and ornamental foliage, edible vegetables and certain roots and tubers, edible fruit and nuts, peel of citrus fruit or melons, coffee, tea, mate and spices, cereals, products of the milling industry, oil seeds and oleaginous and vegetable plaiting materials.

of pollution. Therefore, we limit our study to vegetable products so we can introduce the appropriate undesirable output.

As for the selected inputs, we introduce two economic production factors. First, agricultural land (x_{1jt}) expressed in 1000 hectares of arable land[16] and permanent crops area[17] in each country. The second economic input is labor (x_{2jt}) that measures the economically-active population in the agricultural field according the World Bank database (World Bank, 2019c).

In addition, our model uses two chemical inputs. Firstly, pesticides imports are used as a proxy for pesticides' consumption (unavailable for all the studied countries). This input is an aggregated variable of all imported pesticide items (in tons), namely insecticides, fungicides, herbicides and disinfectants. Secondly, x_{4jt} is expressed in kilograms per hectare of cropland. The latter provides information on the average use of chemical or mineral fertilizers of primary plant nutrients like Nitrogen, Phosphate and Potash.

2.4.2. Second stage: Truncated regression

The selected variables (Z_{jt}) are developed in Eq. (2.16) and Eq. (2.17) and described in Table 2. 2. We have provided the country list in Table A2. 1 in the appendix of Chapter 2.

To refine our results, we differentiate them according to their income group based on the World Bank classification (World Bank, 2019b). Accordingly, countries are divided into low, middle (upper and lower), and high income countries. In this chapter, we added a fourth category related to the BRICS as shown in the same table.

$$\text{I-Env} = \frac{\text{Environmental protection expenditure in US \$, 2005 prices}}{\text{total government expenditure in agriculture in US \$, 2005 prices}} \tag{2.14}$$

$$\text{I-R\&D} = \frac{\text{Research \& Development expenditure in agriculture in US \$, 2005 prices}}{\text{total government expenditure in agriculture in US \$, 2005 prices}} \tag{2.15}$$

$$\begin{aligned} \text{AEI}_{jt} = {} & \beta_0 + \beta_1 \text{Precip}_{jt} + \beta_2 \text{Precip}_{jt}^2 + \beta_3 \text{Temp}_{jt} + \beta_4 \text{Temp}_{jt}^2 + \beta_5 \text{RCA}_{jt} + \\ & \beta_6 \text{OD}_{jt} + \beta_7 \text{I-Env}_{jt} + \beta_8 \text{I-R\&D}_{jt} + \sum_{j=1}^{n} \delta_{1j} \text{DMU}_j + \sum_{t=1}^{T} \gamma_{1t} \text{year}_t + \varepsilon_{jt} \end{aligned} \tag{2.16}$$

[16] Arable land refers to land under temporary crops (double cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years).

[17] Land under permanent crops is cultivated with crops that need to be replanted after each harvest. This category includes land under flowering shrubs, fruit trees, nut trees and vines but excludes land under trees grown for wood or timber.

Equation (2.16) allows for the isolation of the causal effects of climatic and some macro-economic factors on the agri-environmental inefficiency (i.e. AEI_{jt}). δ_{1j} is a DMU-fixed effect to account for country-specific unobserved heterogeneity, whereas γ_{1t} is a year fixed effect. Country dummies capture all the static factors omitted from the model and affecting DMUs' areas that could explain the dependent variable. Similarly, the temporal fixed effects consider all the dynamic determinants omitted in Eq. (2.16). ε_{jt} is the statistical noise.

The parameter estimates (β) report marginal effects of regressors on AEI. The variables of interest are described in Table 2. 2 and can be divided into three categories. First, climate variables, namely Precip and Tempr extracted from FAOSTAT (FAO, 2018) and World Bank (World Bank, 2019a) databases, respectively. The variable Precip denotes the annual mean of precipitation by country, whereas Tempr reflects the temperature change in each country over the period 2003-2013. According to Barnabás et al. (2008) and Korres et al. (2017), climate plays an important role in shaping agricultural systems and is most likely to affect their agri-environmental performance. In low income countries, economies are tied with the primary sector. Accordingly, climate variability is expected to have a major impact on the inefficiency.

Moreover, we add quadratic terms of precipitation ($Precip^2$) and temperature ($Tempr^2$) to reflect the nonlinearity of the response function between inefficiency scores and climate variables (Popoola et al., 2018; Schlenker & Roberts, 2006). The function will have either a convex (when the estimated parameter of the quadratic term is positive) or a concave (negative sign) shape.

The second category of control variables includes the environmental (I-Env) and Research & Development (I-R&D) investment shares in total agricultural investment as shown in Eq.(2.14) and Eq.(2.15), respectively. Indeed, increasing environmental protection and R&D expenditures are expected to decrease the agri-environmental inefficiency. Both variables are calculated based on data from FAOSTAT (FAO, 2018).

As for international trade, we introduce the following variables. First, the agricultural trade openness degree (OD_{jt}) representing the relative importance of international trade in the economy of the country. The variable (expressed in %) is computed using data from FAOSTAT (FAO, 2018). It is calculated by dividing the aggregate value (in US$) of imports and exports of agricultural commodities by the agricultural gross domestic product (GDP), the whole multiplied by 50. Agricultural GDP is simply the product of total GDP (in US$) and the value added of agriculture (in % of GDP), both extracted from the FAOSTAT database (FAO, 2018). Accordingly, a larger OD ratio would suggest a higher exposure to international trade.

Second, we have included RCA_{jt} to control for the country's revealed comparative advantage in agriculture. The variable was first introduced by Balassa (1965) and is extracted from the data portal of world integrated trade solution (World Bank, 2018). In our model, the revealed comparative advantage indicator is employed as a specialization index of crop commodities'

exports. If the ratio is greater than one, then the country exports more vegetable products than the world average. Accordingly, the country has a comparative advantage for this good.

To investigate the effect of international trade openness on the domestic environmental performance, it is essential to appeal to theories of environmental economics. As explained in the general Introduction of the thesis, the schools of thought concern both the impact of environmental regulations on competitiveness and environmental outcomes of trade. In this study, we relate more to the second aspect that suggests the following theories.

First, the "race-to-the-bottom" hypothesis was initially formulated in the context of local competition for investments and jobs within federal states in the USA before 1970. Back then, responsibilities for the environment were decentralized. The theory argues that increased competition for trade and foreign direct investment could lead to lowering environmental standards and regulations (World Bank, 2000; WTO, 1999).

However, few studies have countered this negative link using the terms "race to the top" and "the gains-from-trade hypothesis". For instance, Frankel and Rose (2005) examined the positive impact of globalization on environmental regulation and argued that increased trade could eventually lead to better environmental protection. The second theory was supported later on par several scholars, namely Dong et al. (2012) and Tamazian et al. (2009).

In their study, Dong et al. (2012) investigated the interrelationship between foreign direct investment and environmental policy using a north–south model in a market share game. Their results show that foreign direct investment may enhance the environmental standard of the host country if market sizes of the two partners are small. In turn, Tamazian et al. (2009) employed a standard reduced-form modeling approach to investigate the linkage between economic development and environmental quality in BRIC economies over the period 1992–2004. Results show that higher degree of economic and financial development decreases the environmental degradation. This would suggest that financial liberalization and openness are essential factors for the CO_2 reduction in emerging countries.

In our case, a positive impact of trade openness variable ($\beta_6 > 0$) on the agri-environmental inefficiency would mean that trade can directly and negatively affect domestic agri-environmental performance. This result would confirm thereby the race-to-the-bottom hypothesis. However, a negative impact of the OD variable on the estimated inefficiency would suggest that agricultural trading enhances the stringency of environmental regulations, supporting therefore the gains-from-trade hypothesis.

As for the RCA indicator, two hypotheses need to be verified. First, a positive sign of the estimator ($\beta_5 > 0$) would suggest that the specialization in crop commodities' exports is increasing the agri-environmental inefficiency. By contrast, a negative impact would suggest that the specialization in crop commodities' exports enhances the environmental standard.

Table 2. 2. Second-stage regression variables

Variable	Definition	Data sources	Mean	Std. Dev.	Min	Max
$Precip_{j,t}$	Annual mean precipitations	World Bank data portal (World Bank, 2019a)	87.07	61.26	1.96	316.2
$Temp_{jt}$	Annual mean temperatures	FAOSTAT data (FAO, 2018)	0.88	0.472	-0.44	2.98
$I\text{-}Env_{jt}$	The share of environmental investments in total agricultural investment	Own elaboration using FAOSTAT data (FAO, 2018)	1.42	1.62	0	7.35
$I\text{-}R\&D_{jt}$	The share of Research & Development in total agricultural investment	Own elaboration using FAOSTAT data (FAO, 2018)	1.68	17.25	0	214.6
OD_{jt}	degree of openness to trade		295.2	163.63	37.3	1011
RCA_{jt}	revealed comparative advantage indicator	WITS data portal (World Bank, 2018)	3.09	4.58	0	35.78
SPS_{jt}	endured sanitary and phytosanitary measures	WTO's integrated trade intelligence portal (I-TIP) (WTO, 2018)	215.84	201.76	2	541
TBT_{jt}	endured technical barriers to trade		37.45	36.9	1	104

Source: the table is created by the author. It reports definitions and descriptive statistics of control variables.

Model (2.17) allows to determine whether or not environmentally-related non-tariff measures (previously described in Chapter 1) are determinants of the agri-environmental performance.

$$AEI_{jt} = \beta_0 + \beta_1 Temp_{jt} + \beta_2 Precip_{jt} + \beta_3 I\text{-}Env_{jt} + \beta_4 RCA_{jt} + \beta_5 SPS_{jt} + \beta_6 TBT_{jt} + \sum_{j=1}^{n} \delta_{2j} DMU_j + \sum_{t=1}^{T} \gamma_{2t} year_t + \mu_{jt} \quad (2.17)$$

Where AEI_{jt} denotes the truncated variable (i.e. the agri-environmental inefficiency) of the country j at time t. δ_{2j} is a DMU-fixed effect to control for country-specific unobserved heterogeneity. γ_{2t} is a year fixed effect and μ_{jt} is the error term. Finally, β are the estimated parameters and report marginal effects of the truncated variable.

So far, most of the literature dealing with NTMs were interested in their trade effect. Several studies show that they act as barriers to agricultural exports of developing and developed countries (Bureau et al., 1998; Melo et al., 2014; Santeramo & Lamonaca, 2019; Webb et al., 2019). This finding explains thereby the nomenclature 'non-tariff barriers', commonly used by scholars. An alternative strand of empirical studies suggests that NTMs expand trade and can act as market-creating "catalysts" in particular in the sanitary and phytosanitary (SPS) area (Cadot et al., 2018; Maertens & Swinnen, 2007).

However, new features of such measures merit further study. To that end, we introduce the variables SPS_{jt} and TBT_{jt} that refer to the cumulative number of sanitary and phytosanitary and technical barriers to trade applied to vegetable products, respectively. We recall that technical NTMs mostly target imported products despite their origin. Nonetheless, some measures are only applied to selected countries. According to UNCTAD (2018), this is valuable information that should not be discarded.

Accordingly, we use a complementary source of information to seek a better indicator of these measures, namely specific trade concerns. As explained in section 1.2.2, STCs address differences between countries concerning the conformity of national measures in the SPS and TBT areas (Horn et al., 2013). Thereby, SPS_{jt} and TBT_{jt} account not only for the cumulative number of measures endured by the country j, but also for STCs raised by the same country at SPS and TBT committees. Data are gathered under the integrated trade intelligence portal (I-TIP) under the section 02 (WTO, 2018).

According to our basic assumptions, a negative parameter estimate would suggest that higher SPS and TBT restrictions stimulate exporters to upgrade their agri-environmental performance to meet their partners' environmental requirements. The opposite case would suggest that the more an exporter endures technical NTMs, the more agri-environmentally inefficient is.

2.5. Results and discussion

2.5.1. And the Oscar for best agri-environmental policy goes to…

Table 2. 1 reports the descriptive statistics of both economic and undesirable outputs. Overall, agricultural production shows a significant variability across countries over the period 2003-2013. On the one hand, the lowest production is recorded by Luxembourg (193 000 tons), whereas China records the highest vegetable production (74 billion tons). On the other hand, Malta records the lowest level of nitrous oxide emissions (25 gigagrams) contrary to China, considered as the largest polluter of our sample (375 673 gigagrams).

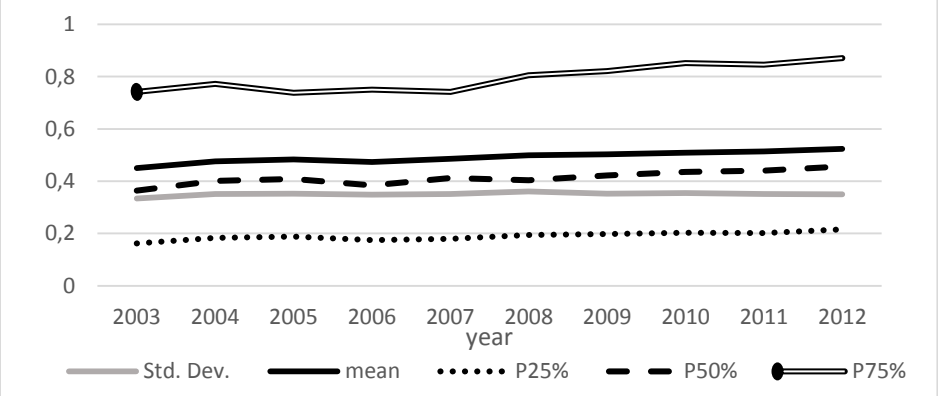
Additionally, the consumption of inputs varies considerably from country to another. For instance, agricultural land and labor are respectively less than 100000 ha and 5000 workers in countries like Malta, Luxembourg and Oman. However, Canada, Brazil, China, India and Russia are characterized by large agricultural land (over 50 million ha) and large agricultural employment that exceeds 5 million workers per year. Moreover, our sample includes small chemical users like Niger, Benin, and Togo since their fertilizer's consumption does not exceed 1 kg per ha. Conversely, giant consumers, namely USA, India and China show high values that exceed 1000 kg/ha. The United States happens also to be, along with the EU member states, an important importer of pesticides (over 100 million tons per year). However, annual pesticide imports of Benin, Mozambique and Gambia do not exceed 1000 tons per year. To sum up, we are clearly dealing with a heterogeneous country sample.

The computed agri-environmental efficiency (AEE) by country from 2003 to 2013 are reported in Table A2. 3 in the Appendix of chapter 2 (A2). Overall, scores range between 0.02 (recorded by the least efficient countries) and 3.12 (recorded by the super-efficient DMU). In addition, Figure 2. 1 shows a global improvement in AEE scores. In fact, we note that the yearly average is in a constant increase over the period.

However, the overall average hides an individual heterogeneity as shown in Figure 2. 2. The latter reports the geographical breakdown of efficiency scores in 2013. Interestingly, our results highlight the significant gap between economically similar countries and sharing the same agricultural policy. For instance, France, Greece and the United Kingdom recorded respectively 1.34, 0.52 and 0.88 although they are under the Common Agricultural Policy.

Our findings are consistent with those of Vlontzos et al. (2014). The authors employed a non-radial DEA model to assess the energy and environmental efficiency of the EU member states. Results show a considerable variation of efficiency scores between countries. Despite the specific environmental preconditions included in the Common Agricultural Policy, the authors argue that the average EU environmental efficiency has declined especially after 2006, when the new decoupled subsidy administration scheme was applied.

Figure 2. 1. Overall AEE scores over the period 2003-2013



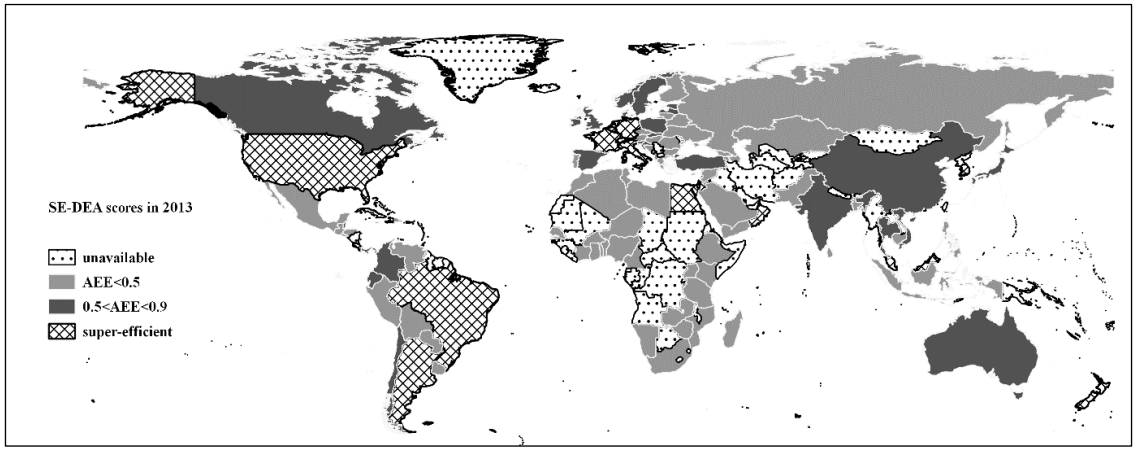
Source: own calculations.

According to Table A2. 3, efficiency scores range between 0.03 and 3.12 in 2013. In fact, over half of the studied countries are agri-environmentally inefficient (AEE scores under 0.45), whereas only 10% of our sample are qualified as super-efficient, namely Germany, Luxembourg, Israel, Switzerland, Costa Rica, France, Netherlands, Belgium, the US, Argentina, Brazil, Malaysia and Chile (Figure 2. 2). By contrast, only short-listed countries were qualified as super-efficient in 2003, namely Belgium, France, Luxembourg, Netherlands, Egypt, and Jordan.

We note that the least efficient countries are mostly African, namely Niger, Ethiopia, Gambia, and Burkina Faso. Nonetheless, some middle and high income countries (like Japan, South Africa, Ukraine and Mexico) are in turn clustered at the bottom of the ranking.

So far, our findings are consistent with previous studies. According to Hoang & Coelli (2011), the most sustainable OCDE systems are Belgium–Luxembourg, Netherlands and Denmark. We note that this study has identified the same three 'worst' countries, namely Mexico, Iceland and Japan. In turn, Hoang and Alauddin (2010) have computed the environmental indicator and showed that France, Greece and Turkey were the top performers, whereas Iceland, Mexico and Japan were the worst agricultural performers. As for southern and developing countries, we are unable to check the validity of our findings given the absence of previous studies.

Figure 2. 2. AEE scores by country in 2013



Source: own calculations.

In sum, we note that the ranking of countries is time-varying. In this regard, analyzing the efficiency scores' change over time will most likely be more straightforward to argue their agri-environmental stringency. Nonetheless, the classification based on average annual growth rates is not determinant for drawing any conclusions on the overall performance. For instance, Figure A2. 1 in the Appendix of chapter 2 (A2) shows that both Luxembourg and Oman have recorded

high AEE values over the period 2003-2013. However, efficiency values of Oman are volatile over time, whereas scores of Luxembourg remain stable.

In this regard, we introduce the standard deviation of AEE scores (over time and by country) as an indicator of the stability of the agri-environmental performance. In other words, we assume that two conditions must be fulfilled to consider an agri-environmental performance as sustainable. On the one hand, the country should record positive growth rate that would reflect increasing AEE scores. On the other hand, DEA scores must record low standard deviation. This would reflect the stability of efficiency values over time.

Therefore, the two criteria will likely reveal the stringency of agri-environmental policies conducted by the studied countries. According to Figure 2. 3, our country sample can be divided into five groups.

- First, the best agri-environmental practice countries defined by group 1. The latter includes some high income countries such as Belgium Luxembourg, Switzerland, Germany, France, and Netherlands. We also note the presence of some CAIRNS members, namely New Zealand, Costa Rica and Guatemala. Surprisingly, developing countries like Bosnia and Herzegovina, Armenia and Bangladesh belong to group 1. What these countries have in common is that, despite their income heterogeneity, their efficiency scores are sustainable (low standard deviation), and are increasing over time (high growth rate).

- Second, the worst agri-environmental practice countries, designated as group 5 in Figure 2. 3. This group includes both overly protectionist industrialized countries like Austria, Greece, United Kingdom and Japan as well as southern countries (like Burundi, Gambia, Niger, Peru, Ecuador and Philippines). We note that these countries have recorded decreasing efficiency scores according to our findings.

Between the two extremes are situated three additional country-groups that made a trade-off between the stability of their scores and their growth rate over time.

- Countries belonging to group 2 have recorded obviously the highest, yet volatile, efficiency scores over time (Figure 2. 3). The group includes mostly net food exporters such as the United States of America, Italy, Argentina, India, Indonesia, Malaysia, Vietnam and Turkey.

- On the other hand, countries of the third group have "privileged" their efficiency stability over growth rate. Interestingly, group 3 gathers more than 50% of our sample. The group is composed of China, several CAIRNS members (such as Australia, Canada, Chile, Paraguay and Uruguay), 19 countries of the EU[18], several net food exporters (i.e.

[18] namely Romania, Spain, Sweden, Slovakia, Slovenia, Poland, Portugal, Netherlands, Latvia, Lithuania, Ireland, Finland, France, Germany, Croatia, Cyprus, Czechia, Denmark and Bulgaria

Norway, Morocco, Bolivia, Honduras, Ethiopia, Panama and Zambia), and high income countries like Switzerland and Korea.

We note also the presence of several southern nations including African countries (namely Zimbabwe, Togo, Senegal, Mozambique, Kenya, Ghana, Côte d'Ivoire, Burkina Faso and Cameroon), some Mediterranean countries (such as Albania, Tunisia and Egypt) and central and southern American countries, namely Mexico, Venezuela, Dominican Republic, El Salvador and Jamaica. Although they have recorded low growth rates, Switzerland, Germany, Egypt, France, South Korea and Netherlands, have mostly registered super-efficient scores. Therefore, it is more insightful to integrate them into the first group.

- Finally, group 4 defines the moderately satisfactory rating countries. The latter are characterized by lower growth rates compared to the first and second groups and barely stable efficiency over time. The group is composed of two CAIRNS members, namely Brazil and Thailand in addition to Malta, Jordan and Lebanon.

Contrary to our expectations, this classification does not meet any economic nor income criteria. One may notice the heterogeneous composition of each group, especially the third and fifth ones. In other words, low and high income countries conducting heterogeneous agricultural and environmental policies may belong to the same group and thus, have the same agri-environmental performance.

This finding is even more surprising for the EU given the considerable variation of AEE scores within member states. Our findings suggest that the CAP's "decoupling" subsidies reform had the expected results in Belgium, Luxembourg Germany, Netherlands, France and Italy contrary to Austria, Greece and the United Kingdom. AEE scores join a long series of dissimilarities such as production costs (Duboz & Le Gallo, 2011).

In the same vein, countries like the United States, Japan, Norway, South Korea and Switzerland maintain high level of agricultural protection on grounds of public policy. Nevertheless, they present mixed results. Firstly, the US recorded increasing yet volatile DEA scores. Secondly, efficiency outcomes of Norway, South Korea and Switzerland show better stability despite their lower growth rate compared to the United States.

On the other hand, Japan has recorded decreasing agri-environmental performance, calling into question the stringency of its environmental policies. According to WTO (2019), the basic action plan for the revitalization of Japanese agricultural policy was introduced in 2011 to promote sustainable and rigorous agriculture and develop renewable energy supplies. In addition, a total of 54 technical regulations are in force based on the law of organic agricultural standards, including cross-category quality labelling standards for organic plants and organic processed foods. Japan has also signed the Nagoya Protocol on access to genetic resources and the fair sharing of benefits arising from their use.

Finally, the breakdown of CAIRNS members in Figure 2. 3 shows some interesting findings. For most of these countries, AEE scores grew over time despite the relatively different levels of stability. These findings are in line with the results of section 2.2.2 according to which, environmental side effects have become increasingly integrated into agricultural policies in southern countries. Starting by Brazil that has implemented the low carbon agriculture program in 2010. In the same vein, the Costa Rican government has enacted numerous laws and decrees concerning the agricultural activity, namely the law on the development, promotion and fostering of organic farming.

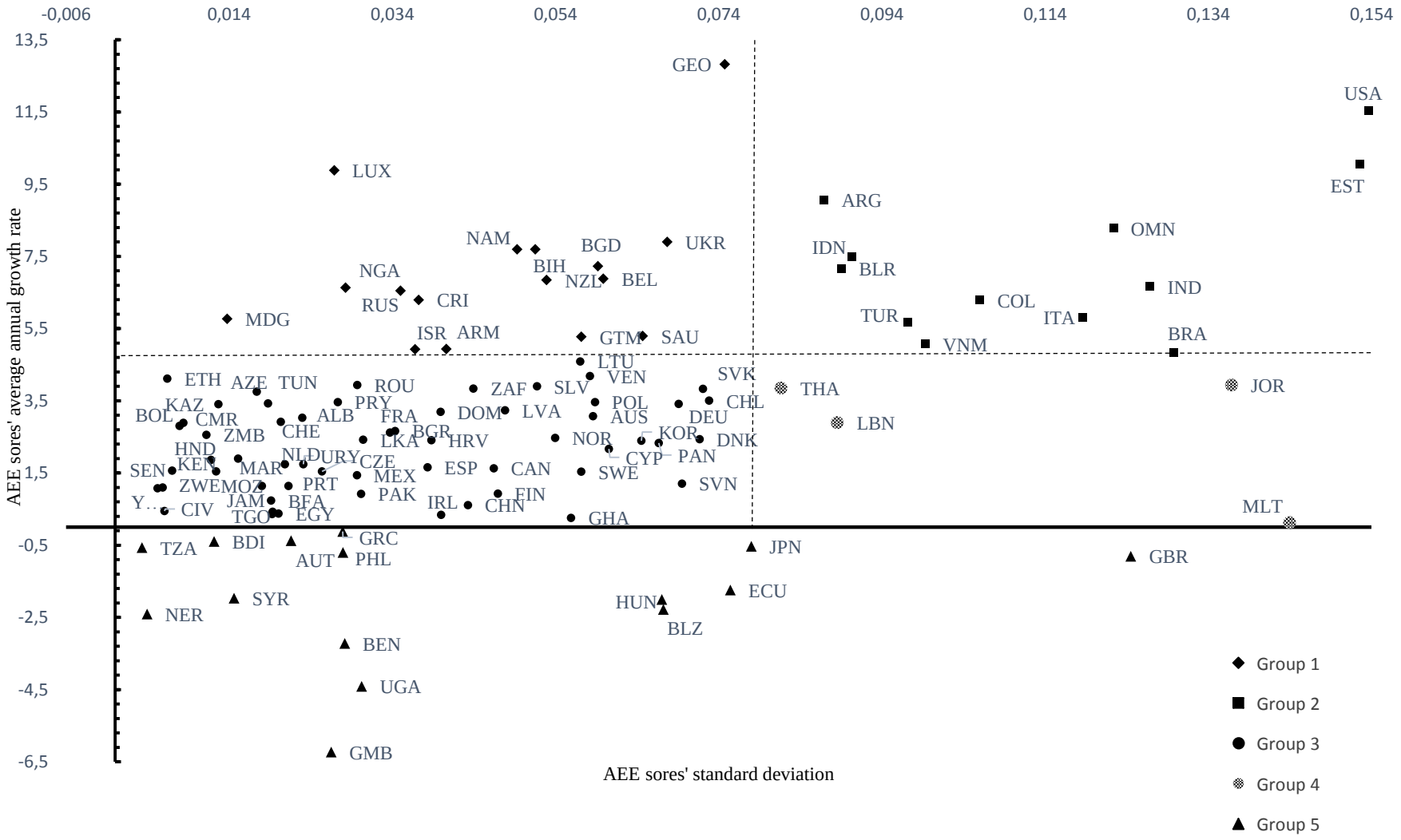
Furthermore, developing countries like China, India, Indonesia, Nigeria Côte d'Ivoire, and Turkey to cite only a few) have recorded increasingly stable AEE scores over the period 2003-2013. This would suggest that the stringency of their agri-environmental policies (e.g. the green for grain program of China, the law on horticulture in Indonesia …) have been embedded over time.

The few studies (Hoang & Alauddin, 2011; Hoang & Coelli, 2011; Hoang & Rao, 2010; Vlontzos et al., 2014) having assessed the energy and environmental efficiency of the agricultural sector had confined their research to the EU and OECD countries without addressing its determinants. In this regard, some questions arise:

- How can we explain the variability of the agri-environmental inefficiency between countries?
- Is it due to climatic variables?
- Do agricultural trade openness and the environmentally-related NTMs have an impact on their agri-environmental performance?

To answer these questions, we present in the next section the results of the double bootstrapped truncated model.

Figure 2. 3. Classification scheme



Source: own calculations.

2.5.2. Impact of climatic and public expenditures on the agri-environmental inefficiency

The second stage of our study allows the isolation of the causal influences of contextual factors on agri-environmental inefficiencies (AEI) of each country j (j=1…108) in year t. In a panel data framework, Eq. (2.16) and Eq. (2.17) are estimated using time and countries fixed effects[19]. Parameter estimates report the marginal effects of regressors on the truncated variable (i.e. the expected agri-environmental inefficiency).

Table 2. 3. Trade openness effects on the environmental performance

	Dependent: agri-environmental inefficiency (AEI)		
	(1)	(2)	(3)
Variables	ALL	HI&BRICS	MI&LI
Precip	0.0503*	-0.0241***	0.0433**
	(0.0298)	(0.00922)	(0.0262)
$(Precip)^2$	-0.000107	-0.00014	-0.000103
	(1.597)	(0.108)	(0.118)
Temp	0.369	0.0998	1.55***
	(1.107)	(0.0849)	(1.553)
$(Temp)^2$	-0.0976	-0.0428	-0.428
	(0.413)	(0.0330)	(0.487)
RCA	**-0.162***	**-0.0376****	**-0.250****
	(0.334)	(0.137)	(0.312)
OD	**-0.00118**	**-0.0013****	**-0.0949*****
	(0.0128)	(0.000421)	(0.00866)
I_Env	-0.143**	-0.0226*	-0.490**
	(0.552)	(0.0281)	(0.255)
I_RD	-0.000260	-0.0844	-0.00137
	(0.00089)	(0.937)	(0.00214)
Constant	0.209**	0.658*	0.577**
	(0.645)	(0.366)	(0.942)
Number of groups	108	46	62
Observations	1167	505	662
Country FE	yes	yes	yes
Year FE	yes	yes	yes

Source: own calculations. The table reports estimations of double bootstrapped truncated model. Dependent variable is the agri-environmental inefficiency score. All models contain year dummies for 2003 through 2013 and country fixed effects. Income heterogeneity of countries is considered: LI (low income), MI (middle income), BRICS (group of emerging countries composed of Brazil, Russia, India, China and South Africa), HI (high income) countries. Bootstrap standard errors in parentheses. *, **, ***: significance at the 10, 5 and 1 % levels, respectively.

[19] To control for changes through time and across countries that are not captured by our explanatory variables.

Column (1) of Table 2. 3 reports the estimation results of Eq. (2.16) regarding the entire sample of countries. Overall results show that the marginal effect of increased precipitation (β=0.05) on the inefficiency is positive and statistically significant at the 10%-level. However, the coefficient of the annual mean temperatures is not statistically different from zero. Similarly, quadratic terms of climate variables are statistically irrelevant according to the same column.

Interestingly, the parameter estimate of the variable I-Env is negative and statistically significant at 5%-level (β = -0.143). This would indicate that increasing public investments reduce highly and significantly the agri-environmental inefficiency of the countries studied. On the other hand, further results show that public expenditures on Research and Development (I-R&D) are not determinant for the agri-environmental performance of the whole sample.

Given the low statistical significance of previous estimations, we refine our analysis by dividing the country sample into two groups: emerging and high income economies (column (2)) and low and middle income countries (column (3)).

Our findings suggest that climate impact on the agri-environmental performance is rather mixed and differ from country-group to another. Results of column (3) show that raising temperature increases highly and significantly the agri-environmental inefficiency of developing countries (β=1.55). Nonetheless, the parameter estimate is positive, yet statistically insignificant (column (2)) in the case of the BRICS and developed countries (β=0.0998). Accordingly, developing countries are more sensitive to temperature changes than the emerging and high-income countries. This is particularly true for low income economies according to column (5) of Table 2. 4 where the coefficient is statistically significant at 5%-level and show a positive and important effect (β=1.563) of the variable Temp. This finding is consistent with some previous studies according to which, raising temperatures have been decreasing agricultural outputs in the sub-Saharan area (Adesina, 2010; Liu et al., 2008) and in tropical and semi tropical regions (Mohammed & Tarpley, 2009; Peng et al., 2004).

On the other hand, increased precipitation has weak yet positive impact on inefficiency scores of developing countries where the parameter estimate (β=0.0433) is statistically significant at 5%-level. The same variable decreases significantly (at 1%-level) but slightly the inefficiency in high-income and BRICS groups (β=-0.0241). This seems quite intuitive since wetlands require an excessive use of pesticides and fungicides (Chen et al., 2002; Wauchope, 1978). Our results suggest that developed and emerging countries control better this kind of sanitary risks compared to middle and low income economies.

In addition, parameter estimates of $Temp^2$ and $Precip^2$ remain statistically irrelevant according to columns (2) and (3) of Table 2. 3. This would suggest that the non-linearity of the relationship between rainfall, temperature and the inefficiency cannot be verified in our case.

Further results suggest that public expenditures on environmental measures (I-Env) are determinant for the agri-environmental inefficiency of developing countries (column (3), Table

2. 3). The parameter estimate is negative (β = -0.49) and statistically significant at 5%-level. This would indicate that increasing public investments reduce highly and significantly the agri-environmental inefficiency in low and middle income countries.

The effect is similar, yet lower in the BRICS and high income countries (β = -0.0022) and the coefficient is significant at 10%-level. In fact, the result coincides with the findings of section 2.2. The latter show that environmental policies of southern countries are characterized by the overwhelming presence of public authorities. Conversely, developed countries rely more likely on private means and devices like payments for environmental services programs (Bertke & Marggraf, 2005; Perrot-Maître, 2006; Turpie et al., 2008).

Finally, public expenditures on Research and Development (I-R&D) do not have a significant impact on the agri-environmental performance according to Table 2. 3, regardless of the country-group.

2.5.3. Is agricultural trading good for the environment?

In this section, we explore how international agricultural trade can steer domestic agri-environmental policies. Interestingly, Table 2. 3 shows that the revealed comparative advantage index (RCA) for crop commodities' exports significantly reduces the environmental inefficiency of the entire sample. The parameter estimate reported in column (1) is negative (β= -0.162) and statistically significant at 10%-level. However, the degree of trade openness (OD) does not have a significant impact on the agri-environmental performance of the overall sample according to our findings.

Surprisingly, Table 2. 3 shows that the revealed comparative advantage index is determinant for the environmental performance despite the income heterogeneity of countries. Results of column (3) show that the estimated coefficient (β= -0.25) is negative and statistically significant at 5%-level. This would suggest that the specialization in exporting agricultural products reduces significantly the agri-environmental inefficiency in developing countries. The same, yet lower, impact (β= -0.00376) is noticed for the BRICS and high income countries (column (2)). Accordingly, developed and emerging countries specialized in crop commodities' exports have been enhancing their environmental performance.

In addition, estimators of the degree of trade openness back up these findings when we consider the income heterogeneity of countries. Column (3) of Table 2. 3 shows that the variable affects significantly (at 1%-level) and negatively (β= -0.09) the inefficiency of developing countries. Additionally, trade openness has similar, yet lower impact (β= -0.0013) on the BRICS and high income countries' inefficiency.

So far, our findings show that international trade features are determinant for the environmental performance. The negative effect of RCA and trade openness indicators on the truncated variable means that trade can directly and positively affect domestic agri-environmental policies whether in developed or developing countries. That is to say, trade openness and the specialization in agricultural exports are enhancing countries to upgrade their environmental regulations and, accordingly, the stringency of their policies.

In sum, our results are quite explicit: openness to trade offers clearly opportunities for sustainable development especially in developing countries. It effects the manner in which commodities are produced and the existence of substances in food that are perceived to be unsafe, including those purposefully used in crops (e.g. pesticides). This is a major result of our study since it implies that trade openness and the specialization in crop commodities' exports enhance low and middle income countries to upgrade their agri-environmental regulations and to adapt their environmental policies. On the opposite of the race-to-the-bottom theories, these findings confirm the environmental gains-from-trade hypothesis which suggests that agricultural- exporting countries feature higher environmental performances and that globalization stimulates innovations and environmental regulations.

2.5.4. Environmentally-related NTMs and the "Race to the Top" phenomenon

Model (2.17) allows us to extend the analysis by investigating the effect of another feature of international agricultural trade on the environmental efficiency. To that end, we introduce the environmentally-related NTMs from the agreement on agriculture, namely the SPS and TBT measures.

Overall results are reported in column (1) of Table 2. 4. The parameter estimate of the cumulative number of endured SPS measures is negative (β= -0.21) and statistically insignificant. Similarly, the coefficient of TBT variable (β= -0.66) is not statistically different from zero. This would suggest that the environmentally-related NTMs imposed on agricultural exports are not determinant for the agri-environmental performance of the whole sample. In this regard, we must proceed with a finer analysis. To that end, columns (2) and (3) of Table 2. 4 report the results of high income and BRICS as well as developing countries, respectively.

Results of column (2) show that SPS and TBT parameter estimates are negative (-0.0111 and -0.416, respectively) and statistically relevant at 5%-level. Accordingly, endured technical measures decrease significantly the agri-environmental inefficiency in countries like Brazil, India and China in addition to developed economies as highlighted in the section 2.5.1.

Regarding middle and low income economies (column (3)), results are not conclusive since coefficients of the two variables of interest (β_5=-0.00988 and β_6= -0.0201) are statistically

irrelevant. Accordingly, the next step is the estimation of Eq. (2.17) according to the following sub-samples: middle income (column (4)) and low income economies (column (5)).

Results of column (4) show some interesting results related to the group of middle income countries. In fact, both of SPS and TBT parameter estimates (-0.0984 and -0.0493, respectively) are statistically significant at 5%-level and have negative signs. Accordingly, the more middle income countries are subject to environmentally-related measures, the less agri-environmentally inefficient they are. This finding can explain the favorable ranking (section 2.5.1) of southern countries (like Turkey, Armenia and Bangladesh) as well as several CAIRNS members, namely Argentina, Colombia, Costa Rica, Indonesia, Malaysia, Pakistan, Paraguay, Thailand and Vietnam.

On the other hand, a different trend applies to low income economies. According to the results of column (5), the cumulative number of endured SPS measures records a positive (β= 0.195) and statistically significant coefficient at 1%-level. Similarly, the parameter estimate of TBT variable is relevant (at 1%-level) and shows a positive sign (β= 0.143). This would suggest that environmentally-related NTMs imposed on agricultural exports of low income countries increase highly and significantly their environmental inefficiency.

According to Table A2. 1 in the Appendix of chapter 2 (A2), LI group is mostly composed of African countries. The vulnerability of their performance toward technical NTMs may be explained by the weight of the agricultural sector in their economy. The more their products are affected by TBT and SPS restrictions, the less their agricultural exports will be (Kareem et al., 2015, 2017; Otsuki et al., 2001a, 2001b; Scheepers et al., 2007) and the less likely they will be able to promote their primary sector (Diao et al., 2010; OECD & FAO, 2016). We thereby conclude that the least developed economies are trapped in a vicious circle which may explain the low AEE scores recorded by countries like Benin, Burkina Faso, Burundi, Ethiopia, Gambia, Madagascar and Zimbabwe over the period 2003-2013.

To sum up, our findings suggest that SPS and TBT measures do affect the agri-environmental performance. In addition, they turn out to be levers for enhancing environmental regulations not only of northern countries but also of the BRICS and middle income economies. This is a second major result of our study suggesting that environmentally-related NTMs do stimulate environmental protection in developing countries. This led to the convergence of their domestic standards at a higher level to meet their partners' requirements, confirming therefore the race to the top hypothesis. However, low income economies feature decreasing performance due to technical NTMs. Southern countries show clearly mixed results that merit further investigation. In the next section we perform a number of robustness checks to see how our results hold using new regressors and to deal with potential endogeneity problem between AEE scores and technical NTMs.

Table 2. 4. Effects of technical NTMs on the environmental performance

	Dependent: agri-environmental inefficiency (AEI)				
	(1)	(2)	(3)	(4)	(5)
VARIABLES	ALL	HI & BRICS	MI & LI	MI	LI
Temp	0.167	0.0100	0.332**	0.0902**	1.563**
	(0.320)	(0.0149)	(0.361)	(0.110)	(0.790)
Precip	0.00237*	-0.00226**	0.00119	0.00283	0.118
	(0.00710)	(0.00129)	(0.00461)	(0.00174)	(0.0502)
I-Env	-0.341	-0.0103**	-0.0719**	-0.299*	-1.906**
	(0.396)	(0.0358)	(0.215)	(0.169)	(0.790)
RCA	-0.00511	-0.0058***	-0.00794	-0.0428*	-0.0259**
	(0.00770)	(0.000500)	(0.00666)	(0.00249)	(0.0252)
SPS	**-0.210**	**-0.0111****	**-0.00988**	**-0.0984****	**0.195*****
	(0.111)	(0.0128)	(0.0150)	(0.0263)	(1.010)
TBT	**-0.660**	**-0.416****	**-0.0201**	**-0.0493****	**0.143*****
	(0.369)	(0.851)	(0.978)	(0.312)	(0.312)
Constant	0.935*	0.418***	0.117**	0.109**	-0.0214**
	(0.063)	(0.210)	(0.568)	(0.043)	(0.930)
Number of groups	108	46	62	49	13
Observations	1167	505	662	522	140
Country FE	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes

Source: own calculations. This table reports estimations of double bootstrapped truncated model. Dependent variable is the agri-environmental inefficiency score. All models contain year dummies for 2003 through 2013 and country fixed effects. Income heterogeneity of countries is considered: LI (low income), MI (middle income), BRICS (group of emerging countries composed of Brazil, Russia, India, China and South Africa), HI (high income) countries. Bootstrap standard errors in parentheses. *, **, ***: significance at the 10, 5 and 1 % levels, respectively.

2.5.5. Robustness check

Table A2. 4 in the Appendix of chapter 2 (A2) provides detailed information about the way phytosanitary norms (SPS) affect the agri-environmental performance using interaction variables[20] to check the consistency of Eq. (2.17). The results diverge according to the group of countries by income and back up the previous findings. All income groups exhibit a negative specific effect except for low income countries. At the same time, we note that the average effects of endured SPS on the inefficiency are negative and statistically significant at 10%-level.

Regarding the specific effects of TBT measures, results are reported in Table A2. 5 in the Appendix of chapter 2 (A2) where we introduce the same interaction variables [21] to Eq. (2.17). The average effect of TBT measures on the agri-environmental performance is negative and statistically significant at 10%-level. However, specific effects are above average for low income countries whereas high income, the BRICS and middle income countries exhibit negative specific effects.

This is an additional major result of our study since it implies that increasing endured technical NTMs deteriorate the environmental performance (increase the agri-environmental inefficiency) of low income agro-producers. This means that environmentally related NTMs do not attend their overall objective: while they protect, from an environmental point of view, the consumers of importing countries, they do not improve the environmental performance for low income producers.

In sum, NTMs have a diverging impact on southern farmers. While some producers, usually the largest ones, manage to adapt to the new environmental norms for exporting crops (mainly in emerging and middle income countries), smaller-size producers do not have the means to attend such goals. This explains why SPS and TBTs feature opposite effects on low and middle income countries. The reaction function of low income countries is not as expected: instead of adapting to the new standards and improving their environmental performance, they develop alternative strategies which appear to be less environmental friendly. The latter aim in compensating income losses from crop commodities' export and to combat the prevailing food

[20] We add four variables to Eq. (2.17) to capture the specific effects of endured SPS measures by high income (SPS*HI), the BRICS (SPS*BRICS), middle income (SPS*MI) and low income (SPS*LI) countries. HI takes the value 1 if the country's income group is high income, and 0 elsewhere. BRICS takes the value 1 if the country is an emerging one, and 0 otherwise. MI is equal to 1 if the country is a middle income, and 0 otherwise. LI takes the value 1 if the country's income group is low income, and 0 otherwise. Formally:
$$AEI_{jt} = \beta_0 + \beta_1 Temp_{jt} + \beta_2 Precip_{jt} + \beta_3 I\text{-}Env_{jt} + \beta_4 RCA_{jt} + \beta_5 SPS_{jt} + \beta_6 SPS*HI_{jt} + \beta_7 SPS*BRICS_{jt}$$
$$+\beta_8 SPS*MI_{jt} + \beta_9 SPS*LI_{jt} + \sum_{j=1}^{n} \delta_j DMU_j + \sum_{t=1}^{T} \gamma_t year_t + \varepsilon_{jt}$$

[21] Formally:
$$AEI_{jt} = \beta_0 + \beta_1 Temp_{jt} + \beta_2 Precip_{jt} + \beta_3 I\text{-}Env_{jt} + \beta_4 RCA_{jt} + \beta_5 TBT_{jt} + \beta_6 TBT*HI_{jt} + \beta_7 TBT*BRICS_{jt}$$
$$+\beta_8 TBT*MI_{jt} + \beta_9 TBT*LI_{jt} + \sum_{j=1}^{n} \delta_j DMU_j + \sum_{t=1}^{T} \gamma_t year_t + \varepsilon_{jt}$$

insecurity. Meanwhile, African exports have been witnessing a diversion away from high income countries like the EU and North America to inter-regional and other southern destinations that impose less environmentally-related measures (Amanor & Chichava, 2016). Besides, the increasing inefficiency could be due to slow productivity growth associated with smallholder farming, poor soils and low diffusion of new technologies (Buerkert et al., 2001; Johnson & Evenson, 2000; Mrema et al., 2008; Nziguheba et al., 2016; Sanchez et al., 2009; Staatz & Dembélé, 2008).

Although the BRICS and MI countries face increasingly strict SPS and TBT standards in their export markets, they improve domestic food safety and agricultural productivity by adopting a strategic approach to sustainable agricultural productivity. This can maintain and improve their market access and seize the fast-growing demand of high income countries that offers eventually high returns, export market development, rural income generation and growth for emerging and middle income countries.

The exposure to technical NTMs (originally imposed to address market failure in response to global social activism regarding environmental and health issues) seems to motivate emerging and middle income countries to self-regulation to promote their competitive advantage through quality signals. SPS and TBT regulatory requirements of export markets act as catalysts to develop farmers' capacity-building (Henson & Humphrey, 2009; WTO, 2005) and help suppliers improve the quality of their products to gain access to high-quality markets.

This idea is supported by some experiences. First, Jaffee (2003) highlights how rising technical standards have posed challenges to the Kenyan fresh produce industry. Henson and Jaffee (2004) argue how Peru has positioned itself as a globally competitive exporter of fresh and processed asparagus through concerted efforts to upgrade food safety capacity in line with the standards of industrialized countries. Finally, the study conducted by UNCTAD (2007) shows how Thailand, Malaysia and Vietnam, that were proactive in introducing technical standards, have easily complied with developed countries' standards.

However, Jaffee (2003) argues that many of the original exporters of fresh vegetables have left the sector, which has been progressively dominated by large firms. This reflects economies of scale in processes of compliance and indicates that the costs of complying with regulatory requirements and the additional cost of certification can be a problem especially for smallholder farmers in low income countries. According to Siméon (2006), too many of the less-developed countries lack capacity to manage food safety and agricultural health risks effectively. Small countries suffer special constraints due to their limited institutional capacity, human resources, and also because they have to bear higher per capita costs of public investments than larger countries.

Such small countries tempted to explore whether some activities can be shared at regional level. As argued in section 2.2, Benin, Burkina Faso and Mali adopted a common environmental improvement policy in 2008 to harmonize their environmental standards and technical regulations (WTO, 2019). In turn, the West African Economic and Monetary Union has adopted in 2007 a framework for animal health and food safety to align their sanitary measures on international directives (the Codex Alimentarius and the international plant protection convention). However, such cooperation are set by the subsidiarity principle and are not as efficient as national bodies.

As a final sensitivity analysis, we try to answer the following question: Are the lowest imposers of technical NTMs the least agri-environmentally efficient. We initially assume that all the technical NTMs that feature in the Agreement on Agriculture of the World Trade Organization are environmentally-related (Fontagné et al., 2005; Fontagné & Mimouni, 2001). This implies that SPS and TBT defenders are the most agri-environmentally efficient countries and this should be the case for the European Union. The latter is considered as one of the strongest users of NTMs but also as one of the least affected regions by these measures (Beestermöller et al., 2018; Fontagné et al., 2005; UNCTAD, 2018).

In this regard, we consider the European Union as the reference region and examine the impact of the gap[22] of imposed NTMs between the EU and any other country j on its AEI_{jt} score. The identified gaps are proxies aiming to capture the environmental norms' divergence or convergence to the EU standards. Additionally, we can test whether they represent legitimate environmental and food safety measures or hidden protectionist procedures in the trade of crop commodities.

[22] The first gap (i.e. $|Gap_{EU/SPSjt}|$) measures the absolute value of the difference between the total imposed SPS measures of the EU and those imposed by a country j. The second gap term (i.e. $|Gap_{EU/TBTjt}|$) considers the absolute value of total TBT measures' differential. To control for the signs of the gaps, we introduce a set of discrete variables denoted $SignGap_{EU/\ldots}$ that take value 1 if $Gap_{EU/\ldots} > 0$ and 0 otherwise. Formally, we estimate the following model:

$$AEI_{jt} = \beta_0 + \beta_1 Temp_{jt} + \beta_2 Precip_{jt} + \beta_3 I\text{-}Env_{jt} + \beta_4 RCA_{jt} + \beta_5 |Gap_{EU/SPSjt}| + \beta_6 SignGap_{EU/SPSjt} + \beta_7 |Gap_{EU/TBTjt}| + \beta_8 SignGap_{EU/TBTjt} + \sum_{j=1}^{n} \delta_j DMU_j + \sum_{t=1}^{T} \gamma_t year_t + \varepsilon_{jt}$$

Where

$$Gap_{EU/SPSjt} = |SPS_{EUt} - SPS_{jt}|$$

$$Gap_{EU/TBTjt} = |TBT_{EUt} - TBT_{jt}|$$

$$SignGap_{EU/\ldots jt} = \begin{cases} 0 \text{ if } Gap_{EU/\ldots jt} \geq 0 \\ 1 \text{ otherwise} \end{cases}$$

Table A2. 6 in the Appendix of chapter 2 (A2) shows that the results are mixt. The parameter estimates of both SPS and TBT gap measures are positive but statistically insignificant for the full country sample (columns (1)-(2)), the BRICS and HI economies (columns (3)-(4)) as well as middle income countries (columns (5)-(6)). This would suggest that emerging, middle income and other high income countries that are imposing less TBT and SPS measures than the EU are not necessarily the least agri-environmentally inefficient. Imposed technical NTMs by the EU on these producers are therefore susceptible to be disguised protectionism measures as suggested by Markovic and Markovic (2014) as well as Tagliabue (2017).

Additionally, the parameter estimates reported in columns (7) and (8) suggest that the less a low income country imposes NTMs, the more agri-environmentally inefficient it is. Basically, this implies that technical NTMs imposed by the EU on low income countries are in line with their environmental grounds stated by the WTO.

A plausible explanation could be that low income countries don't manage to enhance the environmental standards because they lack subsequent investment in Research and Development (Juma, 2015; Mrema et al., 2008). Although most of them have ratified several environmental international agreements to promote sustainable development in the primary sector, low investment and inadequate technologies lead then to a race-to-the-bottom strategy. The weight of the primary sector in their economies allows no alternatives but to follow a low road of sustainable development.

2.6. Conclusions and policy implications

This chapter aims to shed light on some of the key questions arising from agricultural policies, trade and environmental issues by providing additional empirical evidence. To that end, we investigate the stringency of the greening agricultural reforms that took place in a large sample of 108 countries over the period 2003-2013.

Our study is based on a two-step super-efficiency DEA model developed by Andersen and Petersen (1993) and based on the fundamental work of Farrell (1957). First, we use time-varying data and undesirable output to compute the efficiency scores following the method of Seiford and Zhu (2002).

We employ in the second step the double bootstrapped truncated regression suggested by Simar and Wilson (2007) to conduct a sensitivity analysis and test the effect of a wide range of variables on the agri-environmental performance. In this model, we consider the income heterogeneity of countries and control for country-specific unobserved heterogeneity.

Our findings show that agricultural trade liberalization can directly and positively affect the agri-environmental performance, suggesting that trade openness and the specialization in agricultural exports are inciting southern and northern countries to upgrade the stringency of

their environmental regulations. This confirms the environmental gains-from-trade hypothesis and highlights the positive impact of globalization on environmental regulations.

In this chapter, we have also explored the effect of technical NTMs on the environmental performance. As highlighted in Chapter 1, they represent a major feature of international agricultural trade that happens to be environmentally-related and intimately linked to crop production. However, results are mixed.

First, increasing SPS and TBT measures have a negative incidence on the agri-environmental performance of low income countries. Their agricultural development depends on their exporting capacity which is highly restricted by technical NTMs. We thereby conclude that the least developed economies are trapped in a vicious circle.

On the other hand, technical barriers to trade and sanitary and phytosanitary norms affect positively the agri-environmental performance of developed, middle income and emerging countries. This would suggest that environmentally related measures stimulate the environmental protection. Technical NTMs have led these countries to harden their domestic standards in order to meet their partners' requirements.

The second chapter provides efficient supports for policy-makers to pursue discussions and negotiations of new trade agreements in a framework where the Doha round stalls (Martin & Mercurio, 2017; Wilkinson et al., 2016). In fact, agricultural multilateral trade negotiations under the Doha development agenda relate less to environmental issues and more to food security and market access of developing countries (Bellmann, 2014). Although the Nairobi outcome (2015) has energized the Doha round, the future for the multilateral trading system is questioned by several scholars in the absence of a universal endeavor. Martin and Mercurio (2017) argue that the Nairobi ministerial has marked the end of the Doha round. They suggest that the inability of WTO members to reach a comprehensive agreement is likely to foster plurilateral agreements (e.g. FTA, PTA, etc.) at the expense of the single undertaking and the multilateral level.

In this regard, environmental issues are usually the main cut-off points during the negotiation of new trade agreements, especially when partners conduct heterogeneous environmental regulations. A key example is the European Union that stays reluctant to open up its market to the Mercosur products. Although they have reached agreement in 2019 after twenty years of negotiations, final texts have not entered into force yet. The main argument of the EU is the potential environmental drawbacks of such agreement on the Amazon rainforest. Similarly, the Transatlantic Trade and Investment Partnership's negotiation was stalling for environmental reasons related to agricultural commodities.

In light of the above findings, policy makers need to consider that trade liberalization is demonstrated as a catalyst for important agri-environmental reforms, especially in southern countries and can consequently strengthen their environmental regulations.

Furthermore, the overall increase of environmentally-related NTMs against tariff dismantling has aligned several southern exporting countries with their partners' strict norms inducing a race to the top phenomenon in their domestic standards. Accordingly, trade agreements appear as an opportunity to beneficially reorient domestic agricultural policies of exporting countries towards environmental protection, at least for the sector of crop commodities.

Obviously, productivity gains from improved control of crop production may benefit the rural development and achieve the expected results in emerging and middle income countries. However, a strategy that sets higher standards might have damaging impacts on poorer producers. Controls set by the SPS and TBT standards, if not designed with small producers in mind, are likely to favor large-scale production units. The problems are particularly difficult in areas of market failure, and specific support needs to be provided in research, surveillance systems, monitoring and capacity building in risk assessment given the lack of institutional and financial capacity in LI countries.

Low income countries faced with rising technical NTMs in their export markets need to enhance their market access by improving agricultural productivity in a sustainable manner. Policy makers must recognize the key importance of the environmental issues in the implementation of any agricultural policy. They also need to participate in international standard-setting bodies such as the Codex Alimentarius Commission.

In Chapter 3, we will deeply examine the question of agricultural trade and environmental regulation using the computed agri-environmental efficiency scores.

2.7. Appendix of chapter 2 (A2)

Table A2. 1. Country list

Income Group	Countries
High income countries & BRICS	Argentina, Australia, Austria, Belgium, Canada, Chile, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Israel, Italy, Japan, Latvia, Lithuania, Luxembourg, Malta, Netherlands, New Zealand, Norway, Oman, Poland, Portugal, Republic of Korea, Saudi Arabia, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom, United States of America, Uruguay, Bolivarian Republic of Venezuela, Brazil, China, India, Russian Federation and South Africa.
Upper and lower middle income countries	Albania, Algeria, Armenia, Azerbaijan, Bangladesh, Belarus, Belize, Bolivia, Bosnia and Herzegovina, Bulgaria, Cameroon, Colombia, Costa Rica, Côte d'Ivoire, Dominican Republic, Ecuador, Egypt, El Salvador, Georgia, Ghana, Guatemala, Honduras, Indonesia, Jamaica, Jordan, Kazakhstan, Kenya, Lebanon, Libya, Malaysia, Mexico, Morocco, Namibia, Nigeria, Pakistan, Panama, Paraguay, Peru, Philippines, Romania, Senegal, Syrian Arab Republic, Thailand, Tunisia, Turkey, Ukraine, Vietnam, Yemen, Zambia
Low income countries	Benin, Burkina Faso, Burundi, Cambodia, Ethiopia, Gambia, Madagascar, Mozambique, Niger, United Republic of Tanzania, Togo, Uganda, Zimbabwe

Source: the table is made by the author based on the World Bank classification (World Bank, 2019b).

Table A2. 2. Windows breakdown

DEA windows	Windows' width									
window 1	2003	2004								
window 2	2003	2004	2005							
window 3		2004	2005	2006						
window 4			2005	2006	2007					
window 5				2006	2007	2008				
window 6					2007	2008	2009			
window 7						2008	2009	2010		
window 8							2009	2010	2011	
window 9								2010	2011	2012
window 10									2011	2012	2013
window 11										2012	2013

Source: own calculations.

Table A2. 3. Computed agri-environmental efficiency (AEE) scores

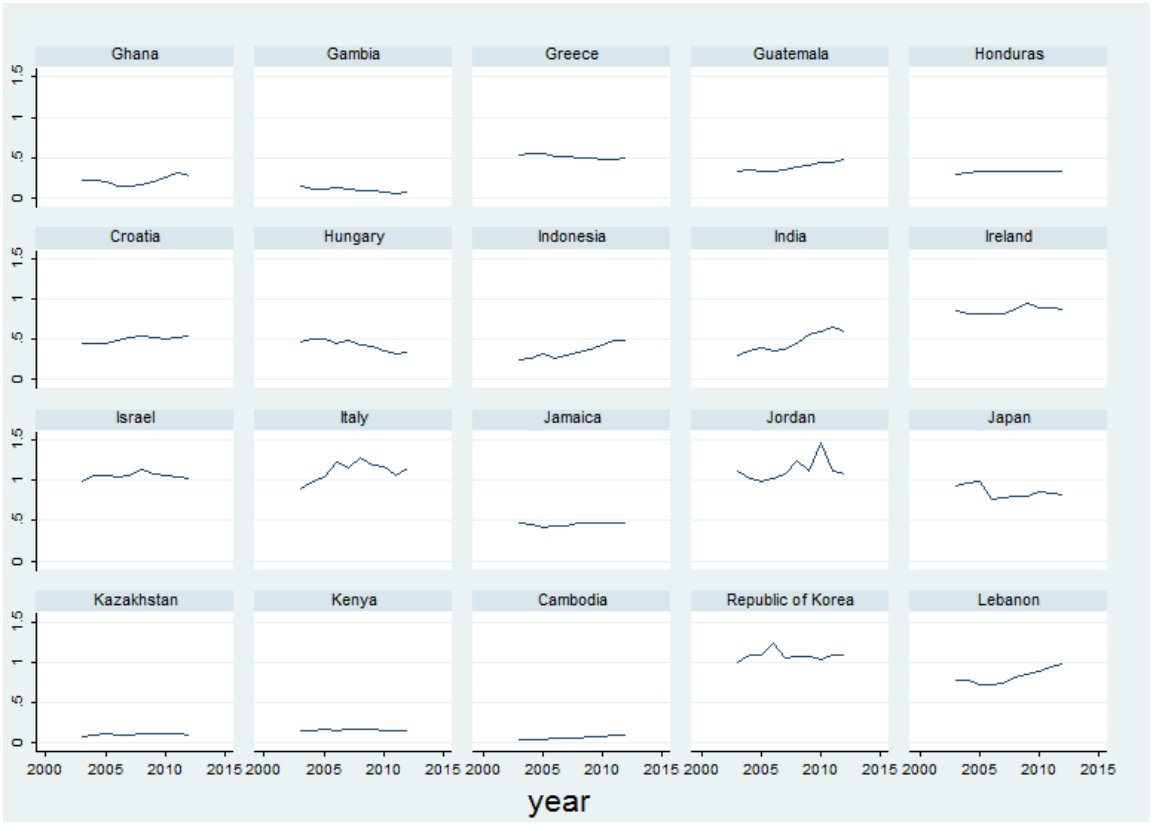
country	ISO3	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Albania	ALB	0.16	0.17	0.17	0.18	0.18	0.20	0.21	0.21	0.22	0.22	0.22
Algeria	DZA	0.16	0.20	0.20	0.19	0.19	0.20	0.23	0.26	0.28	0.31	0.35
Argentina	ARG	0.91	1.04	1.05	1.15	1.18	1.06	1.03	1.01	0.90	1.06	2.37
Armenia	ARM	0.19	0.23	0.24	0.28	0.29	0.31	0.31	0.30	0.29	0.31	0.32
Australia	AUS	0.41	0.48	0.50	0.41	0.41	0.39	0.44	0.47	0.55	0.55	0.58
Austria	AUT	0.54	0.50	0.49	0.48	0.50	0.52	0.52	0.49	0.48	0.49	0.52
Azerbaijan	AZE	0.11	0.12	0.11	0.12	0.12	0.13	0.13	0.14	0.15	0.16	0.17
Bangladesh	BGD	0.18	0.22	0.24	0.21	0.23	0.26	0.29	0.33	0.33	0.35	0.38
Belarus	BLR	0.24	0.30	0.38	0.41	0.43	0.45	0.48	0.50	0.49	0.49	0.51
Belgium	BEL	1.20	1.09	1.04	1.17	1.05	1.11	1.13	1.04	1.02	1.06	2.49
Belize	BLZ	0.92	0.79	0.72	0.75	0.72	0.74	0.72	0.71	0.69	0.71	0.72
Benin	BEN	0.12	0.08	0.05	0.04	0.04	0.06	0.08	0.10	0.10	0.09	0.08
Bolivia	BOL	0.16	0.18	0.19	0.18	0.18	0.18	0.18	0.18	0.18	0.19	0.22
Bosnia&Herz	BIH	0.13	0.21	0.23	0.24	0.24	0.28	0.29	0.29	0.29	0.29	0.29
Brazil	BRA	0.74	0.72	0.68	0.67	0.73	0.80	0.86	0.89	0.98	1.06	1.25
Bulgaria	BGR	0.30	0.26	0.27	0.28	0.30	0.31	0.32	0.33	0.34	0.37	0.40
Burkina Faso	BFA	0.07	0.09	0.10	0.10	0.09	0.06	0.05	0.05	0.07	0.07	0.08
Burundi	BDI	0.16	0.16	0.15	0.15	0.15	0.16	0.17	0.17	0.14	0.14	0.16
Cote d'Ivoire	CIV	0.12	0.12	0.11	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.13
Cambodia	KHM	0.03	0.04	0.04	0.05	0.06	0.06	0.07	0.08	0.09	0.10	0.11
Cameroon	CMR	0.11	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.14	0.16
Canada	CAN	0.83	0.90	0.96	0.82	0.80	0.87	0.90	0.85	0.86	0.88	0.99
Chile	CHL	0.69	0.77	0.82	0.77	0.84	0.89	0.92	0.91	0.85	0.89	1.01
China	CHN	0.94	0.97	0.95	0.95	0.94	1.09	0.97	0.96	0.98	0.97	1.00
Colombia	COL	0.59	0.65	0.73	0.64	0.68	0.67	0.70	0.79	0.83	0.94	1.15
Costa Rica	CRI	0.97	1.05	1.12	1.06	1.05	1.06	1.08	1.07	1.04	1.03	1.90
Croatia	HRV	0.44	0.44	0.45	0.48	0.53	0.53	0.52	0.50	0.52	0.53	0.57
Cyprus	CYP	0.59	0.59	0.57	0.56	0.60	0.65	0.70	0.69	0.71	0.71	0.75
Czechia	CZE	0.36	0.40	0.43	0.43	0.45	0.40	0.40	0.38	0.37	0.39	0.43
Denmark	DNK	0.64	0.70	0.83	0.83	0.89	0.81	0.82	0.79	0.75	0.75	0.84
Dominican Rep.	DOM	0.31	0.32	0.32	0.34	0.36	0.37	0.39	0.40	0.41	0.42	0.44
Ecuador	ECU	0.72	0.71	0.63	0.56	0.52	0.49	0.53	0.58	0.56	0.55	0.59
Egypt	EGY	1.05	1.03	1.08	1.05	1.06	1.07	1.06	1.04	1.03	1.02	1.09
El Salvador	SLV	0.30	0.33	0.35	0.38	0.40	0.40	0.42	0.44	0.45	0.46	0.46
Estonia	EST	0.27	0.31	0.33	0.35	0.43	0.53	0.58	0.59	0.63	0.70	0.78
Ethiopia	ETH	0.04	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.07
Finland	FIN	0.47	0.49	0.56	0.56	0.57	0.51	0.49	0.46	0.44	0.45	0.52
France	FRA	1.01	1.05	1.04	0.99	1.07	1.11	1.05	1.02	1.01	1.04	1.34
Gambia	GMB	0.14	0.11	0.11	0.12	0.11	0.09	0.09	0.07	0.06	0.06	0.07
Georgia	GEO	0.12	0.20	0.21	0.20	0.19	0.24	0.26	0.30	0.32	0.38	0.44
Germany	DEU	0.84	0.92	0.97	0.92	0.98	1.04	1.06	1.02	1.02	1.01	1.21
Ghana	GHA	0.21	0.22	0.19	0.14	0.14	0.16	0.20	0.26	0.31	0.28	0.22

Greece	GRC	0.52	0.55	0.55	0.51	0.51	0.49	0.49	0.48	0.48	0.49	0.52
Guatemala	GTM	0.33	0.35	0.33	0.32	0.34	0.38	0.40	0.43	0.45	0.48	0.57
Honduras	HND	0.29	0.32	0.32	0.33	0.33	0.33	0.33	0.32	0.33	0.34	0.36
Hungary	HUN	0.47	0.50	0.51	0.45	0.48	0.43	0.40	0.36	0.32	0.34	0.37
India	IND	0.30	0.36	0.38	0.35	0.37	0.45	0.55	0.60	0.64	0.60	0.61
Indonesia	IDN	0.23	0.27	0.31	0.26	0.30	0.33	0.37	0.44	0.48	0.48	0.52
Ireland	IRL	0.85	0.82	0.82	0.82	0.82	0.86	0.94	0.89	0.89	0.87	0.88
Israel	ISR	1.00	1.06	1.06	1.03	1.07	1.14	1.08	1.06	1.05	1.03	1.69
Italy	ITA	0.90	0.99	1.03	1.23	1.16	1.29	1.20	1.17	1.06	1.15	1.68
Jamaica	JAM	0.47	0.45	0.42	0.43	0.43	0.47	0.47	0.47	0.47	0.47	0.48
Japan	JPN	0.93	0.96	0.98	0.76	0.78	0.81	0.80	0.87	0.83	0.82	0.88
Jordan	JOR	1.11	1.03	0.99	1.03	1.07	1.24	1.11	1.46	1.11	1.08	1.70
Kazakhstan	KAZ	0.07	0.10	0.11	0.09	0.10	0.11	0.12	0.10	0.10	0.10	0.11
Kenya	KEN	0.15	0.15	0.16	0.15	0.16	0.17	0.17	0.16	0.15	0.15	0.17
Latvia	LVA	0.45	0.42	0.41	0.42	0.47	0.49	0.51	0.50	0.52	0.55	0.64
Lebanon	LBN	0.77	0.78	0.72	0.73	0.74	0.82	0.84	0.88	0.93	0.97	1.05
Libya	LBY	0.10	0.15	0.17	0.16	0.15	0.16	0.16	0.16	0.16	0.17	0.17
Lithuania	LTU	0.32	0.34	0.36	0.36	0.45	0.45	0.47	0.45	0.43	0.45	0.52
Luxembourg	LUX	1.02	1.07	1.10	1.08	1.06	1.11	1.10	1.08	1.07	1.05	2.87
Madagascar	MDG	0.06	0.06	0.07	0.08	0.08	0.08	0.09	0.09	0.09	0.10	0.11
Malaysia	MYS	0.50	0.58	0.62	0.85	0.94	1.03	1.06	1.03	1.05	1.03	1.23
Malta	MLT	0.99	1.02	1.09	1.10	1.20	1.19	1.08	1.03	1.44	1.31	1.00
Mexico	MEX	0.44	0.45	0.46	0.38	0.39	0.40	0.42	0.43	0.45	0.46	0.51
Morocco	MAR	0.18	0.21	0.21	0.17	0.17	0.18	0.18	0.19	0.20	0.20	0.23
Mozambique	MOZ	0.08	0.08	0.08	0.08	0.08	0.07	0.05	0.03	0.03	0.05	0.09
Namibia	NAM	0.08	0.10	0.11	0.12	0.12	0.16	0.18	0.21	0.20	0.20	0.17
Netherlands	NLD	1.08	1.05	1.02	1.03	1.01	1.04	1.02	1.06	1.05	1.05	1.31
New Zealand	NZL	0.98	1.12	1.04	1.08	1.09	1.15	1.10	1.10	1.01	1.03	2.02
Niger	NER	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03
Nigeria	NGA	0.11	0.12	0.13	0.13	0.13	0.14	0.13	0.15	0.18	0.20	0.23
Norway	NOR	0.57	0.60	0.64	0.67	0.72	0.74	0.72	0.69	0.69	0.71	0.75
Oman	OMN	0.89	1.38	1.06	1.12	1.17	1.07	1.14	1.09	1.17	1.07	2.13
Pakistan	PAK	0.24	0.29	0.30	0.23	0.22	0.25	0.27	0.31	0.28	0.26	0.27
Panama	PAN	0.42	0.43	0.47	0.52	0.58	0.60	0.61	0.56	0.55	0.54	0.54
Paraguay	PRY	0.22	0.22	0.22	0.23	0.25	0.25	0.25	0.27	0.28	0.30	0.32
Peru	PER	0.85	0.80	0.74	0.60	0.48	0.32	0.26	0.26	0.26	0.27	0.32
Philippines	PHL	0.46	0.45	0.45	0.38	0.39	0.40	0.40	0.42	0.40	0.39	0.42
Poland	POL	0.48	0.53	0.58	0.56	0.58	0.59	0.61	0.64	0.66	0.67	0.70
Portugal	PRT	0.42	0.46	0.42	0.41	0.41	0.46	0.46	0.44	0.42	0.43	0.48
Rep. of Korea	KOR	0.99	1.08	1.08	1.24	1.05	1.06	1.07	1.02	1.09	1.09	1.28
Romania	ROU	0.19	0.20	0.21	0.17	0.18	0.19	0.21	0.22	0.25	0.27	0.29
Russia	RUS	0.13	0.13	0.14	0.15	0.18	0.20	0.20	0.18	0.20	0.23	0.25
Saudi Arabia	SAU	0.32	0.31	0.32	0.31	0.30	0.29	0.27	0.30	0.40	0.49	0.56
Senegal	SEN	0.10	0.11	0.11	0.11	0.10	0.10	0.09	0.09	0.10	0.11	0.12
Slovakia	SVK	0.47	0.52	0.62	0.63	0.68	0.66	0.69	0.66	0.65	0.65	0.71
Slovenia	SVN	0.83	0.81	0.81	0.89	0.93	0.98	0.95	0.95	0.97	0.97	0.95

South Africa	ZAF	0.23	0.26	0.27	0.22	0.24	0.26	0.29	0.32	0.34	0.34	0.35
Spain	ESP	0.92	0.87	0.85	0.84	0.87	0.84	0.87	0.90	0.93	0.95	1.10
Sweden	SWE	0.49	0.52	0.62	0.63	0.67	0.59	0.58	0.55	0.53	0.53	0.58
Switzerland	CHE	0.97	1.04	1.03	1.01	1.00	1.01	1.01	1.03	1.02	1.01	1.33
Syria	SYR	0.17	0.19	0.18	0.19	0.20	0.20	0.21	0.20	0.18	0.16	0.14
Tanzania UR	TZA	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.07	0.08
Thailand	THA	0.45	0.43	0.44	0.41	0.45	0.49	0.53	0.58	0.62	0.63	0.69
Togo	TGO	0.10	0.08	0.06	0.05	0.05	0.05	0.04	0.05	0.06	0.08	0.11
Tunisia	TUN	0.17	0.18	0.19	0.19	0.19	0.19	0.20	0.20	0.22	0.23	0.24
Turkey	TUR	0.45	0.50	0.52	0.55	0.63	0.65	0.68	0.71	0.69	0.72	0.83
Uganda	UGA	0.18	0.17	0.15	0.15	0.14	0.12	0.10	0.10	0.10	0.10	0.11
Ukraine	UKR	0.18	0.20	0.23	0.21	0.23	0.25	0.28	0.29	0.36	0.39	0.41
United Kingdom	GBR	0.96	1.00	0.98	0.85	0.82	0.66	0.70	0.68	0.89	0.87	0.88
USA	USA	0.94	1.26	1.50	1.08	1.14	1.13	1.10	1.22	1.04	1.06	3.12
Uruguay	URY	0.40	0.42	0.44	0.45	0.45	0.42	0.40	0.38	0.41	0.43	0.48
Venezuela	VEN	0.22	0.27	0.28	0.26	0.27	0.30	0.32	0.37	0.39	0.39	0.35
Vietnam	VNM	0.71	0.76	0.79	0.66	0.72	0.81	0.84	0.93	0.91	0.94	1.21
Yemen	YEM	0.14	0.14	0.14	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.15
Zambia	ZMB	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.15	0.16	0.17
Zimbabwe	ZWE	0.12	0.10	0.10	0.10	0.11	0.11	0.11	0.12	0.13	0.13	0.14
mean/year		0.45	0.48	0.48	0.47	0.49	0.50	0.50	0.51	0.51	0.52	0.67

Source: own calculations.

Figure A2. 1. Evolution of agri-environmental efficiency scores by country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Guatemala
Honduras
Croatia
Hungary
Indonesia
India
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Israel
Italy
Jamaica
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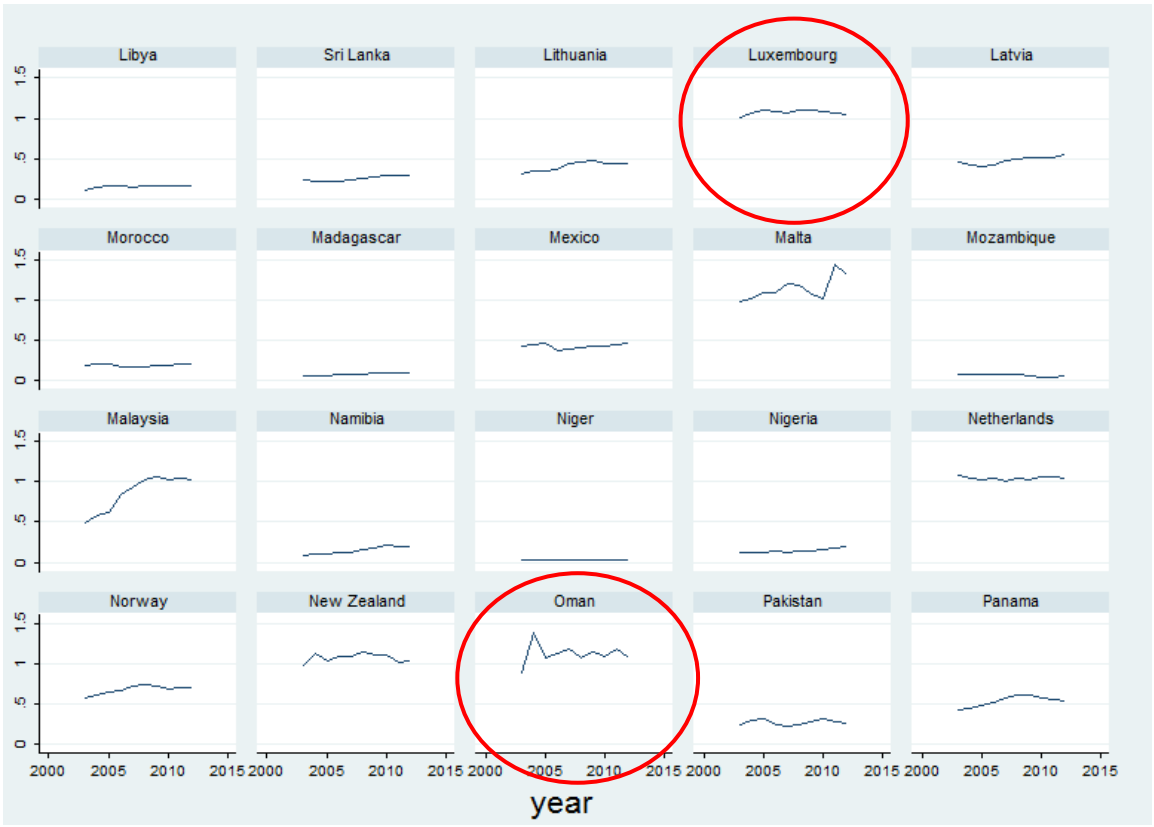
1
1.5
2000
2005
2010
2015
year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Lithuania
Luxembourg
Latvia
Morocco
Madagascar
Mexico
Malta
Mozambique
Malaysia
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Niger
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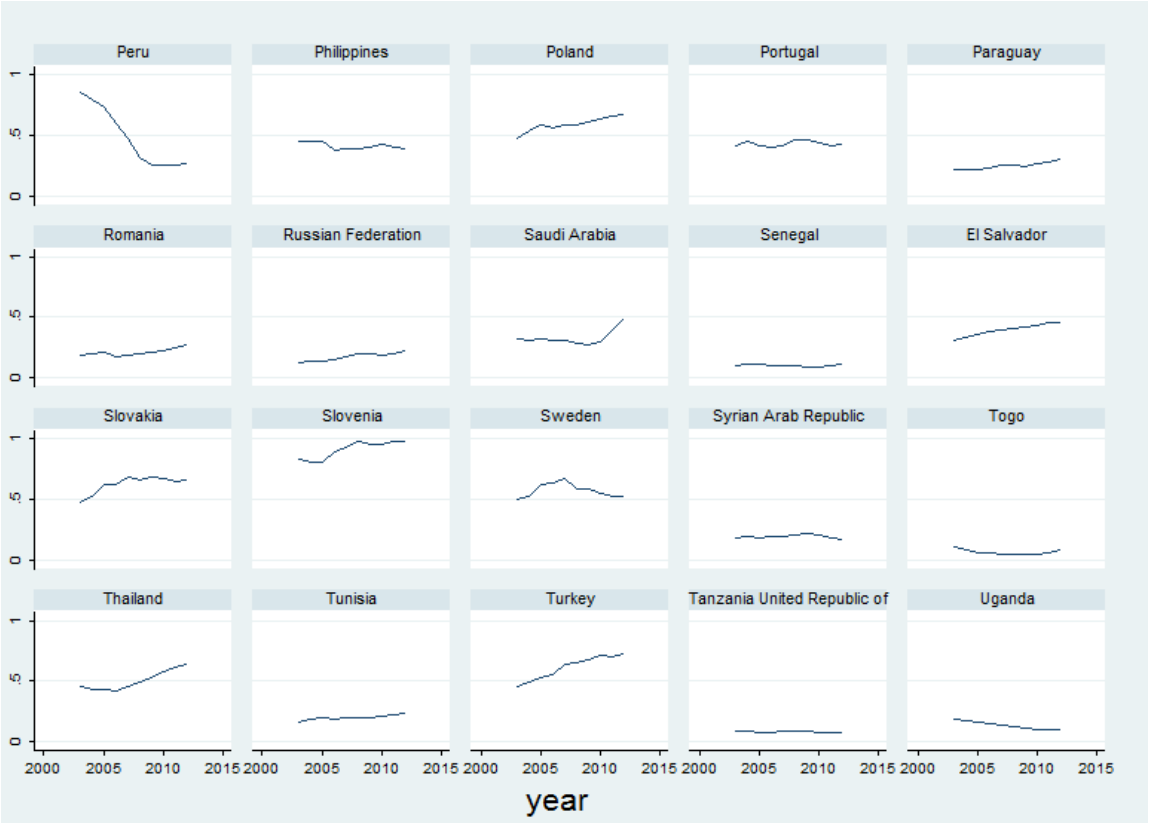
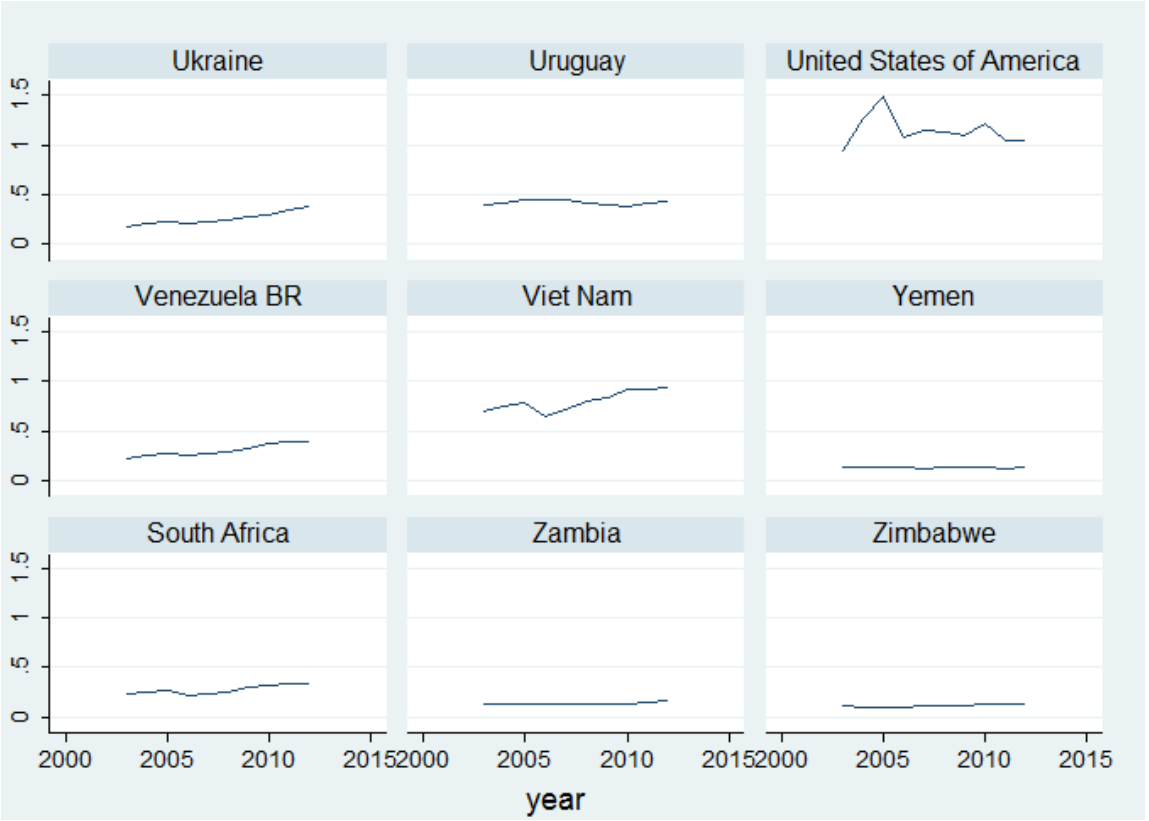
2005
2010
2015
year





Source: own calculations.

Table A2. 4. Robustness check

	Dependent: agri-environmental inefficiency (AEI)			
	(1)	(2)	(3)	(4)
VARIABLES	ALL	ALL	ALL	ALL
Temp	0.162	0.173	0.229	0.171
	(0.337)	(0.305)	(0.324)	(0.301)
Precip	0.00258	0.00237	0.00133	0.00159
	(0.00659)	(0.00646)	(0.00577)	(0.00532)
I-Env	-0.353**	-0.336**	-0.591**	-1.236***
	(0.418)	(0.373)	(0.414)	(0.474)
RCA	-0.00559**	-0.00518**	-0.00255**	-0.00122*
	(0.00804)	(0.00765)	(0.00854)	(0.00687)
SPS	-0.0151*	-0.0149*	-0.0145*	-0.0121*
	(0.116)	(0.123)	(0.127)	(0.122)
SPS*HI	-0.00235**			
	(0.00510)			
SPS*BRICS		-0.000704**		
		(0.00586)		
SPS*MI			-0.00608*	
			(0.00355)	
SPS*LI				0.017***
				(0.00611)
Constant	-1.366***	-1.767**	-1.245***	-1.956*
	(0.0887)	(3.160)	(1.099)	(1.079)
Number of groups	108	108	108	108
Observations	1167	1167	1167	1167
Country FE	yes	yes	yes	yes
Year FE	yes	yes	yes	yes

Source: own calculations. This table reports estimations of double bootstrapped truncated model. Dependent variable is the agri-environmental inefficiency score. All models contain year dummies for 2003 through 2013 and country fixed effects. We add four variables to model to capture the specific effects of endured SPS measures by high income (SPS*HI), the BRICS (SPS*BRICS), middle income (SPS*MI) and low income (SPS*LI) countries. HI takes the value 1 if the country's income group is high income, and 0 elsewhere. BRICS takes the value 1 if the country is an emerging one, and 0 otherwise. MI is equal to 1 if the country is a middle income, and 0 otherwise. LI takes the value 1 if the country's income group is low income, and 0 otherwise. Bootstrap standard errors in parentheses. *, **, ***: significance at the 10, 5 and 1 % levels, respectively.

Table A2. 5. Robustness check

	Dependent: agri-environmental inefficiency (AEI)			
	(1)	(2)	(3)	(4)
VARIABLES	ALL	ALL	ALL	ALL
Temp	0.170	0.173	0.206	0.179
	(0.333)	(0.320)	(0.355)	(0.301)
Precip	0.00250	0.00240	0.00201	0.00255
	(0.00582)	(0.00661)	(0.00603)	(0.00682)
I-Env	-0.350**	-0.336**	-0.552*	-1.084**
	(0.400)	(0.386)	(0.427)	(0.491)
RCA	-0.00558*	-0.00517**	-0.00275**	-0.0022**
	(0.00795)	(0.00762)	(0.00682)	(0.00757)
TBT	-0.0182*	-0.0178*	-0.0339*	-0.0929*
	(0.107)	(0.111)	(0.112)	(0.115)
TBT*HI	-0.00186**			
	(0.00368)			
TBT*BRICS		-0.00533***		
		(0.00534)		
TBT*MI			-0.00497***	
			(0.00361)	
TBT*LI				0.0144**
				(0.00578)
Constant	-0.699**	-2.414**	-2.521***	-2.553**
	(1.683)	(12.55)	(1.976)	(2.388)
Number of groups	108	108	108	108
Observations	1167	1167	1167	1167
Country FE	yes	yes	yes	yes
Year FE	yes	yes	yes	yes

Source: own calculations. This table reports estimations of double bootstrapped truncated model. Dependent variable is the agri-environmental inefficiency score. All models contain year dummies for 2003 through 2013 and country fixed effects. We add four variables to model to capture the specific effects of endured TBT measures by high income (TBT*HI), the BRICS (TBT*BRICS), middle income (TBT*MI) and low income (TBT*LI) countries. HI takes the value 1 if the country's income group is high income, and 0 elsewhere. BRICS takes the value 1 if the country is an emerging one, and 0 otherwise. MI is equal to 1 if the country is a middle income, and 0 otherwise. LI takes the value 1 if the country's income group is low income, and 0 otherwise. Bootstrap standard errors in parentheses. *, **, ***: significance at the 10, 5 and 1 % levels, respectively.

Table A2. 6. Sensitivity analysis

	Dependent: agri-environmental inefficiency (AEI)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	ALL	ALL	HI & BRICS	HI & BRICS	MI	MI	LI	LI
Temp	0.167	0.0918	0.0207	0.0141	0.0779**	0.0829*	0.328**	0.244**
	(0.302)	(0.303)	(0.0260)	(0.0302)	(0.116)	(0.108)	(0.521)	(0.466)
Precip	0.00226	0.00248	-0.000470	-0.00124	0.00267	0.00281	0.00206	0.00212
	(0.00672)	(0.00636)	(0.00209)	(0.00266)	(0.00171)	(0.00182)	(0.00793)	(0.00666)
I-Env	-0.158*	-0.160*	-0.0423**	-0.0337**	-0.332*	-0.311*	-0.385**	-0.382**
	(0.407)	(0.502)	(0.0571)	(0.0654)	(0.159)	(0.171)	(0.440)	(0.672)
RCA	-0.1535*	-0.1847*	-0.0394**	-0.0303***	-0.0415**	-0.0427**	-0.092**	-0.119**
	(0.00837)	(0.00758)	(0.000890)	(0.00899)	(0.00274)	(0.00277)	(0.0116)	(0.00903)
$\lvert GAP_{EU/SPS}\rvert$	0.0118		0.0261		0.00473		0.00883***	
	(0.0418)		(0.00554)		(0.0125)		(0.0811)	
$sign\_GAP_{EU/SPS}$	0.400		2.058		0.00834		0.159***	
	(2.835)		(0.209)		(0.584)		(6.202)	
$\lvert GAP_{EU/TBT}\rvert$		0.243		0.134		0.0368		0.291**
		(0.226)		(0.0607)		(0.0798)		(0.286)
$sign\_GAP_{EU/TBT}$		0.458		0.790		0.495		2.886***
		(1.380)		(0.226)		(0.289)		(1.890)
Constant	-2.648**	-1.252*	-2.505***	-1.664***	-3.723***	-1.618***	-3.931***	-2.075***
	(1.342)	(0.210)	(0.161)	(0.203)	(0.453)	(0.310)	(1.155)	(0.112)
Number of groups	108	108	46	46	49	49	13	13
Observations	1167	1167	505	505	522	522	140	140

Country FE	yes	yes	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes	yes	yes

Source: own calculations. This table reports estimations of double bootstrapped truncated model. Dependent variable is the agri-environmental inefficiency score. All models contain year dummies for 2003 through 2013 and country fixed effects. $|Gap_{EU/SPSjt}|$ measures the absolute value of the difference between the total imposed SPS measures of the European Union and those imposed by a country j. $|Gap_{EU/TBTjt}|$ considers the total TBT measures' differential's absolute value. To control for the signs of the gaps, we introduce a set of discrete variables denoted $SignGap_{EU/...}$ that take value 1 if $Gap_{EU/...} > 0$ and 0 otherwise. Bootstrap standard errors in parentheses. *, **, ***: significance at the 10, 5 and 1 % levels, respectively.

3. Chapter 3. The impact of environmental regulations on agricultural trade: New evidence from a gravity model

3.1. Introduction

The evolution of international trade and the competitiveness of different countries is particularly sensitive to a set of parameters that make up what is called the "trade costs" (Arvis et al., 2013). Inferred through the analysis of international trade flows via gravity models, these costs are specific to each country and its trade partner. They depend on their proximity captured by geographical distance, existence of a common border or contiguity, shared colonial history or a common language, etc.

Many studies have applied the gravity model to identify the determinants of agricultural trade. Huchet et al. (2015), Lambert and McKoy (2009), Grant and Lambert (2008) as well as Korinek and Melatos (2009) examine the impact of regional economic and preferential trade agreements on agricultural trade. Another set of studies investigated trade effects of exchange rates using augmented gravity models namely Achy and Sekkat (2003), Özbay (1999) and Vergil (2002). Additionally, border measures play a determining role in the evolution of these costs. In order to identify their trade effects, scholars like Fontagné et al. (2005), Disdier et al. (2007), Péridy and Ghoneim (2013), Ghali et al. (2013), Looi Kee and al. (2009) as well as Hoekman and Nicita (2008) attempted to characterize the impact of NTMs on agricultural flows using traditional gravity models.

In a world context of increasing interest about environmental issues, environmental policies tend to have some impacts on the level and pattern of trade. In theory, the Porter hypothesis (Porter, 1991; Porter & Van der Linde, 1995) states that environmental control costs halt the production of polluting outputs in countries with stringent environmental regulation. By contrast, countries that fail to undertake an environmental protection program presumably increase their comparative advantage in the production of items that damage the environment, supporting therefore the "pollution haven" hypothesis (Taylor, 2005).

To test the consistency of these assumptions, several empirical gravity studies have focused on the relationship between national environmental policies and trade patterns for goods and

services. However, the debate on this topic is polarized almost exclusively around two dimensions:

- First, the limited geographic scope by focusing mainly on OECD countries (Harris et al., 2002; Koźluk & Timiliotis, 2016; Van Beers & Van Den Bergh, 1997), especially in the European Union (Mirza & Jug, 2005) and the United States (Ederington et al., 2005; Ederington & Minier, 2003; Levinson & Taylor, 2008).
- Second, the prevalence of studies focusing on manufacturing industries (Broner et al., 2012; Ederington & Minier, 2003; Grether & De Melo, 2004) as well as international competitiveness and aggregate trade (Arlinghaus, 2015; Dechezleprêtre & Sato, 2017; Tobey, 1990).

Empirical evidence on the validity of the "pollution haven" or "Porter hypothesis" has been mixed. This has been partly due to the difficulty of evaluating the stringency of environmental policies across countries, time and sector. Such evaluation is challenging due to the large and increasing number of environmental issues and policy instruments. In this regard, it is important to bring specific and sectoral analysis (case-by-case) to have a better understanding and draw clear conclusions. However, little headway has been undertaken over the last years towards the agricultural sector.

Runge and Nolan (1990) were the first authors to address the issue by drawing a descriptive analysis of trade distortion effect of environmental and health regulations. They conclude that developing countries may be prevented from selling their products to richer nations because they fail to reach environmentally acceptable standards. One year later, Tobey (1991) provided a sketchy evidence on the effects of environmental policies on agricultural trade. He performed a simple correlation analysis between the revealed comparative advantage index with the overall pollution content ordinal ranking index of 10 primary crops of the United States. He found that the crops in which the country performs best in world trade are also the most polluting.

Diakosavvas (1994) extented the analysis of Tobey (1991) and tested the hypothesis of whether international trade for agriculture is hampered by environmental control policies. The method was based on the Heckscher-Ohlin theorem of comparative advantage in order to deal with the environment as a productive capital. The author found that trade patterns of polluting commodities have mostly deviated from the Heckscher-Ohlin predictions due to environmental control measures.

Feix et al. (2008) reignited the debate and employed a cross-section approach of the Heckscher-Ohlin-Vanek model to examine the relation between net exports of agribusiness sectors and environmental regulations. The latter were proxied by the Environmental Performance Index of Esty et al. (2008) and the emissions of greenhouse gases. Results were not conclusive and depended on the products as well as on the origin of the exporting country.

More recently, Ramzy and Zaki (2018) showed that stringent environmental regulation affects positively agricultural exports between the European Union and 20 MENA countries during the period 2001-2014. They employed the gravity model and followed the method of Feix et al. (2008) by introducing the Performance Index and total greenhouse gas (GHG) emissions as indicators of environmental regulation. Nonetheless, low GHG emissions levels do not necessarily reflect stringent environmental policies. It could be simply associated with low production performance. In this regard, efficiency scores computed in Chapter 2 remedied the problem since the DEA modelling takes both desirable and undesirable outputs into consideration to estimate such performance.

In this chapter, we look back over this old debate on the trade outcomes of environmental regulations. Our aim is to investigate their effects on the intensive margin, i.e. the volume of crop commodities' exports using panel data. In order to properly identify this impact, we need a suitable control for these policies' stringency that may naturally be difficult to find in reality. To that end, we use the DEA efficiency scores related to the agri-environmental performance to proxy:

- On the one hand, environmental policies' stringency of exporting countries;
- On the other hand, the environmental regulations' heterogeneity between each exporter and its trade partner.

This study uses a theoretically justified gravity model of Anderson and van Wincoop (2003) to examine the impact of environmental policies' stringency on exports, focusing on trade creation and diversion effects. The model is tested on a sample of 108 countries over the period dating from 2003 to 2013 using aggregated export data for crop commodities and recent panel data techniques.

In order to obtain unbiased estimates, we employ the time-varying multilateral resistance terms as recommended by Carrère et al. (2009). As suggested by Baier and Bergstrand (2007), we control for the unobserved heterogeneity that is specific to each trade flow. Additionally, we use a high-dimensional fixed effects Poisson pseudo maximum likelihood (PPML) model of Santos Silva and Tenreyro (2006) to solve the zero-trade issue and the presence of heteroskedasticity. Following the method of Yang and Martinez-Zarzoso (2014), we considered the endogeneity bias problem due to omitted variables by controlling for time-varying multilateral resistance terms and country-pair fixed effects to obtain unbiased and consistent estimates.

Our findings show that the stringency of environmental regulations affects bilateral agricultural exports. However, environmental regulations' elasticity of agricultural trade is affected by the level of development of countries. First, it turns out to be trade reducing in the CAIRNS group, supporting thereby the pollution haven hypothesis. This finding suggests that free agricultural trading nations characterized by lenient environmental regulations have gained comparative advantages in pollution-intensive goods and are turned into pollution havens.

By contrast, rigorous agri-environmental policies have a significant trade-enhancing effect on bilateral agricultural exports of highly protective and industrialized countries such as the EU and the USA. Similarly and surprisingly, further results show that low and middle income countries with higher agri-environmental performances export larger volumes of crop commodities, supporting therefore the Porter hypothesis. Our findings suggest that strict environmental regulations can enhance the competitive advantage of developing countries against foreign rivals.

In addition, we note that agricultural commodities react differently to environmental regulation. The sector of fruit and vegetables is more sensitive to this determinant unlike cereals that remain relatively less affected. Finally, our results show that difference in exporter and importer environmental regulations is more relevant to agricultural trade than trade agreements. The environmental gap between two trade partners is decreasing slightly, but significantly, crop commodities' exports. However, trade effects vary according to the income groups of exporting and importing countries.

The rest of this chapter is organized as follows. First, we present in section 3.2 the major theoretical foundations related to our model to obtain unbiased estimates. The selected variables and data are presented in section 3.3 followed by section 3.4 in which we present the econometric methodology. Section 3.5 presents the estimation results from the empirical analysis. Finally, section 3.6 highlights the main conclusions and policy implications.

3.2. Theory foundations

The inspiration for the gravity model comes from the "Law of Universal Gravitation" of Newton, stating that the force of gravity between two objects i and j is proportional to the product of their masses divided by the square of the distance between them, the whole multiplied by the gravitational constant (G).

$$\vec{F}_{gravity} = G\frac{M_i M_j}{(D_{ij})^2} \tag{3.1}$$

In trade, Tinbergen (1962) and Pöyhönen (1963) were the first scholars applying the gravity equation to analyze international flows. They replaced the force of gravity with the value of bilateral trade and the masses M_i and M_j with the trade partners' economic sizes (GDP or GNP), their populations and a set of dummies incorporating some institutional characteristics common to specific flows.

The economic size of an exporting country reflects its ability to supply, whereas the propensity to demand of the importer is represented by its output (GDP). The distance is a trade-resisting factor as it increases the price of traded items. Greater distance implies higher transport costs and thus, reduces import demand. Conversely, geographical proximity enhances trade flows and increases economic regionalism in attaining mutual gains from trade.

The gravity model has become a popular instrument in empirical foreign trade analysis. Despite its goodness-of-fit, this basic modelling version was highly criticized for its poor theoretical foundations. From the 1970s onwards, several theoretical developments have appeared in support of the gravity equation, starting with the seminal contribution of Anderson (1979). The latter is formally written as follows:

$$M_{ij} = \frac{m_i \Phi_i Y_i \Phi_j Y_j}{\sum_j \Phi_j Y_j} \cdot \frac{1}{f(d_{ij})} \cdot \left[\sum_j \frac{\Phi_j Y_j}{\sum_j \Phi_j Y_j} \cdot \frac{1}{f(d_{ij})} \right]^{-1} U_{ij} \qquad (3.2)$$

where M_{ij} is trade between partners i and j, m and Φ are log-linear functions of income and population. Y denotes income, whereas d_{ij} indicates distance between i and j. U is a log-normally distributed error term (Anderson, 1979).

However, the model was not used extensively by trade economists due to its complexity (Leamer & Levinsohn, 1995). Accordingly, the gravity model continued though theoretical extensions by Bergstrand (1985, 1989, 1990), Deardorff (1998) and Anderson & van Wincoop (2003).

The recent developments in econometric modeling to assess trade flows are of four types:

- First, the intra-industry trade model suggesting that bilateral trade flows can be used to comprehend the trade flow in monopolistically competitive markets (Kabir et al., 2017). In this framework, several studies namely Bergstrand (1990), Helpman and Krugman (1985) and Helpman (1987) used the Heckscher–Ohlin–Samuelson (HOS) model and Linder hypothesis.

- Second, gravity equations are developed for both homogeneous and heterogeneous goods and preferences, along with complete and incomplete specializations. The model has been derived by several studies, namely Chaney (2008) as well as Melitz and Ottaviano (2008) for product differentiation stemming from differences in factor endowment and the effect of preferences, distance, price, and tariffs.

- Third, the structural gravity model based on the monopolistic competition and increasing returns to scale model. The latter focuses on both the elasticity of substitution in consumption and general equilibrium comparative statics according to Bergstrand et al. (2013).

- Finally, the generalized gravity model introduced by Anderson (1979) and Anderson and van Wincoop (2003). The latter is based on a set of general equilibrium models that derive specific inferences for bilateral trade. The model explains bilateral trade flows based on the economic size and distance between two geographical units. Additionally,

it is used to analyze the determinants of bilateral trade flows, namely common borders, common languages, common currencies, etc.

In their model, Anderson and van Wincoop (2003) revise the early theoretical foundations to revitalize the endogeneity of prices in the structural gravity model. Besides the inclusion of prices, they introduce multilateral resistance to trade and explain that bilateral flows between two regions i and j, denoted X_{ij}, depends not only on their bilateral resistances (such as tariffs, distance, intellectual property rights, etc.) but also on their obstacles to trade with other trading partners. Formally, the basic gravity equation of Anderson and van Wincoop (2003) is written as:

$$X_{ij} = \left(\frac{Y_i Y_j}{Y_w} \right) \left(\frac{t_{ij}}{\prod_i P_j} \right)^{1-\sigma} \tag{3.3}$$

where

$$\prod_i = \left(\sum_{j=1}^{N} \left(\theta_j / t_{ij} \right) P_j^{\sigma-1} \right)^{\frac{1}{1-\sigma}} \tag{3.4}$$

$$P_j = \left(\sum_{j=1}^{N} \left(\theta_j / t_{ij} \right) \prod_i^{\sigma-1} \right)^{\frac{1}{1-\sigma}} \tag{3.5}$$

Where Y_w defines the world nominal income. Y_i and Y_j are gross domestic production in regions i and j (j=1…N). The term t_{ij} is the unobserved border effect, and σ represents the elasticity of substitution between all goods. Πi and Pj are the multilateral unobserved prices. Finally, θj defines the region's j income shares (Yj/Yw).

Although the theoretical justification for the gravity model is no longer in doubt, its empirical application has generated notable controversies. They are mostly related to the appropriate estimation technique and equation specification. Several scholars have contributed to the structural form of the equation and argued the implication of misspecification and omitted variables' bias. The work of Anderson and van Wincoop (2003, 2004) as well as Baier and Bergstrand (2007, 2009), to name only a few, are deemed to be influential here.

In this regard, and to avoid methodological problems, we need to address the most relevant estimation issues to our work, namely panel data for gravity, the presence of heteroscedasticity, and zero-trade observations.

3.2.1. Modeling trade costs, multilateral trade resistance and fixed effects estimation

One approach to consistently estimate the theoretical gravity model is to use the panel data technique of fixed effects (FE) estimation. This class of models covers much of the field in applied international trade, including the Ricardian model of Eaton and Kortum (2002) and the heterogeneous firms model of Chaney (2008).

In practice, different combinations of fixed effects such as exporter-time, importer-time and country-pair FE are usually used as controls for multilateral resistance. According to Mátyás (1997), the correctly specified panel gravity models' FE are three-fold. The first dimension is time, which reflects the common business cycle or globalization process. The other two dimensions account for all sources of unobserved heterogeneity that are constant for a given exporter across all importers, and constant for a given importer across all exporters.

On the other hand, Baltagi et al. (2003) proposed a new specification by introducing six dimensions. First, the main effects composed of fixed exporter, importer and time effects. Second, they suggest interaction effects that include:

- A country-pair effect as an interaction effect between unobserved exporter and importer characteristics.
- Time-variant effects, such as the exporting country's business cycle, its cultural, political, or institutional characteristics and unobserved factor endowment variables.
- Another interaction term that accounts for these influences from the importer's perspective.

Estimation of fixed effects models is straightforward. However, determinants that vary only in the same dimension as the fixed effects cannot be included because they would be perfectly collinear. It is only possible, therefore, to identify the effect of determinants that vary bilaterally in fixed effects gravity models. One approach to remedy this situation is by incorporating proxies for multilateral resistance as recommended by Anderson and van Wincoop (2003) to avoid biased estimates.

In a panel data context, Baldwin and Taglioni (2006) argued that multilateral resistance terms have to be time-variant in order to completely eliminate the bias steaming from misspecification and unobserved trade costs. In turn, Baier and Bergstrand (2009) suggest an alternative control for multilateral trade resistance by creating the relative remoteness index of a country in relation to all other countries. Based on this work, Carrère et al. (2009) propose time-varying adjusted multilateral resistance indices, enabling the introduction of time-varying fixed effects in a panel-data framework. Formally, indices of the exporter i (MR_{it}) and importer j (MR_{jt}) are defined as follows:

$$MR_{it} = \sum_{k}^{K} \frac{Y_{kt}}{Y_{wt}} \ln D_{ik}, \quad MR_{jt} = \sum_{k}^{K} \frac{Y_{kt}}{Y_{wt}} \ln D_{jk} \tag{3.6}$$

According to Eq. (3.6), MR_{it} and MR_{jt} are constructed by a weighted average of the exporter's (or importer's) distance to its trade partners, weighted by the trade partners' (denoted k) share of world GDP. Y_{kt} is the GDP of the partner country k at time t. Y_{wt} is the world GDP at time t. D_{ik} is the geographical distance between the exporter i and country k, whereas D_{jk} measures the distance between the importer j and its partner k.

3.2.2. Heteroskedasticity and alternative gravity model estimators

Gravity models are commonly estimated by linear regression applied to the log dependent variable. However, Ordinary least squares (OLS) estimator has been subject to criticism from an econometric point of view. We consider the nonlinear form of the Anderson and Van Wincoop (2003) gravity model in Eq. (3.3) with a multiplicative error term e_{ij}:

$$X_{ij} = \left(\frac{Y_i Y_j}{Y_w} \right) \left(\frac{t_{ij}}{\prod_i P_j} \right)^{1-\sigma} e_{ij} \tag{3.7}$$

Taking logarithms gives the standard gravity model in linearized form as shown below:

$$\log X_{ij} = \log Y_i + \log Y_j - \log Y_w + (1-\sigma)\left[\log t_{ij} - \log \prod_i - P_j \right] + \log e_{ij} \tag{3.8}$$

Eq. (3.8) suggests that the mean of $\log e_{ij}$ depends on higher moments of the error term, including its variance (Shepherd, 2013). Therefore, if the error term is heteroskedastic, then its expected value depends on at least one of the regressors. This violation of the first assumption of OLS raises some concerns about the estimators' reliability. One solution to deal with this issue is by applying a robust covariance matrix estimator. However, this kind of heteroskedasticity affects both the parameter estimates and the standard errors.

In the past years, Poisson pseudo maximum likelihood (PPML) regression has been employed as an alternative estimation technique by several scholars such as Fracasso (2014), Hammarlund and Andersson (2019), as well as Yang and Martinez-Zarzoso (2014) to name only a few. Originally developed by Davies and Guy (1987), PPML regression provides a natural way to deal with zero values on the endogenous variable contrary to the log-linear model.

However, it was not until the work of Santos Silva and Tenreyro (2006) that PPML really took off in the international trade literature. In their paper, they show that the PPML method estimates the gravity model in its original multiplicative form, permitting the inclusion of zeros, and allowing for a more flexible distribution of the error term. In addition, the authors demonstrate that the PPML estimator is suitable for the inclusion of fixed effects, which can be entered as dummy variables as in simple OLS.

Furthermore, estimated coefficients of independent variables can still be interpreted as simple elasticities, as under OLS. Similarly, coefficients of independent variables entered in levels are interpreted as semi-elasticities. Santos Silva and Tenreyro (2006) argue additionally that OLS estimations are inconsistent in the presence of heteroscedasticity. Conversely, they show that estimating the gravity equation in its multiplicative form is more reliable to tackle this issue.

In applied work, scholars like Yang and Martinez-Zarzoso (2014) as well as Hammarlund and Andersson (2019) resorted to log-linear regressions while Poisson results are mostly presented for comparative purposes or as a robustness check. First possible explanation is that log transformation can address the problem of the presence of heteroscedasticity in gravity estimates (Kabir et al., 2017). Second argument is the ease in estimating linear regressions that control for multiple fixed effects. Besides, the emerging estimation techniques for linear regression models with high-dimensional fixed effects (HDFE) allowed scholars using large panel-type datasets to easily control for multiple sources of heterogeneity (Correia et al., 2020).

Nonetheless, some researchers like Ferro et al. (2015) have used alternative count data like the negative binomial model under the assumption of over-dispersion of trade data (variance greater than the mean). According to Shepherd (2013), this approach is flawed for two reasons. First, one should know the exact nature of the over-dispersion to ensure the efficiency of this method, which is usually not the case. Second, the negative binomial estimator is not scale invariant which is undesirable in trade context. However, the pseudo Poisson maximum likelihood method is consistent regardless of how data are distributed, assuming only that the zero and non-zero observations are produced by the same process.

3.2.3. Zero-trade flows issue

Zero trade flows are more frequent as the level of product disaggregation becomes greater. A widely discussed issue in the recent gravity literature is how to handle zeros in the dependent variable. The main concern is that by transforming the original multiplicative model into a log–log model, zero (or missing data) trade flows are dropped out of the estimation. This method is only correct if the zeros are randomly distributed. However, it will provide biased estimates if they reflect a systematic pattern, such as large fixed costs of exporting.

To tackle the problem, some scholars use the sample selection correction developed by Heckman (1979). In this regard, Helpman et al. (2008) introduced a model of international trade that yields a gravity equation with a Heckman correction combined with a correction for firm

heterogeneity. Nonetheless, the model of Helpman et al. (2008) and, more generally, the gravity model of trade are commonly criticized because they lead to biased estimations in the presence of heteroscedasticity (Santos Silva & Tenreyro, 2015).

A second category of studies uses the PPML estimation suggested by Santos Silva and Tenreyro (2006). In their paper, they show that the Poisson estimator includes zero trade observations which are usually dropped from the OLS model. This major asset resolves the sample selection bias caused by OLS estimator. Additionally, simulation evidence presented by Santos Silva and Tenreyro (2011) shows that PPML performs strongly even in datasets with large numbers of zeros.

In sum, the literature does not provide any decisive guidance on which model should be preferred in applied work. Each has its own set of advantages and disadvantages. We conclude that Poisson deals well with heteroskedasticity, but Heckman does not. Similarly, fixed effects Poisson models have desirable statistical properties, but fixed effects OLS models suffer from inconsistency into their estimates. Besides, Fally (2015) argues that Poisson estimates are consistent with the multilateral resistance terms of the Anderson and van Wincoop (2003) model when fixed effects are included.

Taking all these points together, current practice in the literature suggests that Poisson is more commonly used as a workhorse estimator for gravity. The ability to produce consistent estimates under relatively weak assumptions while dealing with empirically important heteroscedasticity are likely to be compelling. To sum up, and from an applied policy research point of view, Poisson results should always be presented in addition to OLS estimates for comparative purposes and robustness check.

3.3. Estimation variables and data

3.3.1. Endogenous variable: crop commodities' exports

We employ an augmented version of the gravity model specification of Anderson and van Wincoop (2003) to conduct an agricultural-specific analysis. The aim of this study is to explore the new determinants of global crop commodities' exports over the time period 2003-2013.

Our estimations are based on trade data gathered from UN Comtrade (UN, 2019). The dataset is balanced whereas the dependent variable includes bilateral exports (in US$) of total cereals (SITC rev. 3 product category 04), vegetables and fruits (SITC rev. 3 product category 05) sugars (SITC rev. 3 product category 06) as well as products under the category 07 (coffee, tea, cocoa, etc.).

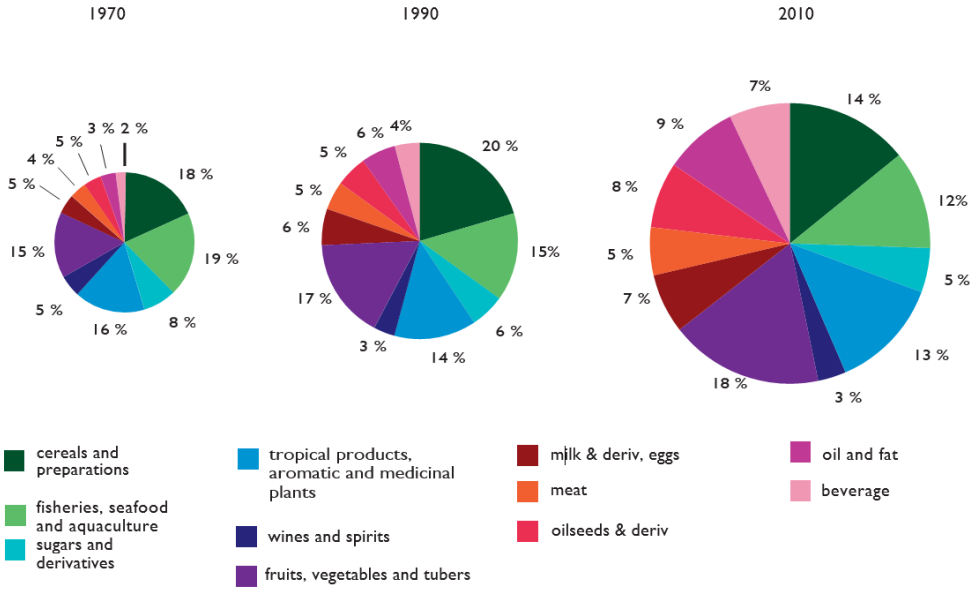
In total, our dataset includes 108 exporters and 108 importers composed of high, emerging, middle and low income countries listed in Table A3. 1 in the appendix of Chapter 3 (A3). Detailed description of the used variables is reported in Table A3. 2 in the appendix of chapter 3 (A3).

A crop implies human intervention through agriculture. Overall, food crops consist of grains, cereals, legumes (including dried beans), seeds and nuts, vegetables, fruit, herbs and spices, beverage plants such as tea and coffee, and so forth. Our choice of commodities is guided by two reasons: First, they share similar production process and, thus, usually are under the same agri-environmental policies (unlike other products such as live animal, meat or dairy production).

The second motivation is the strategic role of these products. According to Figure 3. 1, the basket of traded goods has changed significantly over the past 50 years. Nonetheless, cereals have always represented a substantial proportion of the overall agricultural trade, increasing from 18% in the 1970s to 14% in 2010. However, livestock production like meat as well as milk and derivatives did not exceed 7% over the same period.

While the development of animal products' trade remains limited over the past years, cereals like wheat, corn and rice constitute the "food base" of many countries. For these products, dependence on imports is therefore far from being reduced to a simple trade imbalance. Another striking fact is that the most traded agricultural commodities are fruit and vegetables (18%) in 2010. In terms of value, fruit and vegetables have dethroned cereals and their derivatives as well as tropical products (tea, coffee, cocoa).

Figure 3. 1. Evolution of traded food sectors from 1970 to 2010, at constant prices

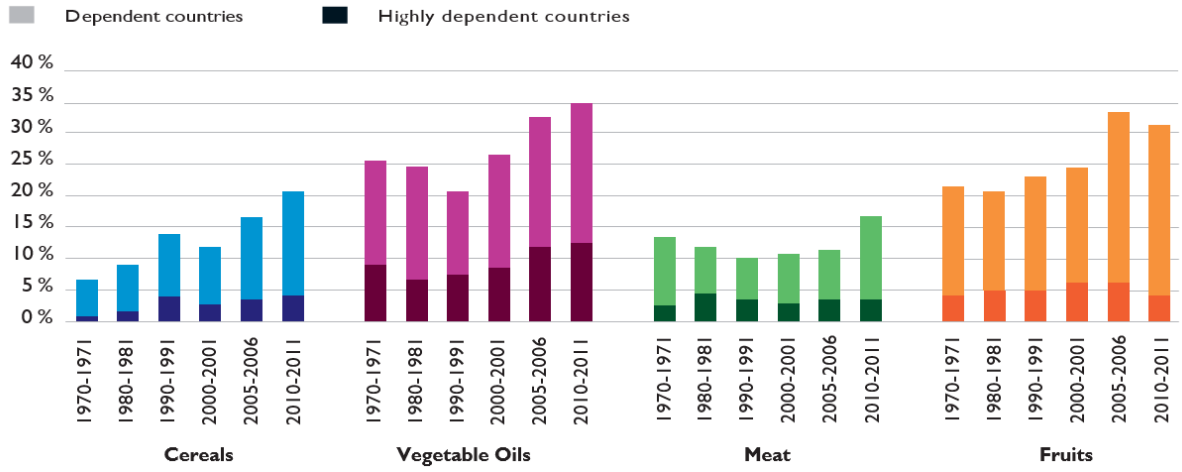


Source: (Claquin et al., 2017)

Gouel (2016) argues that trade policies for food products, unlike other manufacturing sectors, cannot be explained solely by the usual motivations of international competitiveness or improvement of the trade balance. Food security issues and geopolitical considerations play a decisive role. In addition, several authors have regularly stressed that the geography of international trade also responds to very structuring political considerations. For example, a study conducted by Mendez del Villar et al. (2011) shows how different countries in West Africa have sought to reduce their dependence on rice imports by diversifying supplies. We recall that the recent Russian embargoes against Europe and the US (to name only a few) in 2014 have preferentially targeted agricultural products.

Finally, agricultural commodities are usually a vector of economic development and strategic for food security in both high income and developing countries. Figure 3. 2 highlights the increasing dependency of many countries on crops commodities' exports such as cereals, fruit, and vegetable oils. However, dependence on meat exports recorded lower levels over the past years.

Figure 3. 2. Evolution of export dependency ratios



Source: (Claquin et al., 2017)

3.3.2. Variables of interest

3.3.2.1. Agri-environmental regulations' stringency of exporting countries

The aim of this study is to investigate the trade effects of agri-environmental policies on exports volumes of crop commodities. From a theoretical perspective, trade gives efficiency gains and increases total income as discussed in the general Introduction. Accordingly,

agricultural exports are potentially very important for developing countries as they give incomes that could contribute to economic growth and increase welfare. Besides, it is interesting for policy makers to know whether the stringency of their agri-environmental regulations effects agricultural trade.

To tackle this issue, we need a suitable control for their rigor that may naturally be difficult to find. In our case, we use the DEA efficiency scores related to the agri-environmental performance, previously computed in chapter 2 and denoted as AEE_{it}. The latter is used to proxy the stringency of each exporter. By this means, we encounter several problems that make the identification of a good proxy difficult.

First, and contrary to previous studies, such as Ramzy and Zaki (2018), our indicator is proper to crop commodities that are usually under the same environmental regulations. Second, the concept of efficiency is relative. The more we include decision making units (i.e. countries), the better the proxy will be. The third reason is with regard to endogeneity bias. We recall that the regressor AEE_{it} is computed using the non-parametric DEA model and thereby, is not an observed variable. The latter is most likely to be an exogenous regressor, contrary to other classical gravity determinants such as trade agreements (Baier & Bergstrand, 2007; Martinez-Zarzoso et al., 2009).

Potentially, two hypothesis are to be explored. First, and according to the traditional assumption known as the "pollution haven" hypothesis, an environmental regulation adds additional constraints on the possible actions of companies and increases thereby their production costs. Eventually, this would affect negatively their competitive position on the international market (Taylor, 2005). This theory suggests that countries tend to reduce their firms' production costs by applying more lenient environmental regulations. Thus, they improve their ability to export despite the possibility of becoming pollution havens. The hypothesis of "pollution haven" implies a deliberate strategy on the part of host governments to purposely undervalue the environment and attract new investment.

On the other side of this debate, the negative link between environmental regulations and competitiveness was questioned first by Porter (1991) and then by Porter and Van der Linde (1995). Based on what is now known as the "Porter hypothesis", the introduction of well-designed environmental regulations leads, in most cases, to innovation. The latter will ultimately generate a rent to cover the costs of compliance and will eventually allow firms to reach new markets. Put differently, this approach emphasizes the potential synergic effect between environmental regulation and trade competitiveness.

We recall that our indicator is time-varying and is computed for a panel of 108 countries. Positive impact of this variable on agricultural exports will support the Porter (1991) theory. On the other hand, negative impact will favor the pollution haven hypothesis.

3.3.2.2. Agri-environmental regulation heterogeneity between trade partners

Findings of section 2.2 highlight the multitude of agri-environmental instruments. These differences affect both the setup of regulations within countries and their efficiency in mitigating the pollution. Therefore, heterogeneity in agri-environmental regulations between an exporting country and its trade partner is likely to affect agricultural trade. In this regard, the second goal of this work is to support the identification of the real effect of heterogeneity in environmental regulations on crop commodities' exports.

To that end, we introduce a second interest variable, namely $AEEH_{ijt}$ that measures the gap between the efficiency scores of two trade partners. Formally, $AEEH_{ijt}$ is the absolute value of the difference between the agri-environmental efficiency scores of the exporter (AEE_{it}) and its trade partner (AEE_{jt}) in year t. Statistically insignificant parameter estimates would suggest that environmental regulations' heterogeneity does not affect agricultural exports. On the other hand, significant and positive parameter indicates that environmental policies' gap is a trade-enhancing factor between trade partners. Finally, a significant and negative parameter would imply that agricultural exports are restrained by policies' dissimilarities between the exporter and the importing country.

3.3.3. Gravity variables

The remaining explanatory variables are controls inspired by traditional gravity modelling. Given the richness of the literature, our objective is not to identify and cite all the relevant studies on this topic, but rather to target some important currents of literature that deserve to be taken into consideration.

As is customary, gross domestic products (GDP) of exporting and importing countries are introduced to the model to control for their economic weight. In most studies, they are found out to have a positive and significant effect on trade flows. Data on GDPs come from the World Development Indicators database run by the World Bank (World Bank, 2019c). According to Natale et al. (2015), gravity models applied to agricultural products have some specificities insofar. The authors argue that the estimated parameters show low coefficients of the exporter's GDP compared to non-agricultural products. They claim that this finding reflects the limited effect of the domestic market and intra-industry trade.

Furthermore, the geographical distance between two countries measures traditionally bilateral transportation costs. Initial gravity model considers that the long distance represents a greater transit cost. However, costs of distances may include others freight charges, namely cultural dissimilarity and other trade barriers. Khan (2011) explains that costs rise substantially with distance. Additionally, he argues that this effect diminishes with time as the cost of an

extra travelled kilometer may decrease. However, he suggests that the time cost may increase since traded goods become more time sensitive.

In our model, we introduce the geodesic distance calculated following the great circle formula (Mayer & Zignago, 2011). In addition, we control for cultural distance by introducing dummy variables that account for the presence of common border, common language and colonial link between trade partners. In this regard, data are gathered from the CEPII database (CEPII, 2019).

Gravity models have been popularly used to estimate the impact of trade agreements on agricultural flows. To that end, many studies have used an additional dummy variable in the standard model to detect the variations caused by the formation of trade agreements.

Huchet et al. (2015) show that trade in food products is more sensitive to regional trade agreements (RTAs) than trade in agricultural products. In turn, Lambert and McKoy (2009) distinguish between raw agricultural products and food products. By focusing on trade creation and diversion effects, their results show a positive impact of preferential trade associations on both intra- and extra-bloc agricultural and food product trade for 1995, 2000 and 2004 time periods.

Moreover, Grant and Lambert (2008) find that positive effects of RTAs on trade between signatories are greater for agri-food products than for non-agrifood commodities. In turn, Korinek and Melatos (2009) uses a gravity model to estimate trade effects of three RTAs, namely the ASEAN free trade area, the Common Market for Eastern and Southern Africa and MERCOSUR. Their results suggest that the implementation of these agreements has a positive effect on agri-food trade between the signatories.

In this chapter, data on regional and preferential trade agreements are gathered from Egger and Larch (2008).

3.4. Econometric methodology

In accordance with the analysis conducted in section 3.2, we select both of the Ordinary least squares (OLS) and the Poisson pseudo maximum likelihood (PPML) as estimation techniques. As recommended by the recent scientific literature, we add multilateral resistance terms and use different types of fixed effects in the models (Eq. (3.9)-Eq. (3.12)) described below.

However, results drawn from the above methods cannot be validated without comparing them with alternative estimators. To that end, we start by using the following basic gravity model in log-linear form that includes traditional gravity variables.

$$\ln X_{ijt} = \alpha + \beta_1 \ln AEE_{it} + \beta_2 \ln AEEH_{ijt} + \beta_3 \ln GDP_{it} + \beta_4 \ln GDP_{jt} + \beta_5 \ln Dist_{ij} + \beta_6 Contig_{ij} + \beta_7 Lang_{ij} + \beta_8 Trade\_agr_{ijt} + \beta_9 Colony_{ij} + \varepsilon_{ijt} \quad (3.9)$$

Where i denotes the exporting country, j the importing country and t: time. $\ln X_{ijt}$ denotes the log of country j imports of crop commodities from i at time t. The variable of interest $\ln AEE_{it}$ is the log of the agri-environmental efficiency scores of the exporter at time t. $\ln AEEH_{ijt}$ is the log of the environmental regulations' heterogeneity between the exporter and its trade partner.

The remaining variables are controls inspired by traditional gravity modelling. $\ln GDP_{it}$ and $\ln GDP_{jt}$ are respectively the logs of the gross domestic products of the exporter i and importer j at time t. $\ln Dist_{ij}$ is the log of the distance between i and j. $Contig_{ij}$, $Lang_{ij}$ and $Colony_{ij}$ are dummy variables that respectively account for the presence (or not) of a common border, common language and colonial link between trade partners i and j.

Additionally, we include a dummy variable to control for trade agreements, denoted as $Trade\_agr_{ijt}$, that give preferential market access. This variable takes the value 1 if i and j are members of the same regional trade agreement (RTA), free trade agreement (FTA) or preferential trading arrangement (PTA) and zero otherwise. Finally, ε_{ijt} is the error term.

As statistical procedure, we first use the variance inflation factor (VIF) to control the multicollinearity. Second, we compare between several estimators, namely the random effects (RE), the fixed effects (FE), and the Hausman-Taylor (HT) models. The comparison of each estimator will be carried out with adequate validity tests to select the most appropriate estimation procedures.

In fact, the RE model accounts for unobserved heterogeneity while allowing the inclusion of variables that would be collinear with the fixed effects.

Whereas the FE model may correct for the endogeneity bias created by prices (Baier & Bergstrand, 2007; Martinez-Zarzoso et al., 2009). Besides, the introduction of fixed effects is an accepted way to control for the omission of relevant variables in gravity models (Baldwin & Taglioni, 2006; Martinez-Zarzoso et al., 2009). On the other hand, the FE model cannot apply on time invariant variables such as distance, border, colonial or language dummies

Accordingly, the models below are estimated using only OLS and PPML techniques with FE to deal with the unobserved heterogeneity and zero-trade flows issues and given their statistical reliability. We recall that the standard OLS estimation uses a logged dependent variable and thereby, all zero trade flows are dropped. However, our dataset contains over 50% zeros. Hence, logging the dependent variable is not unproblematic. In this regard, we employ the PPML estimation procedure suggested by Santos Silva and Tenreyro (2006) to address the issue. Besides, the PPML model produces more reliable estimates than OLS in the presence of heteroscedasticity as highlighted previously.

$$\ln X_{ijt} = \alpha + \beta_1 \ln AEE_{i(t-k)} + \beta_2 \ln GDP_{it} + \beta_3 \ln GDP_{jt} + \beta_4 Trade\_agr_{ijt} + \beta_5 MR_{it} + \beta_6 MR_{jt} + \delta_{ij} + \tau_t + \varepsilon_{ijt} \quad (3.10)$$

where $k \in \mathbb{N}$

In Eq. (3.10), we investigate the effect of exporters' environmental regulations on the intensive margin, i.e. the volume of crop commodities exports using panel data for the 2003–2013 period. This model is similar to Eq. (3.9) except that we have introduced MR_{it} and MR_{jt} as proxies for multilateral resistance for exporter i and importer j at time t. δ_{ij} is an importer-exporter (bilateral) FE and τ_t is a year FE. Besides the trade impacts of AEE_{it}, we investigated the potential effect of previous policies proxied by the lagged values, namely $AEE_{i(t-k)}$, where k is a positive integer. To refine our analysis, we estimate the trade effect of $AEE_{i(t-k)}$ on the exports of two commodities, namely the fruit and vegetables ($X_{ijt}^{F\&V}$) and cereals ($X_{ijt}^{cereals}$).

In a panel data setting, the required fixed effects are importer-time and exporter-time. The latter would however wipe out our variable of interest. As suggested by Baier and Bergstrand (2009) and Carrère et al. (2009), we introduce to our model the multilateral resistance indices MR_{it} and MR_{jt} following Eq. (3.6) to control for the multilateral trade resistance and proxy the relative distance that varies over time.

One may note that Eq. (3.10) lacks many of the traditional bilateral gravity variables such as distance, common language and contiguity. All non-time varying bilateral variables are deliberately excluded from the model specification since it includes bilateral fixed effects. The latter are introduced to control for unobserved heterogeneity. If we were to have left them out, there would have been a high risk of getting biased estimates because unobservable factors are likely to be correlated with regressors.

In a second step, we add three variables to Eq. (3.11) to capture the specific effects of agri-environmental regulation of the EU and USA (ln AEE_{it}*$EU\&USA_{it}$), the CAIRNS group (ln AEE_{it}*$CAIRNS_{it}$), and middle and low income countries (ln AEE_{it}*$LI\&MI_{it}$). $EU\&USA_{it}$ is a dummy variable which is equal to 1 if the exporter is the USA or a member of the EU, and 0 elsewhere. The binary variable $CAIRNS_{it}$ takes the value 1 if the exporter belongs to the CAIRNS group, and 0 otherwise. Finally, $LI\&MI_{it}$ is equal to 1 if the exporter is a middle or low income country, and 0 otherwise. Therefore, $\beta_1$measures the effect of the agri-environmental efficiency (AEE) of all exporting countries, whereas β_2, $\beta_3$and β_4 show respectively to what extent this effect is greater or lower for these groups.

$$\ln X_{ijt} = \alpha + \beta_1 \ln AEE_{it} + \beta_2 \ln AEE_{it} * EU \& USA_{it} + \beta_3 \ln AEE_{it} * CAIRNS_{it} + \beta_4 \ln AEE_{it} * LI \& MI_{it} + \beta_5 \ln GDP_{it} + \beta_6 \ln GDP_{jt} + \beta_7 Trade\_agr_{ijt} + \beta_8 MR_{it} + \beta_9 MR_{jt} + \delta_{ij} + \tau_t + \varepsilon_{ijt} \quad (3.11)$$

Additionally, we used Eq. (3.11) to refine our analysis by investigating the effect of the exporters' environmental regulations on two commodities, namely fruit and vegetables ($X_{ijt}^{F\&V}$) and cereals ($X_{ijt}^{cereals}$).

Throughout the next model, we investigate the effect of environmental regulations' heterogeneity ($AEEH_{ijt}$) between exporting countries and their trade partners on total crop commodities' exports (i.e. Eq. (3.12)). Formally,

$$\ln X_{ijt} = \alpha + \beta_1 \ln AEEH_{ij(t-k')} + \beta_2 Trade\_agr_{ijt} + \delta_{it} + \delta_{jt} + \delta_{ij} + \varepsilon_{ijt} \quad (3.12)$$

where $k' \in \mathbb{N}$

Where $AEEH_{ij(t-k')}$ are the lags of the environmental gap variable ($AEEH_{ijt}$) and k' is a positive integer. Our purpose is to test to which extent current trade is affected by the previously determined agri-environmental regulations.

In Eq. (3.12), we have deliberately excluded multilateral resistance indices. Our variable of interest ($AEEH_{ij(t-k')}$ with k'=0) varies across importers, exporters and time. In this case, it becomes possible to account for all intergroup variability and control for the unobserved heterogeneity by adding to the set of regressors some dummy variables that absorb group-specific heterogeneity. This approach allows for the existence of general patterns of correlation between unobserved effects and other regressors. Therefore, we introduce exporter-time (δ_{it}) and importer-time (δ_{jt}) fixed effects.

In practice when studying relations in international trade, scholars simultaneously account for two sources of unobserved heterogeneity: the exporter and the importer. In our case, explicit introduction of dummy variables is not an option because the number of units (groups) for exporting or importing countries is too large (108x107x11). Guimaraes and Portugal (2010) tackled the problem of accounting for multiple high-dimensional fixed effects (HDFE) in the linear regression model. Later, Correia et al. (2020) extended this estimation approach and presented an iterative algorithm for PPML models with multiple HDFE.

Finally, we use Eq. (3.12) to investigate the effect of $AEEH_{ijt}$ on exports of two commodities, namely fruit and vegetables ($X_{ijt}^{F\&V}$) and cereals ($X_{ijt}^{cereals}$).

Gravity models' estimations require particular attention to the problem of endogeneity bias due to omitted variables in gravity equations. Following the method of Yang and Martinez-Zarzoso (2014), we considered the issue by controlling for time-varying multilateral resistance terms and country-pair fixed effects to obtain unbiased and consistent estimates.

3.5. Results and discussion

3.5.1. Intuition gravity model and basic estimations

We argue the estimation results of the basic gravity model (Eq. (3.9)) in the section "Basic estimations of the intuitive gravity model " in the Appendix of chapter 3 (A3). In summary, results of the Breusch and Pagan Lagrangian multiplier test show that we must proceed with panel data analysis. In addition, the specification test of Hausman (1978) concludes that the fixed affects model is more appropriate for our data. Furthermore, we measured the variation inflation factor (VIF) of our variables of interest, namely AEE_{it} and $AEEH_{ijt}$. Our findings show that there is no evidence of multicollinearity bias.

On the other hand, overall estimators match their expected signs and are statistically significant. First, importer and exporter GDPs are trade enhancing factors. Second, the distance affects negatively and significantly trade volumes, which is quite intuitive. Third, common borders, languages and colonial background increase significantly agricultural exports.

Regarding our variables of interest, the coefficient of AEE_{it} is negative and statistically significant, suggesting that stringent environmental regulations reduces agricultural exports. As for the variable $AEEH_{ijt}$, parameter estimates are statistically significant and negative. This would indicate that environmental regulations' heterogeneity between two trade partners hampers agricultural trade.

Contrary to standard ordinary least squares (OLS), random effects (RE), fixed effects (FE), and Hausman-Taylor (HT) models, OLS and PPML estimates that consider fixed effects and multilateral resistance terms record high values of R^2 (above 80%). Indeed, the use of different types of fixed effects explains well the variability of the model. Besides, the OLS specification with fixed effects and multilateral resistance terms as well as the PPML model are the only ones to pass the misspecification test. To sum up, estimating our gravity model using OLS and PPML models that control for fixed effects is statistically reliable and is most likely to provide unbiased parameters.

3.5.2. The impact of the exporters' environmental regulation on agricultural trade flows

Results of the econometric analysis are presented in the tables below. From Table 3. 1 to Table 3. 7, odd columns report the standard OLS estimations using the logged dependent variable. On the other hand, even columns present the PPML estimations where the regressand is not logged.

We begin by estimating the effect of exporters' environmental stringency (proxied by the variable AEE_{it}) on the intensive margin of crop commodities' exports. To that end, we use multilateral resistance terms as well as dyadic (exporter-importer) and time fixed effects.

Baseline estimations are presented in Table 3. 1. The first two columns show the results of estimating Eq. (3.10) for the full country sample. Column (1) presents the results of estimating the model with OLS for positive trade flows only, whereas column (2) reports the results of estimating the model with PPML for all trade flows that are not always zero.

All the parameter estimates of the exporter (β^{OLS} =0.36, β^{PPML} =0.23) and importer (β^{OLS} =0.74, β^{PPML} =0.85) gross domestic products present the expected sign and are statistically significant at 1%-level. Countries' economic sizes are clearly relevant and affect positively agricultural exports. Generally, the OLS and PPML results differ as expected due to the change in sample sizes once we account for zero trade flows. Additionally, the coefficient of $Trade\_agr_{ijt}$ turns out to be positive (β^{OLS} =0.07, β^{PPML} =0.02). However, the variable is statistically insignificant in both columns suggesting that the presence of regional, free trade agreement or preferential trade agreement does not affect crop commodities' trade over the 2003-2013 period.

Interestingly, the coefficient of the variable of interest (AEE_{it}), is statistically significant at 10%-level in the first column (β^{OLS} = -0.067) and at 5%-level in the second column (β^{PPML} = -0.018). Additionally, both parameter estimates are negative. This finding clearly shows that overall, the stringency of environmental regulations reduces significantly trade in all countries.

Columns (3) to (8) of Table 3. 1 present the results derived from the estimation of Eq. (3.11) that allows to capture the specific effects of three country groups, namely i/ the EU and USA (columns (3) - (4)), ii/ the CAIRNS group (columns (5) - (6)) and iii/ middle and low income countries (columns (7) - (8)). Overall, our findings show that the parameter estimates of exporters and importers GDPs are similar to the above-mentioned results. They are significantly and positively related to export volumes.

Interestingly, the introduction of specific-effect variables improves the quality of PPML estimates of $Trade\_agr_{ijt}$ that turn out to be statistically significant at 10%-level and range between 0.023 and 0.067. In this regard, we may conclude that once we consider zero trade

flows, having an active trade agreement increases bilateral crop commodities' exports on a global scale.

Regarding environmental aspects, the estimated coefficient of the variable of interest shows interesting results and highlights some specificities among these groups. First, only PPML estimates of the specific effects are statistically significant at 1%-level, with the exception of the CAIRNS group where both OLS and PPML coefficients (columns (5) and (6)) are significant at 1%-level.

In column (4) of Table 3. 1, the PPML estimate of the variable AEE_{it}*UE&USA indicates that, once we consider zero-trade values (that were disregarded by the OLS estimation), the European Union and the United States exhibit a positive specific effect (β^{PPML} =0.12). In this regard, the trade impact of environmental regulation stringency on the European and American bilateral exports is above average (i.e. 0.03) and positive. At the same time, we note that the impact of environmental stringency of the exporting country, reflecting the average value, remains negative for the full sample (β^{PPML} = -0.0877). To sum up, the specific effect of the US and EU exhibits a significant positive trade impact of rigorous environmental regulation.

Surprisingly, we draw the same conclusion from the specific effect of developing countries (AEE_{it}*$LI\&MI_{it}$). In fact, column (8) of Table 3. 1 shows that low and middle income economies record a positive specific effect (β^{PPML} =0.145), whereas the average value remains negative (β^{PPML} = -0.0177). Accordingly, the trade impact of the environmental stringency on developing countries' bilateral exports is above average (i.e. 0.12) and positive. A second interesting fact is that developing countries' positive impact is greater than the one recorded by the EU and USA (i.e. 0.12 > 0.03). In sum, setting up stringent environmental norms enhances clearly the capacity for exporting of middle and low income economies.

Conversely, columns (5) and (6) of Table 3. 1 show that the specific effect recorded by the CAIRNS group is negative and statistically significant using both OLS (β^{OLS} = -0.231) and PPML (β^{PPML} = -0.232) estimation procedures. Moreover, the average impact of AEE_{it} turns out to be positive and exclusively significant when we account for zero trade flows (β^{PPML}=0.0379) as if the CAIRNS group has "absorbed" the trade-restrictiveness effect of the stringency of environmental regulations.

This would suggest that the specific impact is below average for the free agricultural trading countries (i.e. -0.19) and that rigorous environmental regulations adopted by the CAIRNS members reduce clearly their exports. Additionally, this finding indicates that free agricultural trading countries that have recorded high agri-environmental efficiency scores over the period 2003-2013 (c.f. chapter 2, section 2.5.1), namely New Zealand, Costa Rica, Guatemala, Argentina, Indonesia, Malaysia and Vietnam have been losing their capacity for exporting compared to countries with lower scores such as Brazil, Thailand, Peru, Philippines, Australia, Canada, Chile, Paraguay, South Africa or Uruguay.

To sum up, it clearly appears that the stringency of environmental regulations affects bilateral agricultural exports and is significantly trade reducing in all countries. We may therefore conclude that trade in agricultural crop commodities supports the pollution haven hypothesis. This could be related to the increasing production costs induced by the implementation of environmental policies which affect negatively the competitiveness of exporting countries. This is particularly true for the CAIRNS countries characterized by lenient environmental regulations as they gained comparative advantages in pollution-intensive goods and are turned into pollution havens.

However, this finding hides several specificities, suggesting that environmental regulations' elasticity of agricultural trade is affected by the level of development of countries. First, rigorous agri-environmental policies have a significant trade-enhancing effect on bilateral agricultural exports of highly protective and industrialized countries such as the EU and the USA. This seems quite intuitive given the growing awareness of environmental concerns noticed among policy makers and farmers (as highlighted in section 2.2 in chapter 2).

Additionally, the increasing social pressure in these countries has been claiming more sustainable and quality food supply over the past years (Agovino et al., 2019). There is also the fact that agricultural exchanges in high income areas are marked by the supremacy of intra-industry trade in agricultural commodities (Aparicio et al., 2009; Mazerolle & Mucchielli, 1988; Serrano & Pinilla, 2014). Besides, high income countries mostly exchange among themselves and are largely dominated by the intra-European trade as argued in chapter 1.

This finding supports thereby the Porter hypothesis according to which, strict environmental regulations enhance competitive advantage against foreign rivals. Surprisingly, our results show also that developing countries with higher agri-environmental performances export larger volumes of crop commodities, supporting in turn the Porter hypothesis. Following these findings, it could be argued that middle and low income nations are no longer specialized in basic agricultural products for mass consumption as stated by Duarte et al. (2019). Our results suggest that environmental regulations can be seen as an impulse to innovate in developing countries to enhance their productivity and improve their trade competitiveness.

Within this context, are there any particularities among agricultural commodities? To answer this question, we estimate Eq. (3.11) in order to investigate the specific and average effects of environmental regulations' stringency on bilateral exports of two products namely, fruit and vegetables (F&Vs) and cereals. Results are reported in Table 3. 2 and Table 3. 3, respectively. Additionally, we use the same specific effects as above (i.e. the EU and the USA, the CAIRNS group and middle & low income countries).

Table 3. 2 shows that importer and exporter GDPs remain statistically significant at 1%-level and enhance F&Vs exports. However, this sector is not affected by trade agreements ($Trade\_agr_{ijt}$) that turn out to be statistically irrelevant using both OLS and PPML estimation procedures.

Surprisingly, estimated coefficients of the variable of interest back up the results of Table 3. 1. First, average and specific effects of the variable AEE_{it} are mostly significant using the PPML method, except for the specific effect of the CAIRNS group (β^{OLS} = -0.703; β^{PPML} = -0.235) that is relevant at 1%-level in both cases according to columns (5) and (6) of Table 3. 2. This would suggest that the stringency of environmental policies affects F&Vs' trade only when we account for zero trade observations.

Column (4) of Table 3. 2 shows that the EU and the US record a positive specific effect (β^{PPML} =0.156) whereas the average value is negative (β^{PPML} = -0.135). Consequently, their trade impact of environmental regulations' stringency is above average, suggesting that stringent environmental policies enhance their capacity for exporting fruit and vegetables.

We note however that a different trend applies to the CAIRNS. According to column (6), their specific affect is significantly below average (β^{PPML} = -0.235). Once again, the average effect (β^{PPML} = 0.029) become positive once we introduce this specific effect. Thereby, environmental regulations significantly decrease F&Vs' exports of the free agricultural trading countries. Additionally, the PPML estimate of the variable AEE_{it}*LI&MI reported in column (8) in Table 3. 2 indicates that, once we consider zero trade flows, developing countries exhibit a positive specific effect (β^{PPML} =0.181). In this regard, trade effects are clearly above average suggesting that the stringency of environmental regulations enhances their capacity for exporting F&Vs.

To sum up, the F&Vs' sector mostly follows the same pattern as the aggregated crop commodities. Results from Table 3. 2 are mixed and indicate that fruit and vegetables' exports are clearly affected by the level of development of countries. First, results of the CAIRNS group reject the Porter hypothesis in favor of the pollution haven theory. That is to say, more stringent environmental regulations do not enhance, but hinder their exports of F&Vs. Second, and by contrast, developing countries as well as the EU and the USA support the Porter hypothesis. That is to say, rigorous environmental policies turn out to significantly increase their export capacity for exporting these commodities.

The sector of cereals records however different results as reported in Table 3. 3. The same specific effects are introduced, namely the EU and the US (columns (3) and (4)), the CAIRNS group (columns (5) and (6)) and developing countries (columns (7) and (8)). Overall, exporter and importer GDPs remain statistically significant at 1%-level and record positive PPML and OLS coefficients. Nonetheless, trade agreements are mostly irrelevant for bilateral exports of cereals.

The average effect of the variable AEE_{it} reported in columns (3), (4), (5), (6), (7) and (8) of Table 3. 3 is positive, yet statistically insignificant whether zero trade flows are dropped or not. The statistical robustness is clearly lower than the first two sectors (i.e. total crop commodities and F&Vs) suggesting that export capacity of cereals is moderately sensitive to the stringency of environmental regulations.

Results of columns (5) and (6) support this finding and show that free agricultural trading countries exhibit irrelevant specific and average effects. In this regard, environmental regulations' stringency does not affect cereal exports of the CAIRNS group. The EU and USA record however a positive and statistically significant specific effect (β^{PPML} = 0.242 in column (4)) when zero trade observations are considered. Similarly, developing countries (column (8)) exhibit a positive and a statistically relevant (at 10%-level) specific effect (β^{PPML} = 0.115). Accordingly, the trade impact of environmental stringency is above average for both groups which supports the Porter hypothesis.

To sum up, our findings suggest that environmental regulations affect much less cereal bilateral exports compared to the sector of fruit and vegetables. Interestingly, developing countries support once again the Porter hypothesis. Rigorous environmental policies enhance significantly their cereal export potential. The EU and USA show the same tendency suggesting that their agri-environmental regulations increase their cereal export volumes. We note from these findings that agricultural commodities react differently to agri-environmental policies. The sector of F&Vs is clearly more sensitive to this variable unlike cereals that remain relatively less affected.

We complement these results by running estimations using the lagged values of AEE_{it} by two periods (k=1 and k=2 in Eq. (3.10)). Detailed results are reported in Table A3. 9 and Table A3. 10 in the Appendix of chapter 3 (A3). To provide an easy reading, we summarize all the OLS and PPML parameter estimates in Table 3. 4 by showing a breakdown by three sectors, namely total crop commodities (columns (1) and (2)), F&Vs (columns (3) and (4)) and cereals (columns (5) and (6)).

Column (2) exhibits negative and significant coefficients (at 1%-level) of the first and second lags of AEE_{it}. This would indicate that previous environmental policies exert persistent decreasing effect on crop commodities' export volumes when zero trade observations are not omitted. In addition, OLS estimates confirm this finding. However, only the first lag shows a statistically significant coefficient (β^{OLS} = -0.136). The overall pollution haven hypothesis is thereby imbedded within previous environmental regulations.

Moreover, the sector of F&Vs support this finding since $AEE_{i(t-1)}$ and $AEE_{i(t-2)}$ show relevant and negative parameter estimates using the PPML procedure (-0.111 and -0.131 respectively). Previous stringent regulations clearly decrease the export potential of fruit and vegetables.

Nonetheless, cereals exhibit different results. PPML coefficients of the lags are statistically irrelevant despite their positive sign, confirming thereby the previous results. Overall, the stringency of old and current environmental regulations do not matter for cereal exports of the full country sample. However, the trade-enhancing effect of the first and second lags of AEE_{it} turns out to be statistically significant when zero trade flows are dropped ($\beta^{OLS}_{AEE_{i(t-1)}} = 0.3$; $\beta^{OLS}_{AEE_{i(t-2)}} = 0.143$). Consequently, only OLS estimates support the Porter hypothesis in the sector of cereals.

Table 3. 1. Impact of environmental regulations' stringency on exports of crop commodities

	Dependent: total crop commodities' bilateral exports							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	OLS	PPML	OLS	PPML	OLS	PPML	OLS	PPML
$LnGDP_{it}$	0.369***	0.239***	0.241***	0.379***	0.358***	0.249***	0.367***	0.247***
	(0.0425)	(0.0257)	(0.0259)	(0.0427)	(0.0426)	(0.0259)	(0.0425)	(0.0260)
$LnGDP_{jt}$	0.749***	0.856***	0.856***	0.748***	0.751***	0.855***	0.749***	0.857***
	(0.0396)	(0.0282)	(0.0283)	(0.0396)	(0.0396)	(0.0283)	(0.0396)	(0.0283)
MR_{it}	-2.329*	1.302	1.170	-2.526*	-3.356**	0.317	-2.054	0.660
	(1.411)	(0.844)	(0.841)	(1.414)	(1.454)	(0.852)	(1.440)	(0.863)
MR_{jt}	-6.494***	-3.832***	-3.835***	-6.472***	-6.535***	-3.658***	-6.512***	-3.662***
	(1.478)	(0.736)	(0.738)	(1.478)	(1.479)	(0.740)	(1.479)	(0.738)
$Trade\_agr_{ijt}$	0.0718	0.0241	0.0244	0.0675*	0.0724	0.0266*	0.0726	0.0239*
	(0.0409)	(0.0292)	(0.0292)	(0.0408)	(0.0409)	(0.0283)	(0.0408)	(0.0289)
$LnAEE_{it}$	**-0.0674***	**-0.0182****	-0.0242	-0.0877**	0.0179	0.0379*	-0.117**	-0.0177*
	(0.0403)	(0.0225)	(0.0232)	(0.0413)	(0.0505)	(0.0253)	(0.0531)	(0.0243)
$LnAEE_{it}$*UE & USA			**0.0305**	**0.120*****				
			(0.0363)	(0.0445)				
$LnAEE_{it}$*CAIRNS					**-0.231*****	**-0.232*****		
					(0.0690)	(0.0371)		
$LnAEE_{it}$*LI & MI							**0.0790**	**0.145*****
							(0.0690)	(0.0419)
Constant	3.353*	-5.442*	-5.213*	3.479**	5.944**	-3.946**	2.850*	-4.693**
	(5.132)	(2.927)	(2.927)	(5.131)	(5.236)	(2.935)	(5.150)	(2.951)
exporter-time FE	no	no	no	no	no	no	no	no
importer-time FE	no	no	no	no	no	no	no	no
bilateral FE	yes	yes	yes	yes	yes	yes	yes	yes
time FE	yes	yes	yes	yes	yes	yes	yes	yes
Observations	58,165	85,106	85,106	58,165	58,165	85,106	58,165	85,106
R-squared	0.880	0.950	0.980	0.880	0.880	0.989	0.880	0.989

Source: The table is created by the author. Odd columns use the OLS estimator whereas even columns use the PPML estimator. Bilateral and year fixed effects are included in all estimations. Multilateral resistance terms are included as regressors to obtain unbiased estimates. Robust standard errors are reported in parentheses. The p-values read as follows: *** p<0.01, ** p<0.05, * p<0.1. LI: low income countries. MI: middle income countries.

Table 3. 2. Impact of environmental regulations' stringency on exports of fruit and vegetables

	Dependent: Fruit and vegetables' bilateral exports							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	OLS	PPML	OLS	PPML	OLS	PPML	OLS	PPML
$LnGDP_{it}$	0.369***	0.239***	0.427***	0.256***	0.394***	0.251***	0.410***	0.250***
	(0.0425)	(0.0257)	(0.0770)	(0.0267)	(0.0761)	(0.0263)	(0.0762)	(0.0264)
$LnGDP_{jt}$	0.749***	0.856***	0.954***	0.871***	0.957***	0.867***	0.954***	0.869***
	(0.0396)	(0.0282)	(0.0674)	(0.0285)	(0.0674)	(0.0285)	(0.0674)	(0.0285)
MR_{it}	-2.329*	1.302	-7.495***	0.506	-10.41***	0.239	-5.686**	0.406
	(1.411)	(0.844)	(2.560)	(0.856)	(2.613)	(0.857)	(2.630)	(0.866)
MR_{jt}	-6.494***	-3.832***	-10.43***	-2.917***	-10.67***	-2.943***	-10.52***	-2.897***
	(1.478)	(0.736)	(2.468)	(0.725)	(2.466)	(0.727)	(2.467)	(0.726)
$Trade\_agr_{ijt}$	0.0718	0.0241	0.0943	0.0293	0.104	0.0326	0.0951	0.0301
	(0.0409)	(0.0292)	(0.0698)	(0.0299)	(0.0698)	(0.0295)	(0.0700)	(0.0303)
$LnAEE_{it}$	**-0.0674**	**-0.0182****	-0.0413	-0.135***	0.319	0.0292***	-0.164	-0.0149*
	(0.0403)	(0.0225)	(0.0748)	(0.0309)	(0.0817)	(0.0248)	(0.0859)	(0.0245)
$LnAEE_{it}$*UE & USA			**0.0681**	**0.156*****				
			(0.0703)	(0.0322)				
$LnAEE_{it}$*CAIRNS					**-0.703*****	**-0.235*****		
					(0.118)	(0.0373)		
$LnAEE_{it}$*LI & MI							**0.433**	**0.181*****
							(0.122)	(0.0425)
Constant	3.353**	-5.442*	14.91*	-6.557**	22.57**	-5.671*	11.70	-6.162**
	(5.132)	(2.927)	(8.833)	(2.974)	(8.940)	(2.952)	(8.919)	(2.976)
exporter-time FE	no	no	no	no	no	no	no	no
importer-time FE	no	no	no	no	no	no	no	no
bilateral FE	yes	yes	yes	yes	yes	yes	yes	yes
time FE	yes	yes	yes	yes	yes	yes	yes	yes
Observations	58,165	85,106	58,165	85,106	85,106	58,165	58,165	85,106
R-squared	0.880	0.9898	0.866	0.990	0.866	0.991	0.866	0.984

Source: The table is created by the author. Odd columns use the OLS estimator whereas even columns use the PPML estimator. Bilateral and year fixed effects are included in all estimations. Multilateral resistance terms are included as regressors to obtain unbiased estimates. Robust standard errors are reported in parentheses. The p-values read as follows: *** p<0.01, ** p<0.05, * p<0.1. LI: low income countries. MI: middle income countries.

Table 3. 3. Impact of environmental regulations' stringency on bilateral exports of cereals

	Dependent: Cereal bilateral exports							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	OLS	PPML	OLS	PPML	OLS	PPML	OLS	PPML
$LnGDP_{it}$	0.260***	0.324***	0.258***	0.314***	0.265***	0.323***	0.369***	0.245***
	(0.0576)	(0.0771)	(0.0577)	(0.0749)	(0.0576)	(0.0750)	(0.0426)	(0.0258)
$LnGDP_{jt}$	0.268***	0.339***	0.269***	0.341***	0.268***	0.339***	0.749***	0.856***
	(0.0538)	(0.0701)	(0.0538)	(0.0696)	(0.0538)	(0.0696)	(0.0396)	(0.0283)
MR_{it}	-4.132**	-2.615	-4.604**	-3.036*	-4.377**	-2.843	-2.334*	1.227
	(1.857)	(1.839)	(1.853)	(1.801)	(1.857)	(1.806)	(1.412)	(0.847)
MR_{jt}	-8.663***	2.198	-8.784***	2.161	-8.782***	2.139	-6.492***	-3.664***
	(2.063)	(2.292)	(2.062)	(2.300)	(2.062)	(2.302)	(1.478)	(0.740)
$Trade\_agr_{ijt}$	0.0470	0.112	0.0563	0.114	0.0546	0.112	0.0717*	0.0219
	(0.0532)	(0.0814)	(0.0532)	(0.0803)	(0.0532)	(0.0804)	(0.0409)	(0.0286)
$LnAEE_{it}$	**0.190*** **	**0.0239**	0.188	0.0322	0.219	0.0250	0.0138	0.0777
	(0.0561)	(0.0789)	(0.0388)	(0.0333)	(0.0438)	(0.0360)	(0.00311)	(0.0308)
$LnAEE_{it}$*UE & USA			**0.146**	**0.242***				
			(0.102)	(0.118)				
$LnAEE_{it}$*CAIRNS					**-0.0335**	**-0.0138**		
					(0.0757)	(0.0418)		
$LnAEE_{it}$*LI & MI							**0.0207**	**0.115***
							(0.0901)	(0.0359)
Constant	19.75***	-4.888***	20.90***	-3.679**	20.22***	-4.243**	2.125***	-11.82***
	(6.893)	(7.353)	(6.905)	(7.594)	(6.909)	(7.608)	(0.764)	(1.737)
exporter-time FE	no	no	no	no	no	no	no	no
importer-time FE	no	no	no	no	no	no	no	no
bilateral FE	yes	yes	yes	yes	yes	yes	yes	yes
time FE	yes	yes	yes	yes	yes	yes	yes	yes
Observations	55,243	55,247	58,165	85,106	85,106	58,165	58,165	85,106
R-squared	0.838	0.9525	0.838	0.952	0.838	0.955	0.759	0.916

Source: The table is created by the author. Odd columns use the OLS estimator whereas even columns use the PPML estimator. Bilateral and year fixed effects are included in all estimations. Multilateral resistance terms are included as regressors to obtain unbiased estimates. Robust standard errors are reported in parentheses. The p-values read as follows: *** p<0.01, ** p<0.05, * p<0.1. LI: low income countries. MI: middle income countries.

Table 3. 4. Impact of previous environmental policies on current agricultural bilateral exports

	Total crop commodities		F&Vs		cereals	
	(1) OLS	(2) PPML	(3) OLS	(4) PPML	(5) OLS	(6) PPML
$LnAEE_{it}$	-0.0674*	-0.0182**	-0.0674	-0.0182**	0.190***	0.0239
$LnAEE_{i(t-1)}$	-0.136*	-0.122***	-0.0554	-0.111***	0.300*	0.356
$LnAEE_{i(t-2)}$	-0.126	-0.129***	-0.122***	-0.131***	0.143*	0.324

Source: The table is created by the author. Odd columns use the OLS estimator whereas even columns use the PPML estimator. This table provides a summary of trade impact of exporters' environmental stringency on three sectors, namely total crop commodities, fruit and vegetables and cereals, using the first ($AEE_{i(t-1)}$) and second ($AEE_{i(t-2)}$) lags of the variable AEE_{it}. The parameter estimates of AEE_{it} in columns (1) and (2) are extracted from Table 3. 1. The estimated coefficients of AEE_{it} in columns (3) and (4) are extracted from Table 3. 2. The estimated coefficients of AEE_{it} in columns (5) and (6) are extracted from Table 3. 3. Finally, the parameter estimates of $AEE_{i(t-1)}$ and $AEE_{i(t-2)}$ are extracted from Table A3. 9 and Table A3. 10 (in the appendix of chapter 3), respectively. The p-values read as follows: *** p<0.01, ** p<0.05, * p<0.1.

3.5.3. Does environment regulations' heterogeneity matter for agricultural trade?

Baseline estimations of Eq. (3.12) are reported in Table 3. 5. In this section, we investigate the trade impact of the difference in exporter and importer environmental regulations. In other words, we estimate the effect of environmental regulations' heterogeneity, denoted as $AEEH_{ijt}$, on the intensive margin of crop commodities' exports. The first two columns of Table 3. 5 show respectively the OLS and PPLM results of estimating the model for the full country sample using bilateral fixed effects.

In addition, $AEEH_{ijt}$ varies across exporters, importers and time. Thereby, we drop the time-varying multilateral resistance indices and introduce exporter-time and importer-time fixed effects to control for the unobserved heterogeneity. This method provides unbiased parameters and has strong implications on the robustness of our results. As shown in Table 3. 5, R-squared values range between 80% and 90% indicating that the use of three dimensions of FE explains nearly the overall variability of our model.

Columns (1), (3) and (5) show that the effect of trade agreements is positive and not robust according to the OLS results. By contrast, $Trade\_agr_{ijt}$ exhibits a positive and statistically significant parameter estimates ($\beta^{PPML} \simeq 0.04$) as shown in columns (2), (4) and (6). This finding suggests that trade agreements increase bilateral crop commodities' exports when we account for zero trade observations.

Interestingly, the environmental heterogeneity exhibits relevant (at 5%-level) and negative coefficients in both columns (1) and (2) (respectively -0.00869 and -0.0072). This finding has two interpretations. First, it would suggest that the gap between environmental regulations of two trade partners hampers slightly but significantly their bilateral agricultural exports. Second, and surprisingly, the effect of their environmental heterogeneity outweighs (statistically) their trade agreements.

In order to check the robustness of our results, we introduce the lagged values of the gap measure. The trade impact of the first lag ($AEEH_{ij\ (t-1)}$) is reported in columns (3) and (4). We note that our results are consistent with the previous findings since OLS and PPML parameter estimates (respectively -0.0029 and -0.0048) are negative and statistically significant at 5%-level. Moreover, the trade reducing effect of environmental regulations' heterogeneity is reaffirmed by the results of the second lag ($AEEH_{ij\ (t-2)}$) in columns (5) and (6). Both of its OLS and PPML coefficients ($\beta^{OLS} \simeq \beta^{PPML} \simeq -0.03$) are negative and statistically relevant at 5%-level. To sum up, and leaving aside other country characteristics, we conclude that the larger the environmental gap between two trade partners, the lower the volumes of crop commodities' exports are. Additionally, and statistically speaking, this effect is more relevant to agricultural trade than trade agreements.

Considering products' heterogeneity, we can assess the robustness of the main results observed in Table 3. 5 and derive specific patterns for two groups of commodities, namely fruit and vegetables and cereals.

Table 3. 6 displays the estimations of Eq. (3.12) related to bilateral exports of fruit and vegetables ($X_{ijt}^{F\&V}$). OLS and PPML parameter estimates reported in columns (1) and (2) are statistically significant (respectively at 5 and 1%-level) and present a negative sign. This finding suggests that environmental policies' heterogeneity hampers F&Vs' trade volumes of the exporting country. OLS and PPML results of the first lag of the gap measure (i.e. $AEEH_{ij\ (t-1)}$) are reported in columns (3) and (4), respectively. The parameter estimates are statistically relevant and exhibit the same sign as the previous ones.

This confirms that bilateral environmental heterogeneity significantly reduces F&Vs exports. On the contrary, results reported in columns (5) and (6) show that the second ($AEEH_{ij\ (t-2)}$) lag is statistically irrelevant despite its negative parameter estimate. Finally, it is worthwhile to note that OLS and PPML coefficients of the variable $Trade\_agr_{ijt}$ in Table 3. 6 are positive, yet statistically insignificant. This would suggest that trade agreements are irrelevant for the country's export capacity for most fruit and vegetables.

Additionally, we check whether and to what extent cereal exports are affected by environmental heterogeneity. To that end, we estimate Eq. (3.12) using $X_{ijt}^{cereals}$ as the dependent variable and report the results in Table 3. 7. Contrary to the first sector, OLS and PPML coefficients of the variable of interest $AEEH_{ijt}$ (respectively -0.024 and -0.008) are

negative and statistically insignificant. This would suggest that environmental policies' heterogeneity between trade partners do not affect the capacity of cereal exports.

The parameter estimates of the first ($AEEH_{ij\ (t-1)}$) and second ($AEEH_{ij\ (t-2)}$) lagged values of $AEEH_{ijt}$ show the same pattern as they are found to be negative and statistically irrelevant (columns (3) to (6)). We note also that OLS coefficients of the variable $Trade\_agr_{ijt}$ are positive and statistically significant at 10%-level in columns (1), (3) and (5), whereas PPML estimates are irrelevant. Trade agreements do clearly enhance cereal exports but only when zero trade observations are dropped.

To sum up, it is worthwhile to note that the sector of cereals is less sensitive to difference in exporter and importer environmental regulations than fruit and vegetables. That is to say, more heterogeneous environmental regulations between an exporter and a destination country result in a lower export capacity of F&Vs to that destination. However, cereal exports remain unaffected by this gap.

In this regard, and considering country heterogeneity, we can further assess the robustness of the main results and derive specific patterns for each income group. To that end, and as a final exercise, we investigate the trade impact of environmental regulations' heterogeneity according to the income group of the exporting country. Three categories are distinguished, namely high income (HI), in transition (BRICS) and developing (LI&MI) countries.

Results are reported in Table A3. 11, Table A3. 12 and Table A3. 13 in the appendix of chapter 3, respectively. In these tables, importing countries are in turn divided into three categories: high income (HI), in transition (BRICS) and developing (LI&MI) countries.

Table 3. 5. Impact of environment regulations' heterogeneity on exports of crop commodities

	Dependent: total crop commodities' bilateral exports					
VARIABLES	(1) OLS	(2) PPML	(3) OLS	(4) PPML	(5) OLS	(6) PPML
$Trade\_agr_{ijt}$	0.105	0.0426*	0.107	0.0455**	0.110	0.0464**
	(0.0764)	(0.0220)	(0.0764)	(0.0223)	(0.0764)	(0.0224)
$lnAEEH_{ijt}$	**-0.00869****	**-0.0072****				
	(0.0624)	(0.00342)				
$lnAEEH_{ij(t-1)}$			**-0.00299****	**-0.0048****		
			(0.00816)	(0.00201)		
$lnAEEH_{ij(t-2)}$					**-0.00329****	**-0.00309****
					(0.00821)	(0.00192)
$lnAEEH_{ij(t-3)}$						
Constant	11.83***	19.82***	11.76***	19.81***	11.77***	19.82***
	(0.0541)	(0.0204)	(0.0332)	(0.0162)	(0.0334)	(0.0161)
exporter-time FE	yes	yes	yes	yes	yes	yes
importer-time FE	yes	yes	yes	yes	yes	yes
bilateral FE	yes	yes	yes	yes	yes	yes
Observations	58,165	85,106	58,165	85,106	58,165	85,106
R-squared	0.8595	0.9942	0.882	0.9942	0.882	0.9942

Source: The table is created by the author. Odd columns use the OLS estimator whereas even columns use the PPML estimator. Dyadic, importer-time and exporter-time fixed effects are included in all estimations. $AEEH_{ijt}$ measures the agri-environmental policies' heterogeneity between the exporter i and the importer j. This variable is denoted as $AEEH_{ijt}$, where $AEEH_{ijt}=\left|AEE_{it}-AEE_{jt}\right|$. $AEEH_{ij(t-1)}$ and $AEEH_{ij(t-2)}$ are respectively the first and second lags of the variable $AEEH_{ijt}$. Robust standard errors are reported in parentheses. The p-values read as follows: *** p<0.01, ** p<0.05, * p<0.1.

According to columns (1) and (2) of Table A3. 11, crop commodities' flows between high income countries are driven by trade agreements since both of OLS and PPML parameter estimates (respectively 0.0381 and 0.00709) are positive and statistically significant. Nevertheless, bilateral gap variable has a negative sign using both estimation techniques (β^{OLS} = -0.0166; β^{PPML} = -0.00531) and is statistically relevant. In other words, heterogeneous environmental regulations conducted by two high income (HI) partners would lead to a lower level of trade.

In addition, trade agreements turn out to enhance agricultural exports of HI countries to the BRICS when zero trade observations are considered (β^{PPML} = 0.166). Surprisingly, the gap variable has a positive sign and is statistically significant according to columns (3) and (4) despite its low coefficients (β^{OLS} = 0.0160; β^{PPML} = 0.000381). This would suggest that difference in exporter and importer environmental regulations enhances slightly but significantly agricultural exports of developed countries to the BRICS. Finally, and according to the last two columns of Table A3. 11, crop exports of high income to developing countries are not affected by trade agreements, nor by the environmental regulations' heterogeneity.

Results of emerging exporting countries are reported in Table A3. 12 in which we differentiate between three groups of importers: developed, emerging and developing countries. First, we note that preferential and regional trade agreements are not crucial for agricultural exports of the BRICS, regardless of the income group of the importing country. An exception to this finding is their crop commodities' exports to low and middle income countries that are positively affected by trade agreements when zero trade flows are omitted (β^{OLS} = 0.105) (column (5) of Table A3. 12).

Further findings suggest that environmental regulations' gap does not affect crop exports of the BRICS to other emerging countries (columns (3) and (4)). The same finding applies to low and middle income destinations since both OLS and PPML coefficients are not statistically different from zero. However, difference in exporter and importer environmental regulations reduces significantly (at 1%-level) emerging countries' exports to developed nations. In fact, columns (1) and (2) show that OLS and PPML parameter estimates are negative and statistically significant at 1%-level.

Regarding low and middle income exports, our estimates are presented in Table A3. 13 in the Appendix of chapter 3 (A3). The latter indicates that bilateral and regional trade agreements do not affect their crop commodities' exports to developed (columns (1) and (2)) and emerging (columns (3) and (4)) importing countries. Nonetheless, the existence of trade agreements triggers agricultural exports between developing countries as both OLS and PPML coefficients (respectively 0.07 and 0.01) are positive and statistically relevant at 5%-level (columns (5) and (6)).

In addition, the variable of interest shows negative and statistically significant OLS (columns (1) and (5)) and PPML (columns (2) and (6)) coefficients for high income and developing

importing countries. These findings suggest that environmental heterogeneity hinders developing countries' exports to high income nations. Additionally, developing countries conducting homogeneous environmental standards have more tendency to trade crop commodities with each other.

Nonetheless, the environmental gap does not affect LI and MI countries' exports to the BRICS. According to columns (3) and (4) of Table A3. 13, both OLS ($\beta = -0.0236$) and PPML ($\beta = -0.018$) parameter estimates are statistically irrelevant.

In sum, countries breakdown by income groups reveals interesting patterns. First, the most sensitive import area to environmental regulations' gap is clearly high income countries. This would suggest that they have more tendency to trade with agricultural suppliers characterized by similar environmental stringency. Accordingly, developing and emerging countries are more likely to export to developed markets by levelling their environmental standards.

Second, emerging markets show a different tendency. The BRICS are clearly importing from developed countries where the environmental difference is relatively important. It is likely that the BRICS are witnessing a growing demand of high quality and "green" crop commodities as argued by Bruschi et al. (2015), Feil et al., (2020), Nguyen et al., (2019) and Thøgersen et al. (2015). Our findings suggest that high income exporters are seizing this market since they have the resources and technology to meet this demand. By contrast, agricultural imports of the BRICS are not affected by environmental heterogeneity when the supplier is a developing or another emerging country.

Third, environmental regulations' gap does not affect the imports of developing countries coming from high income and emerging economies. But surprisingly, low and middle income countries with the same level of environmental rigor are more likely to trade crop commodities. In the absence of studies using this specific variable, we are unable to check the validity of our findings.

Despite their different methodology, Ferro et al. (2015) have investigated the impact that food safety standards have on international exports of agricultural products using a standards restrictiveness index. Interestingly, our findings back up their results. The latter show that differences in standards between high income importers and low income exporters hampers agricultural trade. The authors argue that supply side constraints, namely the lack of financial and technological resources are the main reasons that prevent these countries from complying with these standards.

Table 3. 6. Impact of environment regulations' heterogeneity on exports of fruit and vegetables

	Dependent: fruit and vegetables' bilateral exports					
VARIABLES	(1) OLS	(2) PPML	(3) OLS	(4) PPML	(5) OLS	(6) PPML
$Trade\_agr_{ijt}$	0.0669	0.00650	0.0670	0.00967	0.0668	0.0101
	(0.0435)	(0.0216)	(0.0435)	(0.0218)	(0.0435)	(0.0219)
$lnAEEH_{ijt}$	**-0.0148****	**-0.00677*****				
	(0.00863)	(0.00340)				
$lnAEEH_{ij(t-1)}$			**-0.00368****	**-0.00497****		
			(0.00463)	(0.00197)		
$lnAEEH_{ij(t-2)}$					**-0.000740**	**-0.00262**
					(0.00461)	(0.00193)
$lnAEEH_{ij(t-3)}$						
Constant	13.28***	19.77***	13.30***	19.77***	13.30***	19.78***
	(0.0207)	(0.0162)	(0.0188)	(0.0156)	(0.0187)	(0.0155)
exporter-time FE	yes	yes	yes	yes	yes	yes
importer-time FE	yes	yes	yes	yes	yes	yes
bilateral FE	yes	yes	yes	yes	yes	yes
Observations	58,165	85,106	58,165	85,106	58,165	85,106
R-squared	0.892	0.9935	0.892	0.9935	0.882	0.9935

Source: The table is created by the author. Odd columns use the OLS estimator whereas even columns use the PPML estimator. Dyadic, importer-time and exporter-time fixed effects are included in all estimations. $AEEH_{ijt}$ measures the agri-environmental policies' heterogeneity between the exporter i and the importer j. This variable is denoted as $\mathrm{AEEH_{ijt}}$, where $\mathrm{AEEH_{ijt}}=\left|\mathrm{AEE_{it}}-\mathrm{AEE_{jt}}\right|$. $AEEH_{ij(t-1)}$ and $AEEH_{ij(t-2)}$ are respectively the first and second lags of the variable $AEEH_{ijt}$. Robust standard errors are reported in parentheses. The p-values read as follows: *** p<0.01, ** p<0.05, * p<0.1.

Table 3. 7. Impact of environment regulations' heterogeneity on exports of cereals

	Dependent: cereal bilateral exports					
VARIABLES	(1) OLS	(2) PPML	(3) OLS	(4) PPML	(5) OLS	(6) PPML
$Trade\_agr_{ijt}$	0.0972*	0.0548	0.0970*	0.0539	0.0979*	0.0547
	(0.0576)	(0.0754)	(0.0576)	(0.0756)	(0.0576)	(0.0754)
$lnAEEH_{ijt}$	**-0.024**	**-0.00808**				
	(0.0125)	(0.00983)				
$lnAEEH_{ij(t-1)}$			**-0.00188**	**-0.00416**		
			(0.00639)	(0.00577)		
$lnAEEH_{ij(t-2)}$					**-0.00852**	**-0.00117**
					(0.00633)	(0.00499)
$lnAEEH_{ij(t-3)}$						
Constant	5.677***	13.28***	5.705***	12.50***	5.697***	12.50***
	(0.0284)	(0.0207)	(0.0254)	(0.0472)	(0.0253)	(0.0457)
exporter-time FE	yes	yes	yes	yes	yes	yes
importer-time FE	yes	yes	yes	yes	yes	yes
bilateral FE	yes	yes	yes	yes	yes	yes
Observations	58,165	58,165	58,165	85,106	58,165	85,106
R-squared	0.856	0.892	0.856	0.9678	0.856	0.9678

Source: The table is created by the author. Odd columns use the OLS estimator whereas even columns use the PPML estimator. Dyadic, importer-time and exporter-time fixed effects are included in all estimations. $AEEH_{ijt}$ measures the agri-environmental policies' heterogeneity between the exporter i and the importer j. This variable is denoted as $AEEH_{ijt}$, where $AEEH_{ijt}=|AEE_{it} - AEE_{jt}|$. $AEEH_{ij(t-1)}$ and $AEEH_{ij(t-2)}$ are respectively the first and second lags of the variable $AEEH_{ijt}$. Robust standard errors are reported in parentheses. The p-values read as follows: *** p<0.01, ** p<0.05, * p<0.1.

3.6. Conclusions and policy implications

This chapter assesses trade effects of agri-environmental policies on crop commodities' exports. It represents a step forward in the study of the main drivers of agricultural trade through environmental regulations. On the one hand, the chapter investigates whether the agricultural sector support Porter (1991) theory or favor the pollution haven hypothesis. On the other hand, this research furthers the analysis by determining the effect of regulations' heterogeneity, highly determined by the level of development of origin and destination countries.

In this regard, we have proposed a gravity model in which traditional gravity variables have been introduced as regressors together with environmental determinants. Our results support the conclusions found in the economic literature concerning the economic variables, i.e., the existence of economic sizes' effects, the significant role of geographical distance and institutional factors driving agricultural trade.

As we have seen, the stringency of environmental regulations affects bilateral agricultural exports. Considering the income heterogeneity of countries, it turns out to be trade reducing in the CAIRNS group, supporting thereby the pollution haven hypothesis. This finding suggests that free agricultural trading countries that have recorded high agri-environmental efficiency scores over the period 2003-2013, namely New Zealand, Costa Rica, Guatemala, Argentina, Indonesia, Malaysia and Vietnam have been losing their capacity for exporting compared to countries with lower scores such as Brazil, Thailand, Peru, Philippines, Canada, Chile, or Uruguay. This would explain the growing environmentally-related conflictual relation that is spreading within southern agro-producers, argued in chapter 1. The finding suggests that CAIRNS members characterized by lenient environmental regulations has gained comparative advantages in pollution-intensive goods and are turned into pollution havens.

By contrast, rigorous agri-environmental policies have a significant trade-enhancing effect on bilateral agricultural exports of the EU and the United States. This seems quite intuitive given the growing awareness of environmental concerns noticed among policy makers and farmers. Besides, the increasing social pressure has been claiming more sustainable and quality food supply in these countries. Accordingly, the EU and USA support the Porter hypothesis according to which, strict environmental regulations enhance competitive advantage against foreign rivals.

Surprisingly, low and middle income countries record the same pattern since higher environmental performances enhance their exports of crop commodities. Following these results, it could be argued that developing nations are no longer specialized in basic agricultural products for mass consumption as stated by Duarte et al. (2019). This would suggest that environmental regulations can be seen as an impulse to innovate in developing countries in order to enhance their productivity and improve their trade competitiveness.

In addition, we conclude that agricultural commodities react differently to environmental regulations. The sector of fruit and vegetables is more sensitive to this determinant unlike cereals that remain relatively less affected.

Further results show that difference in exporter and importer environmental regulations is more relevant to agricultural trade than trade agreements. In fact, the environmental gap between two partners is decreasing slightly, but significantly crop commodities' exports according to our results. On the other hand, countries breakdown by income groups revealed interesting patterns. First, high income countries have more tendency to trade with countries characterized by similar environmental stringency. Accordingly, developing and emerging countries are more likely to export to developed markets by levelling their environmental standards.

Second, the BRICS are clearly importing from developed countries where the environmental difference is relatively important. It is likely that the BRICS are witnessing a growing demand of high quality and "green" crop commodities. This would suggest that high income exporters are seizing this market since they have the resources and technology to meet this demand. Third, environmental regulations' gap does not affect the imports of developing countries coming from high income and emerging economies. But surprisingly, low and middle income countries with the same level of environmental stringency are more likely to trade crop commodities.

Besides their significant role in resource and biodiversity conservation, agri-environmental policies turn out to be determinant for agricultural trade. Knowing that the stringency of environmental regulations has trade effects is thus interesting for policy makers. Political implications of these results are as follows: First, it is illusory to consider bilateral or regional trade agreements capable, on their own, of increasing agricultural trade. Indeed, our findings suggest that agricultural exporting capacity can be enhanced by ecological and sustainable upstream production systems. The environmental issue is therefore essential to be taken into consideration when establishing new agreements.

In the absence of upstream support measures and given the vulnerability of agricultural products, agricultural trade liberalization can, however, only bring a partial benefit, particularly to developing countries. Accordingly, support for the modernization and adoption of new technologies that respect the environment and meet the requirements of the high income market is necessary so that southern countries can truly benefit from the liberalization of agricultural trade.

Moreover, the potential growing demand of high quality and "green" crop commodities in emerging countries is an important area of research that should be investigated using a demand-based framework. This could reveal a new market for developing countries. Finally, the harmonization of agri-environmental measures is strongly recommended and should increase the competitiveness of the sector.

This raises an important point regarding indented trade agreements or those under negotiation. Indeed, it is important to consider the slowness of the transformation of agricultural production systems (namely the conversion to organic farming, training and adaptation of farmers to new technologies, etc.). Therefore, suitable timelines must be taken into account. We suggest that an international consensus should be found on agri-environmental measures that should be the most effective in addressing climate change and the least distorting in international markets.

3.7. Appendix of chapter 3 (A3)

Table A3. 1. List of countries

Income Group	Countries
High income countries	Argentina, Australia, Austria, Belgium, Canada, Chile, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Israel, Italy, Japan, Latvia, Lithuania, Luxembourg, Malta, Netherlands, New Zealand, Norway, Oman, Poland, Portugal, Republic of Korea, Saudi Arabia, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom, United States of America, Uruguay, Bolivarian Republic of Venezuela
BRICS	Brazil, China, India, Russian Federation and South Africa.
Upper and lower middle-income countries	Albania, Algeria, Armenia, Azerbaijan, Bangladesh, Belarus, Belize, Bolivia, Bosnia and Herzegovina, Bulgaria, Cameroon, Colombia, Costa Rica, Côte d'Ivoire, Dominican Republic, Ecuador, Egypt, El Salvador, Georgia, Ghana, Guatemala, Honduras, Indonesia, Jamaica, Jordan, Kazakhstan, Kenya, Lebanon, Libya, Malaysia, Mexico, Morocco, Namibia, Nigeria, Pakistan, Panama, Paraguay, Peru, Philippines, Romania, Senegal, Syrian Arab Republic, Thailand, Tunisia, Turkey, Ukraine, Vietnam, Yemen, Zambia
Low income countries	Benin, Burkina Faso, Burundi, Cambodia, Ethiopia, Gambia, Madagascar, Mozambique, Niger, United Republic of Tanzania, Togo, Uganda, Zimbabwe

Source: The table is created by the author based on the World Bank classification (World Bank, 2019b).

Table A3. 2. Description of the variables

Label	Definition	Source
X_{ijt}	Trade flows concerning crop commodities' exports from country i to j in year t, measured in US$.	UN Comtrade (UN, 2019)
$X_{ijt}^{F\&V}$	Value of exports of vegetables and fruit from country i to j, in US$.	UN Comtrade (UN, 2019)
$X_{ijt}^{cereals}$	Value of exports of cereals and preparations from country i to j, in US$.	UN Comtrade (UN, 2019)
GDP_{it}	Gross domestic product of country i in year t, in US$.	World Bank (2019c)
GDP_{jt}	Gross domestic product of country j in year t, in US$.	World Bank (2019c)
$Dist_{ij}$	Bilateral distance between the capital cities of the exporter and the importer, measured in kilometers.	CEPII (2019)
$Contig_{ij}$	A dummy variable that takes the value 1 if the importer and the exporter share a common border, and zero otherwise.	CEPII (2019)
$Lang_{ij}$	A dummy variable that takes the value 1 if the importer and the exporter share a common language, and zero otherwise.	CEPII (2019)
$Colony_{ij}$	A dummy variable that takes the value 1 if the importer and the exporter have a colonial link, and zero otherwise.	CEPII (2019)
$Trade\_agr_{ijt}$	A dummy variable to control for trade agreements. It takes the value 1 if the importer and the exporter are members of the same regional trade agreement (RTA), free trade agreement (FTA) or preferential trading arrangement (PTA), and zero otherwise.	Egger and Larch (2008)
MR_{it}	Multilateral resistance indices for exporter i at time t.	own calculations
MR_{jt}	Multilateral resistance indices for importer j at time t.	own calculations
AEE_{it}	The agri-environnemental efficiency score of the exporter i in year t.	own calculations
$AEE_{i(t-k)}$	Is the k^{th} lag of the variable AEE_{it}	own calculations
$EU\&USA_{it}$	A dummy variable equal to 1 if the exporter is the USA or a member of the EU, and 0 elsewhere.	own calculations
$CAIRNS_{it}$	A binary variable that takes the value 1 if the exporting country belongs to the CAIRNS group, and 0 otherwise.	own calculations
$LI\&MI_{it}$	A dummy variable equal to 1 if the exporter is a middle or low income country, and 0 otherwise.	own calculations
$AEEH_{ijt}$	The agri-environmental policies' heterogeneity between the exporter i and its partner j where: $AEEH_{ijt} = \lvert AEE_{it} - AEE_{jt} \rvert$	own calculations
$AEEH_{ij(t-k')}$	Is the k' th lag of the variable $AEEH_{ijt}$	own calculations

Source: The table is created by the author to describe the variables used in the setup of the gravity model.

Table A3. 3. Intuition gravity model and basic estimations of the model (3.9) (part1)

VARIABLES	(1) OLS	(2) RE	(3) FE	(4) HT[23]	(5) OLS	(6) PPML
$LnGDP_{it}$	0.686***	0.726***	0.514***	0.560***	0.369***	0.239***
	(0.00731)	(0.0136)	(0.0250)	(0.0221)	(0.0425)	(0.0257)
$LnGDP_{jt}$	0.694***	0.718***	0.940***	0.887***	0.749***	0.856***
	(0.00560)	(0.0117)	(0.0242)	(0.0207)	(0.0396)	(0.0282)
$LnDist_{ij}$	-0.751***	-0.871***		-1.642***		
	(0.0125)	(0.0348)		(0.136)		
$Contig_{ij}$	1.766***	2.025***		0.461		
	(0.0539)	(0.170)		(0.334)		
$Lang_{ij}$	0.597***	0.563***		0.834***		
	(0.0322)	(0.0900)		(0.122)		
$colony_{ij}$	0.985***	1.396***		1.317***		
	(0.0598)	(0.190)		(0.247)		
$Trade\_agr_{ijt}$	0.116	0.0808***	0.101***	0.0985***	0.0718	0.0241
	(0.0284)	(0.0262)	(0.0272)	(0.0266)	(0.0409)	(0.0292)
$LnAEE_{it}$	-0.364***	-0.161***	-0.0496***	-0.102***	**-0.0674***	**-0.0182****
	(0.0171)	(0.0269)	(0.0333)	(0.0305)	(0.0403)	(0.0225)
MR_{it}					-2.329*	1.302
					(1.411)	(0.844)
MR_{jt}					-6.494***	-3.832***
					(1.478)	(0.736)
Constant	-16.23***	-17.60***	-17.60***	-11.18***	3.353*	-5.442*
	(0.262)	(0.482)	(0.482)	(1.263)	(5.132)	(2.927)
Breusch and Pagan Lagrangian multiplier test (p-value)		0.000				
Hausman test FE vs RE (p-value)			0.000			
Hausman test FE vs HT (p-value)			0.000			
exporter-time FE	no	no	no	no	no	no

[23] See Table A3. 7 for the Sargan-Hansen test

importer-time FE	no	no	no	no	no	no
bilateral FE	no	no	no	no	yes	yes
time FE	no	no	no	no	yes	yes
RESET test (p-value)	0.000	0.000	0.000	0.000	0.237	0.396
Observations	59,101	59,101	59,101	59,101	58,165	85,106
R-squared	0.365	0.3613	0.227	0.382	0.880	0.950
Number of id		7,810	7,810	7,810		

Source: The table is created by the author. Column (1) uses the OLS estimator. Column (2) uses the RE estimator. Column (3) uses the FE estimator. Column (4) uses the HT estimator. Columns (1) to (4) do not control for the multilateral resistances nor for the FE. Column (5) uses the OLS estimator and the multilateral resistance indices. Column (6) uses the PPML estimator as well as the importer-exporter and time fixed effects. Standard errors are reported in parentheses. The p-values read as follows: *** p<0.01, ** p<0.05, * p<0.1.

Table A3. 4. Matrix of correlation and Variation Inflation factor (VIF)

	GDP_{it}	GDP_{jt}	$Dist_{ij}$	$Contig_{ij}$	$Lang_{ij}$	$Trade\_agr_{ijt}$	$colony_{ij}$	AEE_{it}	**1/VIF**
GDP_{it}	1.00								**0.620**
GDP_{jt}	0.0156	1.00							**0.939**
$Dist_{ij}$	-0.0019	-0.0019	1.00						**0.724**
$Contig_{ij}$	0.0255	0.0255	-0.3966	1.00					**0.788**
$Lang_{ij}$	-0.0624	-0.0624	-0.1346	0.1570	1.00				**0.887**
$Trade\_agr_{ijt}$	0.0827	0.0827	-0.0830	0.1365	0.1846	1.00			**0.900**
$colony_{ij}$	0.0814	0.0814	-0.3151	0.1167	0.0723	0.0575	1.00		**0.926**
AEE_{it}	0.2942	0.0069	-0.0228	-0.0032	-0.0445	0.1422	0.0412	1.00	**0.640**

Source: The table is created by the author. The table reports the scores of correlation between explanatory variables. The last column shows the tolerance (defined as $\frac{1}{\text{Inflation factor,VIF}}$) to check the severity of Multicollinearity.

Table A3. 5. Intuition gravity model and basic estimations of the model (3.9) (part 2)

VARIABLES	(1) OLS	(2) RE	(3) FE	(4) HT[24]	(5) OLS	(6) PPML
$LnGDP_{it}$	0.806***	0.903***	0.637***	0.772***		
	(0.00838)	(0.0155)	(0.0342)	(0.0310)		
$LnGDP_{jt}$	0.511***	0.492***	0.692***	0.593***		
	(0.00663)	(0.0142)	(0.0326)	(0.0303)		
$LnDist_{ij}$	-1.301***	-1.307***		-0.894***		
	(0.0155)	(0.0409)		(0.174)		
$Contig_{ij}$	1.338***	1.869***		2.601***		
	(0.0648)	(0.195)		(0.422)		
$Lang_{ij}$	0.775***	0.585***		1.071***		
	(0.0385)	(0.104)		(0.154)		
$colony_{ij}$	0.741***	1.126***		1.153***		
	(0.0732)	(0.220)		(0.317)		
$Trade\_agr_{ijt}$	0.211***	0.281***	0.267***	0.228***	0.105	0.0426*
	(0.0351)	(0.0366)	(0.0388)	(0.0373)	(0.0764)	(0.0220)
$LnAEEH_{ijt}$	-0.801***	-0.105***	-0.178***	-0.0665**	**-0.00869****	**-0.0072****
	(0.0222)	(0.0279)	(0.0318)	(0.0292)	(0.0624)	(0.00342)
Constant	-17.77***	-20.52***	-28.81***	-23.39***	11.83***	19.82***
	(0.302)	(0.557)	(0.611)	(1.586)	(0.0541)	(0.0204)
Breusch and Pagan Lagrangian multiplier test (p-value)		0.000				
Hausman test FE vs RE (p-value)			0.000			
Hausman test FE vs HT (p-value)			0.000			

[24] See Table A3. 8 for the Sargan-Hansen test

exporter-time FE	no	no	no	no	yes	yes
importer-time FE	no	no	no	no	yes	yes
bilateral FE	no	no	no	no	yes	yes
Time FE	no	no	no	no	no	no
RESET test test (p-value)	0.000	0.000	0.000	0.000	0.307	0.410
Observations	56,247	56,247	56,247	56,247	58,165	85,106
R-squared	0.319	0.1317	0.3058	0.347	0.8595	0.9942
Number of id		7,810	7,810	7,810		

Source: The table is created by the author. Column (1) uses the OLS estimator. Column (2) uses the RE estimator. Column (3) uses the FE estimator. Column (4) uses the HT estimator. Columns (1) to (4) do not control for the multilateral resistances nor for the FE. Column (5) uses the OLS estimator and introduces exporter-time, importer-time and bilateral fixed effects. Column (6) uses the PPML estimator and the same fixed effects as in column (5). Standard errors are reported in parentheses. The p-values read as follows: *** p<0.01, ** p<0.05, * p<0.1.

Table A3. 6. Matrix of correlation and Variation Inflation factor (VIF)

	GDP_{it}	GDP_{jt}	$Dist_{ij}$	$Contig_{ij}$	$Lang_{ij}$	$Trade\_agr_{ijt}$	$colony_{ij}$	$AEEH_{ijt}$	**1/VIF**
GDP_{it}	1.00								**0.925**
GDP_{jt}	0.0155	1.00							**0.932**
$Dist_{ij}$	-0.0019	-0.0019	1.00						**0.610**
$Contig_{ij}$	0.0256	0.0256	-0.3966	1.00					**0.786**
$Lang_{ij}$	-0.0623	-0.0623	-0.1344	0.1568	1.00				**0.890**
$Trade\_agr_{ijt}$	0.1249	0.1249	-0.4410	0.2064	0.0833	1.00			**0.732**
$colony_{ij}$	0.0827	0.0827	-0.0826	0.1367	0.1848	0.0365	1.00		**0.924**
$AEEH_{ijt}$	0.0980	0.0980	0.0992	-0.0887	-0.0316	-0.0731	0.0196	1.00	**0.965**

Source: The table is created by the author. The table reports the scores of correlation between explanatory variables. The last column shows the tolerance (defined as $\frac{1}{\text{Inflation factor,VIF}}$) to check the severity of Multicollinearity.

Table A3. 7. Sensitivity analysis with Hausman-Taylor model (part 1)

VARIABLES	HT (1)	HT (2)	HT (3)
$LnGDP_{it}$	0.601***	0.560***	0.514***
	(0.0222)	(0.0221)	(0.0233)
$LnGDP_{jt}$	0.941***	0.887***	0.940***
	(0.0207)	(0.0207)	(0.0226)
$LnDist_{ij}$	-0.422	-1.642***	-2.392
	(0.116)	(0.136)	(7.793)
$Contig_{ij}$	4.544***	0.461	8.363
	(0.303)	(0.334)	(15.41)
$Lang_{ij}$	0.890***	0.834***	1.471
	(0.122)	(0.122)	(1.755)
$colony_{ij}$	1.337***	1.317***	1.427
	(0.248)	(0.247)	(2.652)
$Trade\_agr_{ijt}$	0.0326	0.0985***	0.101***
	(0.0266)	(0.0266)	(0.0254)
$LnAEE_{ijt}$	-0.131***	-0.102***	-0.0496
	(0.0306)	(0.0305)	(0.0311)
Constant	-31.23***	-11.18***	-45.94
	(1.058)	(1.263)	(66.74)
Sargan-Hansen (p-value)	0.000	**0.1505**	0.000
Observations	59,101	59,101	59,101
Number of id	7,810	7,810	7,810

Source: The table is created by the author. The table reports the results over-identifying restrictions test of Sargan-Hansen to select legitimate instruments variables for the HT estimator. The selected instruments in column (1) are $lnGDP_{it}$ and $lnGDP_{jt}$. The selected instruments in column (2) are $lnGDP_{it}$, $lnGDP_{jt}$ and $lnDist_{ij}$. The selected instruments in column (3) are $lnGDP_{it}$, $lnGDP_{jt}$ and $Trade\_agr_{ijt}$.
The p-value of Sargan-Hansen in column (2) is greater than 0.05 which validates its set of instruments. Standard errors are reported in parentheses. The p-values read as follows: *** p<0.01, ** p<0.05, * p<0.1.

Table A3. 8. Sensitivity analysis with Hausman-Taylor model (part 2)

VARIABLES	HT (1)	HT (2)	HT (3)
$lnGDP_{it}$	0.977***	0.772***	0.637***
	(0.0297)	(0.0310)	(0.0328)
$lnGDP_{jt}$	0.510***	0.593***	0.692***
	(0.0304)	(0.0303)	(0.0312)
$lnDist_{ij}$	-0.330**	-0.894***	-2.640***
	(0.151)	(0.174)	(0.516)
$Contig_{ij}$	5.078***	2.601***	9.458***
	(0.374)	(0.422)	(1.085)
$Lang_{ij}$	1.081***	1.071***	1.639***
	(0.143)	(0.154)	(0.258)
$Colony_{ij}$	1.105***	1.153***	1.303**
	(0.294)	(0.317)	(0.511)
$Trade\_agr_{ijt}$	0.171***	0.228***	0.267***
	(0.0378)	(0.0373)	(0.0372)
$LnAEEH_{ijt}$	-0.0740**	-0.0665**	-0.178***
	(0.0294)	(0.0292)	(0.0305)
Constant	-37.05***	-23.39***	-52.70***
	(1.341)	(1.586)	(4.406)
Sargan-Hansen (p-value)	0.000	**0.1214**	0.000
Observations	56,247	56,247	56,247
Number of id	7,687	7,687	7,687

Source: The table is created by the author. The table reports the results over-identifying restrictions test of Sargan-Hansen to select legitimate instruments variables for the HT estimator. The selected instruments in column (1) are $lnGDP_{it}$ and $lnGDP_{jt}$. The selected instruments in column (2) are $lnGDP_{it}$, $lnGDP_{jt}$ and $lnDist_{ij}$. The selected instruments in column (3) are $lnGDP_{it}$, $lnGDP_{jt}$ and $Trade\_agr_{ijt}$.
The p-value of Sargan-Hansen in column (2) is greater than 0.05 which validates its set of instruments. Standard errors are reported in parentheses. The p-values read as follows: *** p<0.01, ** p<0.05, * p<0.1.

Basic estimations of the intuitive gravity model

Table A3. 3 and Table A3. 5 in the Appendix of chapter 3 (A3) report the estimation results of Eq. (3.9) that considers traditional gravity variables. Table A3. 3 displays the impact of the exporter's environmental efficiency (AEE_{it}) on agricultural trade flows. Columns (1) to (4) report the results from each estimator, namely simple ordinary least squares (OLS), random effects (RE), fixed effects (FE), and Hausman-Taylor (HT). Columns (5) and (6) display the OLS and Poisson pseudo maximum likelihood (PPML) estimators, respectively. The latter use multilateral resistance indicators as well as bilateral and time fixed effects. In addition, Table A3. 5 reports the impact of the agri-environmental heterogeneity ($AEEH_{ijt}$) on crop commodities' flows. Estimation techniques of columns (1) to (4) are similar to those of Table A3. 3. However, OLS and PPML estimators in columns (5) and (6), respectively, use exporter-time, importer-time and bilateral fixed effects.

First, we had to verify whether random effects model is more appropriate than simple OLS by performing the Breusch and Pagan Lagrangian multiplier test. According to Table A3. 3 and Table A3. 5, results show that the test for random effects is highly significant (p-value =0.000<0.01) which rejects the hypothesis that there is no significant difference across units (i.e. no panel effect). Therefore, we must proceed with panel data analysis.

Second, we used the specification test of Hausman (1978) to select between random effects versus fixed effects. The null hypothesis (H_0) states that RE model is consistent, whereas the alternative hypothesis (Ha) suggests that FE model is the consistent one. According to Table A3. 3 and Table A3. 5, the p-value is below 5%. We then reject the H_0 and conclude that the FE model is more appropriate for our data.

However, the latter omits the variation across individuals and, thus, is not fully efficient. Fixed effects model also removes time-constant explanatory variables (namely the distance as well as dummy variables of contiguity, common language and colonial link). Both of these problems can be solved by the model of Hausman and Taylor (1981). We thereby performed tests to select legitimate instruments for the Hausman and Taylor (HT) estimator. To that end, we employ the over-identifying restrictions test of Sargan-Hansen to see if the set of instruments is valid or not.

Results are reported in Table A3. 7 (for the variable AEE_{it})) and in Table A3. 8 (for the variable $AEEH_{ijt}$). In both cases, and unlike models HT(1) and HT(3), the p-value of model HT(2) is greater than 5%, suggesting that the null hypothesis of choosing a set of instruments composed of the geographical distance as well as the exporter and the importer GDPs is valid. Moreover, we performed the Hausman test to compare between FE and HT estimators. The computed p-value (=0.000<0.01) suggests that the FE estimator is more efficient than HT.

In addition, we measure the variation inflation factor (VIF) of our interest variables, namely AEE_{it} (in Table A3. 4 in the appendix of chapter 3) and $AEEH_{ijt}$ (Table A3. 6 in the appendix of chapter 3) to test their degree of collinearity. The two matrices of correlation indicate that most of the correlation's coefficients are low. As a rule of thumb, a variable whose VIF value is greater than 10 may merit further investigation. Similarly, tolerance (defined as 1/VIF) is used by many scholars to check on the degree of collinearity. A tolerance value lower than 0.1 is comparable to a VIF of 10. Accordingly, the variable is considered as a linear combination of other independent variables. According to Table A3. 4 and Table A3. 6, the reported tolerances are above 0.1. This would suggest that standard errors are not being inflated by a factor of 2 or more. We can conclude that there is no evidence of multicollinearity bias.

Furthermore, results of OLS, RE, FE, HT and PPML estimators match their expected signs and are statistically significant. First, importer and exporter GDPs are trade enhancing factors. Second, the distance affects negatively and significantly trade volumes, which is quite intuitive. Third, common borders, languages and colonial background increase significantly agricultural exports.

Regarding our variables of interest, the coefficient of AEE_{it} is negative and statistically significant in columns (1), (2), (3) and (4) of Table A3. 3. This finding suggests that stringent environmental regulations have a negative impact on agricultural exports. As for the variable $AEEH_{ijt}$, parameter estimates reported in columns (1), (2), (3) and (4) of Table A3. 5 are statistically significant and negative. This would indicate that environmental regulations' heterogeneity between two trade partners hampers agricultural trade.

However, these models have low goodness of fit since their R squared (R^2) values range between 13% and 36%. Conversely, OLS and PPML estimates that consider fixed effects and multilateral resistance terms (columns (5) and (6) of Table A3. 3 and Table A3. 5) record high values of R^2 (above 80%). Indeed, the use four different types of fixed effects explains well the variability of the model.

Finally, the p-values of the Ramsey RESET test[25], reported at the bottom of Table A3. 3 and Table A3. 5 reveal that the OLS specification with fixed effects and multilateral resistance terms as well as the PPML model are the only ones to pass the misspecification test. In sum, estimating our gravity model using OLS and PPML models that control for fixed effects is statistically reliable and is most likely to provide unbiased parameters.

[25] The Ramsey RESET test detects whether potential variables are omitted in the model specification. The null hypothesis (H0) states that the model is correctly specified. If the p-value is smaller than the critical value, then we can reject the null hypothesis. Conversely, the null hypothesis cannot be rejected if the p-value is larger than the significance value (Yotov et al., 2016)

Table A3. 9. Trade effects of the first lag of exporters' agri-environmental efficiency $AEE_{i(t-1)}$

	Sector					
	Total crop commodities		Fruit and vegetables		cereals	
VARIABLES	(1) OLS	(2) PPML	(3) OLS	(4) PPML	(5) OLS	(6) PPML
$LnGDP_{it}$	0.359***	0.210***	0.345***	0.209***	0.165***	0.254***
	(0.0865)	(0.0291)	(0.0478)	(0.0287)	(0.0634)	(0.0765)
$LnGDP_{jt}$	0.967***	0.859***	0.747***	0.848***	0.360***	0.364***
	(0.0757)	(0.0309)	(0.0443)	(0.0306)	(0.0606)	(0.0763)
MR_{it}	-6.062**	-0.0642	-2.317	0.162	-2.802	1.478
	(2.774)	(0.925)	(1.537)	(0.921)	(1.982)	(2.013)
MR_{jt}	-9.345***	-3.262***	-7.507***	-4.052***	-9.507***	1.579
	(2.609)	(0.798)	(1.560)	(0.812)	(2.222)	(2.281)
$Trade\text{-}agr_{ijt}$	0.0836	0.00523	0.0745*	0.00284	0.0269	0.107
	(0.0738)	(0.0328)	(0.0449)	(0.0311)	(0.0559)	(0.0831)
$LnAEE_{i(t-1)}$	**-0.136***	**-0.122*****	**-0.0554**	**-0.111*****	**0.300***	**0.356**
	(0.0815)	(0.0284)	(0.0459)	(0.0284)	(0.0660)	(0.0790)
Constant	10.98***	-2.971***	6.211***	-1.481***	18.92**	-10.91***
	(9.658)	(3.148)	(5.602)	(3.117)	(7.475)	(7.817)
exporter-time FE	no	no	no	no	no	no
importer-time FE	no	no	no	no	no	no
bilateral FE	yes	yes	yes	yes	yes	yes
time FE	yes	yes	yes	yes	yes	yes
Observations	53,312	76,406	53,312	76,406	53,312	76,406
R-squared	0.873	0.9904	0.885	0.9917	0.848	0.9910

Source: The table is created by the author. Odd columns use the OLS estimator whereas even columns use the PPML estimator. Bilateral and year fixed effects are included in all estimations. Multilateral resistance terms are included as regressors to obtain unbiased estimates. Columns (1) and (2) report the results of total food crops' bilateral exports. Columns (3) and (4) report the results of the sector of fruit and vegetables. Columns (5) and (6) report the results of the sector of cereals. Robust standard errors are reported in parentheses. The p-values read as follows: *** p<0.01, ** p<0.05, * p<0.1.

Table A3. 10. Trade effects of the secnd lag of exporters' agri-environmental efficiency $AEE_{i(t-2)}$

	Sector					
	Total crop commodities		Fruit and vegetables		cereals	
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	OLS	PPML	OLS	PPML	OLS	PPML
$LnGDP_{it}$	0.382***	0.172***	0.300***	0.166***	0.179**	0.231**
	(0.0983)	(0.0338)	(0.0550)	(0.0334)	(0.0706)	(0.0948)
$LnGDP_{jt}$	0.946***	0.824***	0.768***	0.816***	0.473***	0.421***
	(0.0872)	(0.0354)	(0.0506)	(0.0349)	(0.0692)	(0.0872)
MR_{it}	-5.342*	-0.755	-3.471**	-0.613	-3.622*	-1.365
	(3.036)	(0.982)	(1.676)	(0.978)	(2.117)	(2.150)
MR_{jt}	-12.61***	-4.118***	-8.368***	-5.015***	-8.239***	2.175
	(2.787)	(0.912)	(1.656)	(0.924)	(2.415)	(2.699)
$Trade\text{-}agr_{ijt}$	0.0983	0.0301	0.0611	0.0393	0.00443	0.143
	(0.0808)	(0.0351)	(0.0491)	(0.0330)	(0.0603)	(0.0974)
$LnAEE_{i(t-2)}$	**-0.126**	**-0.129*** **	**-0.122*** **	**-0.131*** **	**0.143***	**0.324**
	(0.0833)	(0.0274)	(0.0471)	(0.0276)	(0.0669)	(0.0825)
Constant	16.27***	2.410***	11.15*	4.382***	14.61*	-6.993***
	(10.76)	(3.395)	(6.174)	(3.359)	(8.218)	(8.829)
exporter-time FE	no	no	no	no	no	no
importer-time FE	no	no	no	no	no	no
bilateral FE	yes	yes	yes	yes	yes	yes
time FE	yes	yes	yes	yes	yes	yes
Observations	45,908	67,905	45,908	67,905	45,908	67,905
R-squared	0.879	0.9910	0.891	0.9551	0.857	0.9561

Source: The table is created by the author. Odd columns use the OLS estimator whereas even columns use the PPML estimator. Bilateral and year fixed effects are included in all estimations. Columns (1) and (2) report the results of total food crops' bilateral exports. Multilateral resistance terms are included as regressors to obtain unbiased estimates. Columns (3) and (4) report the results of the sector of fruit and vegetables. Columns (5) and (6) report the results of the sector of cereals. Robust standard errors are reported in parentheses. The p-values read as follows: *** p<0.01, ** p<0.05, * p<0.1.

Table A3. 11. Trade effects of $AEEH_{ijt}$ by groups of countries (part 1)

	Dependent: crop commodities' exports of **HI countries**					
	(1)	(2)	(3)	(4)	(5)	(6)
	HI to HI	HI to HI	HI to BRICS	HI to BRICS	HI to LI&MI	HI to LI&MI
VARIABLES	OLS	PPML	OLS	PPML	OLS	PPML
$Trade\_agr_{ijt}$	0.0381**	0.00709***	0.0408	0.166***	0.0806	0.0178
	(0.0730)	(0.0280)	(0.0952)	(0.0533)	(0.0582)	(0.0376)
$lnAEEH_{ijt}$	-0.0166**	-0.00531***	0.0160**	0.000381***	0.0177	0.000467
	(0.00988)	(0.00338)	(0.0126)	(0.00344)	(0.0110)	(0.00344)
Constant	13.60***	20.00***	13.65***	19.88***	13.16***	19.85***
	(0.0328)	(0.0213)	(0.0487)	(0.0435)	(0.0306)	(0.0316)
exporter-time FE	yes	yes	yes	yes	yes	yes
importer-time FE	yes	yes	yes	yes	yes	yes
bilateral FE	yes	yes	yes	yes	yes	yes
Observations	36,975	48,654	24,738	32,234	39,806	59,371
R-squared	0.912	0.9947	0.919	0.9910	0.895	0.828

Source: The table is created by the author. Odd columns use the OLS estimator whereas even columns use the PPML estimator. Bilateral, importer-time and exporter-time fixed effects are included in all estimations. In this table, we assess trade effects of difference in exporter and importer environmental regulations ($AEEH_{ijt}$) on crop commodities' exports of high income countries according to three destination markets: HI (high income), the BRICS (group of emerging countries composed of Brazil, Russia, India, China and South Africa) and LI&MI (low and middle income) countries. Robust standard errors are reported in parentheses. The p-values read as follows: *** p<0.01, ** p<0.05, * p<0.1.

Table A3. 12. Trade effects of $AEEH_{ijt}$ by groups of countries (part 2)

	Dependent: crop commodities' exports of **emerging countries**					
	(1)	(2)	(3)	(4)	(5)	(6)
	BRICS to HI	BRICS to HI	BRICS to BRICS	BRICS to BRICS	BRICS to LI&MI	BRICS to LI&MI
VARIABLES	OLS	PPML	OLS	PPML	OLS	PPML
$Trade\_agr_{ijt}$	0.0615	0.0107	0.0964	0.000886	0.105*	0.0206
	(0.0895)	(0.0289)	(0.161)	(0.0831)	(0.0616)	(0.0382)
$lnAEEH_{ijt}$	-0.0321***	-0.00921***	-0.0552	-0.0367	-0.0149	-0.0217
	(0.0110)	(0.00336)	(0.0270)	(0.00992)	(0.0145)	(0.00824)
Constant	14.04***	19.96***	14.15***	19.42***	12.77***	18.89***
	(0.0448)	(0.0221)	(0.0510)	(0.0283)	(0.0283)	(0.0202)
exporter-time FE	yes	yes	yes	yes	yes	yes
importer-time FE	yes	yes	yes	yes	yes	yes
bilateral FE	yes	yes	yes	yes	yes	yes
Observations	26,955	33,786	8,130	10,048	30,246	48,388
R-squared	0.918	0.9891	0.921	0.9938	0.872	0.841

Source: The table is created by the author. Odd columns use the OLS estimator whereas even columns use the PPML estimator. Bilateral, importer-time and exporter-time fixed effects are included in all estimations. In this table, we assess trade effects of difference in exporter and importer environmental regulations ($AEEH_{ijt}$) on crop commodities' exports of emerging countries according to three destination markets: HI (high income), the BRICS (group of emerging countries composed of Brazil, Russia, India, China and South Africa) and LI&MI (low and middle income) countries. Robust standard errors are reported in parentheses. The p-values read as follows: *** p<0.01, ** p<0.05, * p<0.1.

Table A3. 13. Trade effects of $AEEH_{ijt}$ by groups of countries (part 3)

	Dependent: crop commodities' exports of **LI&MI countries**					
	(1)	(2)	(3)	(4)	(5)	(6)
	LI&MI to HI	LI&MI to HI	LI&MI to BRICS	LI&MI to BRICS	LI&MI to LI&MI	LI&MI to LI&MI
VARIABLES	OLS	PPML	OLS	PPML	OLS	PPML
$Trade\_agr_{ijt}$	0.0190	0.0161	0.0234	0.0169	0.0701**	0.0105**
	(0.0619)	(0.0242)	(0.0652)	(0.0270)	(0.0487)	(0.0239)
$lnAEEH_{ijt}$	-0.0205***	-0.00820***	-0.0236	-0.018	-0.0200*	-0.0238***
	(0.0101)	(0.00330)	(0.0129)	(0.00674)	(0.0113)	(0.00643)
Constant	13.39***	19.84***	12.97***	19.37***	12.87***	19.18***
	(0.0314)	(0.0185)	(0.0283)	(0.0145)	(0.0216)	(0.0140)
exporter-time FE	yes	yes	yes	yes	yes	yes
importer-time FE	yes	yes	yes	yes	yes	yes
bilateral FE	yes	yes	yes	yes	yes	yes
Observations	41,808	60,740	31,890	49,491	43,841	67,964
R-squared	0.896	0.9895	0.877	0.9962	0.872	0.892

Source: The table is created by the author. Odd columns use the OLS estimator whereas even columns use the PPML estimator. Bilateral, importer-time and exporter-time fixed effects are included in all estimations. In this table, we assess trade effects of difference in exporter and importer environmental regulations ($AEEH_{ijt}$) on crop commodities' exports of low and middle income countries according to three destination markets: HI (high income), the BRICS (group of emerging countries composed of Brazil, Russia, India, China and South Africa) and LI&MI (low and middle income) countries. Robust standard errors are reported in parentheses. The p-values read as follows: *** p<0.01, ** p<0.05, * p<0.1.

4. General conclusion

This thesis seeks to contribute to the debate over agricultural trade liberalization and the environment. We emphasize that trade can be directly or indirectly affected by environmental regulation, imposing thereby new production techniques and additional costs to producers. Moreover, environmental regulations can be supported by trade restrictions to become effective. With this in mind, we investigate the relations between international trade, upstream and downstream environmental regulations. To that end, we conduct three interconnected empirical studies on a macroeconomic scale, over the period 2003-3013 and using a large sample of northern and southern countries.

As a first step, the thesis starts by a descriptive analysis to depict the new patterns of agricultural trade over the past years and examine one of the most visible and effective facets of the agreement on agriculture, namely the environmentally-related NTMs. The study addresses more precisely the structural characteristics of bilateral specific trade concerns raised at the SPS and TBT committees that are closely tied to agricultural commodities and represent thereby the downstream environmental regulations.

Second, we focus on upstream measures by examining the recent greening agricultural reforms that have marked several countries around the word. To this end, we measure the agri-environmental efficiency of 108 countries over the period 2003-2013 and investigate its determinants. Finally, we deeply examine the question of agricultural trade and environmental regulation using efficiency scores as a proxy of the stringency of environmental policies. On the one hand, we investigate whether the agricultural sector support the "Porter theory" or favor the "pollution haven hypothesis". Finally, our research furthers the analysis by determining the trade effect of regulations' heterogeneity that is highly determined by the level of development of origin and destination countries.

Our study analyzes these macroeconomic policy frameworks and develops the existing literature in several directions. First of all, the thesis starts in the first chapter by using the tools of network analysis developed by Harary (1953) to visualize the evolution of the regulatory distance between trade partners over the period 2003-2013. The second motive is to understand to what extent developing and emerging countries are concerned by environmentally-related trade conflicts.

The concept of interdependence lying within the network analysis is in fact the basic motive behind choosing this tool in our study. To the best of our knowledge, this is the first time that the analysis of bilateral STCs has been expanded to study their global structure using network analysis. Additionally, we use the centrality measures developed by Bonacich (1987) and

Newman (2010) as a way of describing the level of country heterogeneity in bilateral STCs and to identify the new "hotspots" of the environmentally-related conflicts.

Our analysis indicates that agricultural trade has been marked by a strong growth in developing and emerging countries. This increase was nonetheless less reflected by market share gains in exports to developed nations than by a very strong increase in "South-South" flows, which is detrimental to high income suppliers like the US and the EU. In addition, the structure of trade has become more complex in 2013 compared to 2003 and is marked by a growing interconnection and lower trade concentration.

Further results show that bilateral STCs can be thought of as networks. The latter confirm the "old" offensive position of industrialized countries, namely Japan, the US and the European Union. An interesting finding is that this effect has been dissipating over time, suggesting that high income countries have left their central positions within the environmentally-related STC network to several emerging and developing agricultural suppliers, namely Peru, Argentina, Brazil and Indonesia.

The latter clearly hold a notable position in the network, mainly as STCs' destinations. Accordingly, it appears as if trade growth of southern countries has been conducive to rising environmentally- related trade conflicts. Finally, our results reveal new environmentally-related conflictual relation targeting developing and emerging countries on one side and increasing environmental tensions within southern agro-suppliers on the other.

Chapter 2 complements this analysis and examines the greening reforms of upstream policies that have marked several countries around the word. Our findings highlight the asymmetrical agri-environmental instruments and policies between southern and northern countries. We note that environmental drawbacks of intensive agriculture in Western countries have contributed to move their agricultural policies toward a multifunctionality-based agriculture and to greater environmental sustainability. However, two production models are present, namely the market-oriented, liberalistic agriculture and the market-protected one. By contrast, emerging and developing countries show uneven environmental regulations that turn out to be mostly regulatory, except for some middle income and emerging countries like Brazil and Mexico.

Additionally, we examine the efficiency of these policies and investigate the determinants of the agri-environmental performance. To this end, we conduct a large-scaled empirical application to measure the agri-environmental efficiency of 108 countries over the period 2003-2013. The evaluation is based on a two-step super-efficiency data envelopment analysis model, developed by Andersen and Petersen (1993). As a first step, we use time-varying data and undesirable output to compute the efficiency scores following the method of Seiford and Zhu (2002). We employ in the second step the double bootstrapped truncated regression suggested by Simar and Wilson (2007) to conduct a sensitivity analysis and test the effect of a wide range of variables, in particular international trade features, on the environmental inefficiency. In this model, we control for country-specific unobserved heterogeneity.

Findings show that the sector of crops has witnessed globally an increasing trend in average agri-environmental efficiency between 2003 and 2013. An interesting and somewhat expected result is that the agri-environmental inefficiency of developing countries is more sensitive to climatic variables compared to emerging and high-income economies. Moreover, the effect of environmental protection's expenditure is highly detrimental to the inefficiency in low and middle income countries, whereas the effect is weaker in the BRICS and high income economies. An intriguing finding is that agricultural trade openness and the specialization in crop commodities' exports hamper the inefficiency. We confirm by this means the "environmental gains-from-trade" hypothesis.

In addition, our results show that environmentally-related NTMs affect considerably the agri-environmental performance. In fact, technical barriers to trade and sanitary and phytosanitary measures turn out to be levers for enhancing the agri-environmental efficiency of exporters especially in the BRICS and high as well as middle-income countries. This would suggest that the overall increase of environmentally-related NTMs against tariff dismantling in the agricultural sector has aligned developed, emerging and middle income exporting countries with their partners' strict regulations. Accordingly, this has induced a "race to the top" phenomenon in their domestic environmental standards. Nonetheless, low income countries react differently and show a deteriorating agri-environmental performance due to environmentally-related NTMs.

In chapter 3, we explore new environmental determinants of the capacity for exporting agricultural commodities, considering the income heterogeneity of countries. We employ a theoretically justified gravity model of trade of Anderson and van Wincoop (2003) to examine the impact of environmental policies' stringency on exports. The model is tested on a sample of 108 countries over the period dating from 2003 to 2013 and using bilateral export data for crop commodities.

To obtain unbiased estimates, we employ the time-varying multilateral resistance terms as recommended by Carrère et al. (2009) and control for the unobserved heterogeneity that is specific to each trade flow following the method of Baier and Bergstrand (2007). Additionally, we use a high-dimensional fixed effects Poisson pseudo maximum likelihood (PPML) model of Santos Silva and Tenreyro (2006) to solve the zero-trade issue and the presence of heteroskedasticity. Following the method of Yang and Martinez-Zarzoso (2014), we considered the endogeneity bias problem due to omitted variables by controlling for time-varying multilateral resistance terms and country-pair fixed effects to obtain unbiased and consistent estimates.

Results of chapter 3 show that the stringency of environmental regulations is determinant for bilateral agricultural exports. However, the intensive margin of trade varies according to the level of development of countries. First, environmental stringency turns out to be trade reducing in the CAIRNS group, supporting thereby the pollution haven hypothesis. This finding suggests that free agricultural trading nations characterized by lenient environmental regulations have

gained comparative advantages in pollution-intensive goods and are turned into pollution havens.

By contrast, rigorous agri-environmental policies have a significant trade-enhancing effect on bilateral agricultural exports of highly protective and industrialized countries such as the EU and the USA. Similarly and surprisingly, further results show that low and middle income countries with higher agri-environmental performances export larger volumes of crop commodities, supporting therefore the Porter hypothesis. Our findings suggest that strict environmental regulations can enhance the competitive advantage of developing countries against foreign rivals.

In addition, we note that agricultural commodities react differently to environmental regulations. The sector of fruit and vegetables is more sensitive to this determinant unlike cereals that remain relatively less affected. Finally, our results show that difference in exporter and importer environmental regulations is more relevant to agricultural trade than trade agreements. The environmental gap between two trade partners is decreasing slightly, but significantly, crop commodities' exports. However, trade effects vary according to the income groups of exporting and importing countries.

We believe that key results emerging from these chapters enable us to clarify the complex relationship between agricultural trade and environmental regulations, especially when we consider the environmentally-related NTMs in conjunction with the upstream agri-environmental policies.

Overall, the present research reveals the positive relationship between agricultural trade and environmental regulations. Although this finding is highly determined by the income heterogeneity of countries, it shows so far promising results related to southern countries. In light of the above outcomes, this research provides efficient supports for policy-makers to pursue discussions and negotiations of new trade agreements in a framework where the Doha round stalls. Regarding agriculture negotiation topics in the framework of the 12th ministerial conference (November - December 2021 in Geneva), a first draft negotiating text is expected to be submitted before June 2021 (WTO, 2021). Although the Bali and Nairobi outcomes have energized the Doha round, the future for the multilateral trading system is questioned by several scholars. Martin and Mercurio (2017) argue that the Nairobi ministerial has marked the end of the Doha round. The author suggests that the inability of WTO members to reach a comprehensive agreement is likely to foster plurilateral agreements (e.g. FTA, PTA, etc.) at the expense of the single undertaking and the multilateral level.

In this regard, policy makers need to consider that trade liberalization is demonstrated as a catalyst for important agri-environmental reforms, especially in southern countries, and can strengthen thereby their environmental regulations. Furthermore, the overall increase of environmentally-related NTMs against tariff dismantling has aligned several developing countries with their partners' strict norms, inducing a "race to the top" phenomenon in their domestic environmental standards.

On the other hand, it is illusory to consider bilateral or regional trade agreements capable, on their own, of increasing agricultural trade. Indeed, our findings suggest that agricultural exporting capacity can be enhanced by ecological and sustainable upstream production systems. The environmental issue is therefore essential to be taken into consideration when establishing new trade agreements.

Besides, further findings suggest that agricultural trade liberalization can only bring a partial benefit to developing economies given the absence of upstream support measures and the vulnerability of agricultural products. Accordingly, support for the modernization and adoption of new technologies that respect the environment and meet the requirements of the high income market is necessary so that southern countries can truly benefit from the liberalization of agricultural trade.

Moreover, the potential growing demand of high quality and "green" crop commodities in emerging countries should be further investigated using a demand-based framework. This could reveal a new market for developing countries. Finally, the harmonization of agri-environmental measures is strongly recommended and should increase the competitiveness of the sector. This raises an important point regarding indented trade agreements or those under negotiation. Indeed, it is important to consider the slowness of the transformation of agricultural production systems (namely the conversion to organic farming, training and adaptation of farmers to new technologies, etc.). Therefore, suitable timelines must be taken into account. We suggest that an international consensus should be found on agri-environmental measures that should be the most effective in addressing climate change and the least distorting in international markets.

In this thesis, we can highlight some limits. First, and unfortunately, this research does not go beyond 2003-2013. We opted for this time period to be in line with chapter 2 in which, the study extends to 2013 due to missing data. Nonetheless, we consider over fifteen years after the implementation of the agreement of agriculture. During these years, transcendental changes took place related to trade of crop commodities and agricultural policies in addition to significant environmental concerns.

Second, we note some limitations with respect to the DEA model in chapter 2. In fact, the agri-environmental efficiency scores should be measured by adding other inputs like water resources. Additionally, we should have introduced other undesirable (e.g. land erosion) and desirable (positive externalities) outputs, namely landscape maintenance, firefighting as well as cultural and social services. Unfortunately, data unavailability has prevented us from introducing these variables.

In this regard, we note that the efficiency is a growing concept in several countries. In the framework of the new 2021-2027 programming of the Common Agricultural Policy, and according to its new green architecture, the European Commission wants to stop the green payment and ask the Member States to set up cross compliance with high results targets to tackle the issue of deadweight. In this regard, conducting macroeconomic studies is useful for

the comparisons between countries. Nonetheless, our findings need to be considered with caution since they hide territorial disparities.

Finally, our study is limited to crop commodities and excludes livestock products. Accordingly, our findings cannot be generalized to the whole agricultural sector. This thesis can be thereby extended by including animal agriculture. We recall that our choice is purely technical. First, crop commodities share similar production process. Consequently, they have similar environmental impact and are usually under the same agri-environmental measures (unlike live animals, meat and dairy production). The second motivation is the strategic role of these products in both developed and developing countries.

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