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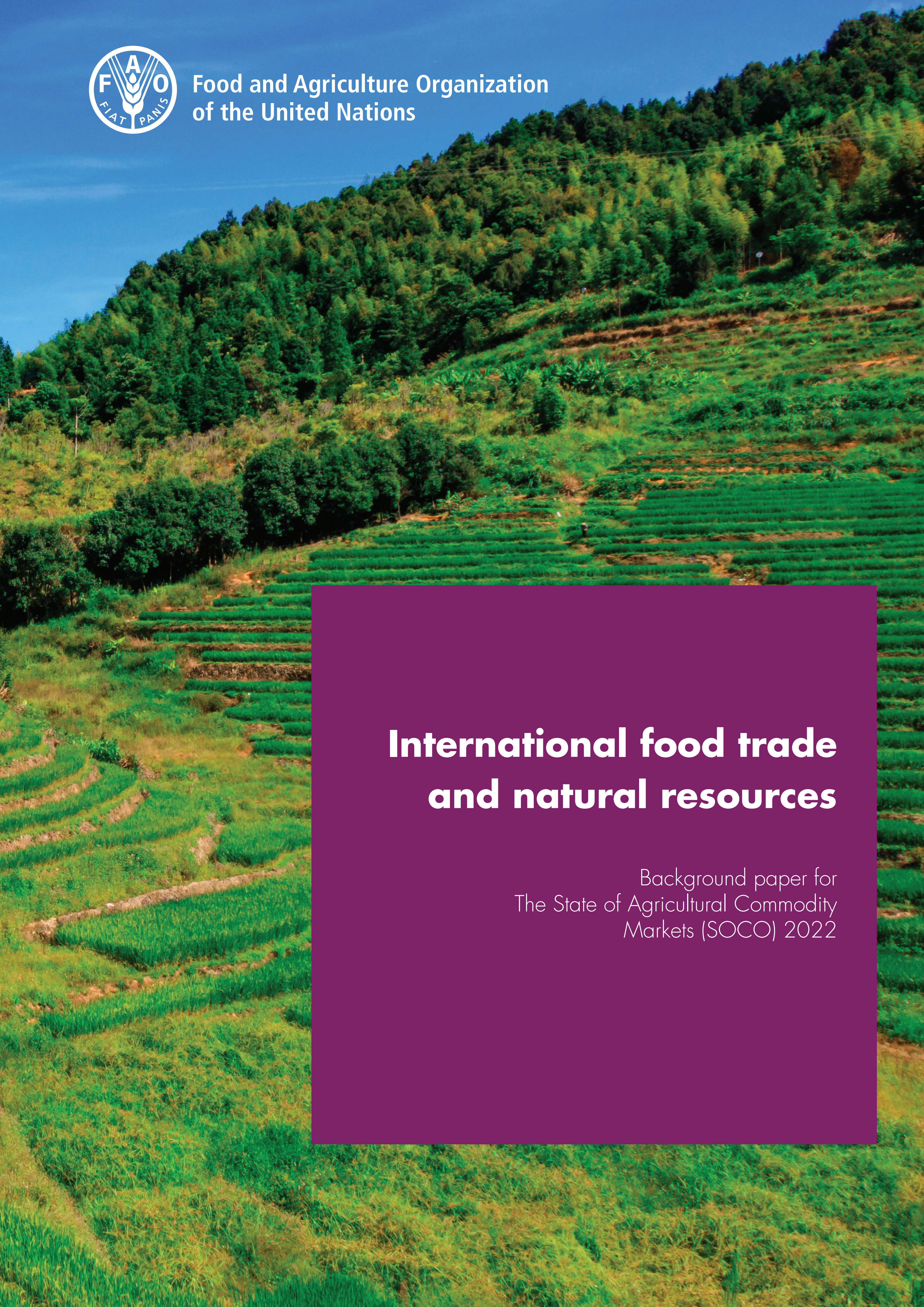

International food trade and natural resources

Background paper for The State of Agricultural Commodity Markets (SOCO) 2022

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The State of Agricultural Commodity
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Abstract

The paper provides a review of the literature on the distribution of natural capital endowments across countries and its impact on determining trade flows. It illustrates the role trade plays in alleviating environmental pressures and the potential negative effects of trade on the environment. Finally, it discusses a range of relevant policy measures that can be adopted to reduce environmental spillovers.

Contents

CHAPTER 1

Introduction and conceptual framework

1 Introduction

In the last four decades, trade in agricultural goods has increased six-fold, leading to the emergence of a truly global food system or, in the words of Robinson (2018), the "*globalization of agriculture*". In fact, nowadays, food accounts 80 percent of international flows of goods, while around 25 percent of agricultural production is traded across borders. International food trade entails the decoupling of consumption from local production and the availability of domestic resources such as water and land. This process has triggered the emergence of a new dimension of the debate on the merits of trade, centered on the potential increase on the environmental pressures generated, or at least channeled by international trade flows.

On the one hand, international trade has the potential to enhance global efficiency, and thus contribute to the conservation of natural resources, if goods are sourced from places featuring a higher efficiency—lower resource intensity per unit of production. On the other hand, trade can be associated with an increase in the environmental footprint of the food system if new opportunities created by accessing foreign markets and liberalization, which can trigger an expansion of production that leads to unsustainable agricultural practices, deforestation or the loss of biodiversity.

The fact that a large part of the environmental footprint of the food system is related to goods that are traded does not imply that trade causes environmental damages (Copeland *et al.*, 2021). In the absence of trade, factors of production would find other uses and crops grown elsewhere, which can generate pressure on natural resources than the world is experiencing today. In general, international trade can either increase pressure on natural habitats and resources in areas with high potential for agricultural production or reduce the global footprint of the food system by allowing production to take place elsewhere. It is local conditions that shape farmers' incentives. Trade can be an issue in poorly regulated contexts or a solution when it allows access to alternative sourcing patterns that reduce overall environmental pressures.

An additional source of concern is the possibility that globalization leads to a race-to-the-bottom in environmental protection, which would increase the overall pressure on natural resources as all countries scramble to retain activities with large material footprints and thus lower their standards and regulations. A related, but a conceptually different view is that some countries develop a "comparative advantage" in pollution (or environmentally harmful activities), also known as the pollution haven hypothesis. In this second case, however, the location of activities matters only if environmental pressures are the source of the comparative advantage that drives specialization. If, on the contrary, it stems from differences in preferences, for example, because nature conservation is considered a luxury good whose demand increases more than proportionally as income rises, then, the global footprint of the food system would not change.

On the contrary, international trade can be viewed as an adaptation strategy to lower the global impact of climate change on the food system. Gouel and Laborde (2021) find that the possibility to change sourcing patterns offered by international trade is as important as changes in the crop mix in determining countries' ability to face the negative impacts of rising temperatures on agricultural production. Moreover, the free movement of goods can have an additional positive effect in the face of weather shocks and climate-induced uncertainty, by reducing price volatility (see Verma *et al.*, 2014 for an application to the US corn market).

From a theoretical point of view, there are three main channels through which trade can affect the environment. The first is a simple scale effect whereby higher (agricultural) output requires

more inputs such as land, water, fertilizers. This mechanism is likely to increase environmental pressures on exporting countries. The second channel is a composition effect driven by comparative advantages. The localization of production according to comparative advantages should lead to more efficient use of natural resources, at least if resource endowments and resource efficiency are a source of comparative advantage and can drive sourcing patterns. Third, trade can affect technology by providing greater incentives for the adoption of modes of production that save on scarce factors and facilitate technological spillovers (Fracasso and Vittucci Marzetti, 2015).

Using data from 1995 to 2009, Copeland *et al*. (2021), assess several greenhouse gas (GHG) emissions and pollutants and find that the technique effect is much larger than the composition effect and, in many countries, larger than the scale effect. An important element for the current discussion is that for two pollutants primarily associated with agriculture, namely ammonia and nitrous oxide, the composition effects play a more systematic and important role, compared to other pollutants and GHGs, suggesting that shifting resources out of agriculture and into the secondary and tertiary sectors contribute to reducing some sector-specific pollutants.

A simple Heckscher-Ohlin framework where comparative advantages are based on relative endowments of factors of production, market integration leads natural resource-intensive food production to relocate to countries that are abundant in land and water. For instance, Dombi *et al*. (2021) uses a multi-regional input-output table to explore the material footprint of food consumption and provide a decomposition of the various factors that have driven the increase in environmental pressures between 1990 and 2013. Population growth appears the main force in increasing natural resource use, whereas international trade counteracts this tendency by shifting production to areas with a lower material footprint.

The savings associated with international flows of "virtual" land and water, defined as the factor content of traded (agricultural) goods, have been analyzed by a large body of literature reviewed in Section 2. Results suggest that trade does promote the conservation of water (Hoekstra and Chapagain, 2008), although there are counter-examples, for instance, the inter-regional flows in China and India, and where possible trade-offs exist across different resources (water vs. land) or environmental goals (e.g. water conservation, pollution, GHG emissions).

One critical point in the discussion of the environmental benefits and costs of international trade is the lack of an appropriate benchmark and the difficulty in establishing a clear-cut causal nexus between trade integration and the use (or abuse) of natural resources. For instance, most of the literature dealing with virtual water trade (see Hoekstra and Chapagain, 2008 and the ensuing works) assess the merit of trade by comparing the current situation with a notional scenario in which all countries produced domestically the food they consume, typically finding large water savings. This ought to be overly optimistic because in case trade is restricted, price changes are likely to induce shifts in consumption patterns that favor products more easily produced domestically. At the opposite side of the spectrum, building on multi-regional input-output tables (see for instance Wiedmann and Lenzen, 2018), trade is attributed to the whole environmental damage of final consumption that takes place in countries different from the production site, irrespective of the fact that without international transactions the same amount of food still needs to be produced elsewhere.

This review paper focuses on international trade in food and agricultural products and its effects on natural resources and the environment. It takes an empirical stance by primarily surveying the available evidence while theories or models. From time to time, when broadening the perspective can provide readers with a sense of the different mechanisms at play, the paper goes

beyond these self-determined boundaries whose purpose is simply to guarantee a coherent framework and a reference point in an otherwise extremely vast literature.

The rest of the paper is organized as follows: Section 2 reviews the arguments on the positive effects of trade on efficiency by looking at the literature of the “virtual trade” of natural resources such as water, land and biodiversity. Section 3 focuses on the possible negative environmental spillovers of international trade on exporting countries. Section 4 provides an overview of policy-relevant issues and possible measures to maximize the beneficial effects of international flows, while reducing harmful consequences. Finally, section 5 offers some concluding points.

CHAPTER 2

Virtual trade of natural resources

2 Virtual trade of natural resources

International food trade entails the de-coupling of consumption from local production and the availability of domestic resources such as water and land. Because direct water trade is often impractical and land trade is impossible, trade in agricultural goods represents one way to alleviate water and land scarcity by allowing for the international division of labour and for specialization based on resource endowments.

Since the early 1990s, vast literature has blossomed that describes the complex web of "virtual" flows in natural resources associated with international trade in food and agricultural commodities and analyzes their determinants. In fact, this is just the re-branding of an old idea in economics, namely that trade in goods is a substitute for trade in factors of production, since goods contain the factors that are used to produce them (Leontief, 1953; Leamer, 1980). Globally, different estimates (as reported in Chen *et al*., 2018) put the share of virtual resources embedded in international trade in the range of 20–32 percent in the case of water, and between 24–37 percent for land.

The bulk of research deals with "virtual water", a concept coined by the late geographer Tony Allan (1997; 1998) as a possible solution to water-related conflicts, that has been operationalized and popularized by Arjen Hoekstra and co-authors (Hoekstra and Hung, 2005; Hoekstra and Chapagain, 2008). Within this field, innumerable case studies have investigated the structure, evolution and determinants of virtual water trade (VWT) for specific crops or countries, especially arid or semi-arid zones, which supposedly can reap large benefits from the imports of water-intensive crops (see D'Odorico *et al*., 2019, for a recent review of the literature). China, for instance, has applied this by often looking at intra-national flows across Chinese regions, with VWT mainly flowing from the water-scarce North to the water-rich South due to the rapid industrial development of coastal regions in the last 20 years. However, less effort has been devoted to virtual land trade, and even less research exists on broader aspects such as biodiversity or environmental services.

2.1 Virtual water trade

Between 70 and 80 percent of world freshwater resources are devoted each year to agricultural production. International food trade allows for population growth to no longer depend on local resources may enhance global efficiency by fostering specialization and overall saving in water, land and other natural resources that are unevenly distributed across the world.

As long as VW flows are unrelated to water scarcity conditions, however, the policy relevance of these findings is limited. Moreover, water savings are not alike: only blue water savings (that is, surface and groundwater) alleviate water stress because green water (which accounts for soil moisture from precipitation) has no alternative uses and therefore cannot be diverted elsewhere.

The literature on water endowments as a determinant of virtual water exports finds mixed results. An early analysis of 131 WVT by Kumar and Singh (2005) find almost no correlation between VWT and water availability. The authors suggest that land plays a greater role in determining net VWT than water does, since access to land implies access to the water available in the soil, and land represents a tighter constraint on agricultural production, so that a number of water-scarce, but land-rich countries may indeed be able to export VW. In fact, there is a strong link between water withdrawal for agricultural uses and cropped area.

These findings are confirmed by a number of subsequent studies such as Fracasso (2014), Fracasso *et al*. (2016), Sartori *et al*. (2017), D'Odorico *et al*. (2019). Duarte *et al*. (2019) noting that land and renewable water are relevant in determining virtual water flows, although their absolute values play a more important role than bilateral relative endowments. This is not surprising as countries' specialization patterns are likely shaped by global or regional comparative advantages, rather than bilateral ones.

Adopting a gravity model augmented with land and water endowments, Fracasso (2014) finds that both natural resources are significantly associated with virtual water exports, while indicators of water stress only correlate with imports.

Studying the case of China, Zhao *et al*. (2019) confirms that water endowments do not explain regional VWT flows, whereas land is much more important as water-scarce but land-rich regions find it more convenient to allocate land to non-agricultural activities. In this context, physical water transfer schemes such as the South-North Water Transfer Project, may represent a solution as they allow agricultural production to take place in land-abundant regions where the opportunity cost of land is low, while at the same time reducing the water stress experienced in those areas. Conversely, Karandish *et al*. (2021) concludes that when analysing the case of Islamic Republic of Iran, indicating that local conditions are crucial.

Debaere (2014) finds that more water abundant countries tend to export more water-intensive products, as predicted by a simple Heckscher-Ohlin framework where factor endowments determine comparative advantages, specialization and trade. Yet, the role of water in determining export patterns is less critical than other traditional factors. While Debaere (2014) finds no significant role for land, his analysis spans to all sectors of the economy, not just agriculture, where land is particularly relevant. Restricting the analysis to the agricultural sector reverses the original findings: land is a significant determinant of exports, whereas water no longer is.[1]

Delbourg and Dinar (2020) use a gravity model to study the determinants of VW flows. They find that relative water endowments and productivity both contribute to shaping food trade patterns, which is in line with both Ricardian and Heckscher-Ohlin theories of international trade, although this is not true for all products. In fact, in some cases, other factors such as land or labour can play a crucial role, or specific climate conditions are necessary and therefore determine the location of crop production. Water productivity matters up to a certain point, and water is often not the biding constraint.

There are several explanations for the lack of a well-defined role for water as a determinant of VWT. First, from a theoretical point of view, a simple Heckscher-Ohlin model focuses on relative factor endowments, whereas most empirical applications use absolute water availability instead (Fracasso, 2014; Wichelns, 2015). Second, differences in endowments should be reflected in different opportunity costs of factors of production and thus in prices. If this is not the case, then no trade would ensue. However, water is seldom priced to reflect scarcity and also land is not always allocated to competing uses based on market prices. While this may be a wise choice, as much as it reflects concerns about conservation of natural resources or fair access to them, it also implies that endowments will not play a crucial role in determining food trade. In fact, Kumar and Singh (2005) suggest that forcing users to pay for water of limiting water usage can induce large improvements both in water efficiency (yield per unit of water) and water productivity

1 The analysis is possible thanks to the availability of the original dataset used in Debaere (2014). Focusing on the agricultural sector only restricts the sample to just 700 observations, making estimates less precise.

(which has to do with the allocation of water across different crops and types of use). Third, agricultural production depends on a host of complementary factors, so that countries with a lot of water but, say, scarce in land will not be able to export water-intensive crops.

Dalin *et al*. (2017) find that 11 percent of groundwater depletion is embedded in trade, and around two-thirds of it is exported by just three countries, namely India, Pakistan and the US. Because the share of food that is traded is around 18 percent, groundwater depletion rises less than proportionally with trade, suggesting international flows are enhancing efficiency. A similar conclusion is supported by the evidence presented by Rosa *et al*. (2019), noting that between 2000 and 2015 food trade grew by 65 percent, but the share of unsustainable irrigation embedded in agricultural exports increased much less (18 percent), indicating that trade does not necessarily drive water scarcity.

Most of the virtual water literature agrees on the positive effect international trade has on global water use. Liu *et al*. (2018) indicates that estimates of water savings linked to VW trade vary a great deal and different methodologies yield quite different results. In fact, estimates range from 164 billion m3 per year (plus an additional 112 bil m3 of irrigation water depletion, de Fraiture *et al*., 2004) to 455 bil. m3/year (Oki and Kanae, 2006), while a more recent review of the literature by D'Odorico *et al*. (2019) put water savings in the range of 230–350 bil. m3 per year. The source of the (virtual) gains from trade is driven by productivity differences between importing and exporting countries.

It is however important to distinguish between blue and green water, because only the former has alternative uses and, therefore, an opportunity cost. In fact, 80 percent of global cropland is rainfed (D'Odorico *et al*., 2019), but irrigated land is twice as productive, and 40 percent of global food is produced with irrigation. Hence, there is a trade-off between land and water use, in addition to the intertemporal tension between current crop yields (enhanced by irrigation) and future sustainability (threatened by groundwater depletion for agricultural use).

Kagohashi *et al*. (2015) investigates the channels through which trade contributes to water saving, and find that while the scale effect puts additional pressure on natural resources, both technological improvements and the composition effect lower water use. Dang and Konar (2018) complement these findings by highlighting that the beneficial effect of trade on water use is limited to the agricultural sector, and suggest the bulk of it comes from the adoption of water saving technology. This is somehow strange given that water is not priced competitively and therefore farmers do not always have incentives to invest in this kind of innovation.

Trade can contribute towards resolving the tension between water saving and cropland expansion. Restrictions to trade will make it harder to meet competing goals by limiting the range of tools that are available. Reducing water usage requires a combination of increase in cropland, more international trade, the intensification of agriculture and a shift toward less water-demanding crops.

Rather than focusing on a single natural resource, Xu *et al*. (2020) take a more holistic approach and assess the impact of international trade on nine sustainable development goal (SDGs) targets that are related to environmental issues and for which it is possible to build precise quantitative metrics.[2] The global effect of trade (against a notional no-trade benchmark) over

2 These are SDG 6.4 (sustainable water withdrawals and supply); SDG 7.2 (increase the share of renewable energy); SDG 7.3 (energy efficiency); SDG 8.4 (resource efficiency in consumption and production); SDG 9.4 (clean and sustainable industrialization); SDG 12.2 (sustainable management and efficient use of natural resources); SDG 13.2 (integrate climate

the 1995–2009 period is positive, yet unevenly distributed. Advanced countries unambiguously benefit from globalization, whereas developing and emerging economies as a group lose out, although there are improvements in later years. Distant trade is more beneficial than adjacent trade for high-income countries, while it lowers SDG scores for many LDCs, which on the contrary, benefit from trade with close partners.

Dalin and Rodrìguez-Iturbe (2016) review the impact of food trade on the environment, which encompasses water, land, pollution and GHG emissions. One of the key findings is that the impact depends on the location of production, suggesting that trade policy in itself cannot address localized negative spillovers on natural resources generated by agricultural activities.

Virtual water trade is associated with global water saving, with the result driven by trade of wheat, corn and meat. Chinese soy imports are also a large source of water saving, although sourcing from Brazil and South-East Asia favors deforestation.

Although VWT is associated with global water saving, as long as VW flows are unrelated to water scarcity conditions, the policy relevance of these findings is limited. What is more, because not all VW flows entail saving blue water, it is difficult to assess the actual contribution of trade to the conservation of water.

2.2 Virtual land trade

Virtual land trade (VLT) has increased from 128 million hectares (Mha) in 1986 to 350 Mha in 2016, following the globalization of agriculture (Qiang *et al*., 2020). This notwithstanding, trade accounts for only 24 percent of the total land footprint (Meyfroidt *et al*., 2013), suggesting that domestic markets still represent the main driver of agricultural and forestry production. Yet, for some products, such as Brazilian oilseeds or Russian timber, the shares are much higher and reach almost 50 percent.

As of 2008, the increased efficiency allowed for trade is estimated to have reduced cropland demand by almost 90 Mha per annum, relative to a notional scenario where each country produced domestically the food it consumes (Kastner *et al*., 2014a). Infante-Amate *et al*. (2018) and Roux *et al*. (2021) quote evidence from Kastner *et al*. (2012) to argue that, at a global level, a notional autarky scenario would require an increase in the land dedicated to agriculture of around 8 percent.

One issue with the literature on virtual land trade is that findings are sensitive to the data and methodology used (Kastner *et al*., 2014b; Schaffartzik *et al*., 2015). Top-down analyses using multi-regional input-output tables that start from monetary values and convert them into land use, are not considered very reliable. At the same time, no well-defined methods exist to compute the land footprint of crop production.

The globalization of food trade results in an increasingly complex network of VLT flows where both the number of trade partners and the size of each bilateral relationship have grown. VL exports are much more concentrated than imports, with a stable group of major exporters (Argentina, Canada, Australia, and the United States of America), recently joined by Brazil,

change measures into national policies); SDG 15.1 (sustainable use of terrestrial ecosystems); SDG 15.2 (sustainable forest management).

Russia Federation and Ukraine, featuring large land endowments. On the other hand, almost all virtual land importers have a per capita land endowment that is below the world average.

Infante-Amate *et al*. (2018) review the Spanish case by looking at historical data spanning the 20th century. The evidence shows a widening gap between the cropland embedded in consumption and the actual land dedicated to agricultural production in Spain, which testifies for a structural transformation of the economy, made possible by an increase in productivity and crop yields, and also for increasing reliance on international trade. Virtual land import is estimated to save around 6.4 Mha of land every year, corresponding to a striking 36.8 percent of Spanish cropland. Of course, increased efficiency may well create environmental damages depending on where and under which conditions it takes place.

Roux *et al*. (2021) examine whether international trade manages to reduce human pressure on the environment by improving the mix of origin, i.e., the sourcing patterns behind human consumption. Rather than looking at the hectares of land embedded in agricultural products, they propose an alternative metric, namely the Human Appropriation of Net Primary Production (HANPP). This sums the change in biomass productivity due to land use change and the biomass removed during harvest. The advantage of such an indicator is that it reflects the extent of land use, and its intensity. However, the authors point out that an increase in HANPP is not necessarily problematic, as similar values would have different implications depending on whether they result from deforestation, or the conversion of grassland. The paper finds that virtual HANPP was flat during 1986–1999 and trended upward afterward. Moreover, sourcing patterns do not always contribute to reducing environmental pressures. In particular, after 1999, the evolution of trade worsened the mix of origin effect so that by 2011 the sourcing patterns of the global food systems is less efficient than it was in 1986. Most of this negative effect comes from the rapid increase in agricultural exports from South America and South Asia, but also derives from rising food demand in Sub-Saharan Africa which is met by inefficient domestic production.

Hertel *et al*. (2020) estimate that greater integration by African countries in world markets would result in less cropland being required in that region by 2050, with technology transfers improving agricultural productivity playing the most important role. Hence, increasing pressures on natural resources can come either from "too much" or "too little" market integration, highlighting that international trade is a tool rather than a deep determinant of environmental harm *per se*. All in all, the analysis presented in Roux *et al*. (2021) suggests that the mix of origin effect has played a rather small role in driving the evolution of HANPP over the last 30 years or so, much smaller than changes in population, agricultural intensity, and per-capita consumption patterns.

2.3 Virtual emissions and pollution

A number of studies have extended the analysis of virtual flows to pollution. Especially relevant for agricultural trade is the virtual flow of nitrogen (N), an important pollutant found in many fertilizers. Huang *et al*. (2019) find that Chinese imports reduce environmental degradation associated with nitrogen pollution by shifting agricultural production to places with higher soil fertility and, consequently, requiring less fertilizer use. In fact, products for which China is a net importer have lower nitrogen yield than the world average, whereas the opposite holds in the case of crops for which China is self-sufficient (such as rice), suggesting that –at least in the case of nitrogen– the pattern of specialization driven by comparative advantages fosters efficiency and reduces environmental harm.

Of course, access to imports could increase (domestic) pollution if it leads to conversion toward crops that are more nitrogen intensive (as would be the case for a shift from soybean to rice in China, see Sun *et al.*, 2018). This reasoning can be easily generalized to all natural resources and environmental pressures: the impact on each of them ultimately depends on local (i.e., production-related) conditions.

2.4 Discussion

The leading exporters of virtual water are India, China, Pakistan, and the United States of America. However, some authors such as, (Mekonnen and Hoekstra, 2020) add Islamic Republic of Iran and Indonesia (Chen *et al*., 2018). Virtual land exporters are Argentina, Canada, the United States of America, Australia, and Brazil (Chen *et al*., 2018). This pattern of specialization resonates well with the prediction of trade theory, whereby market integration leads to the concentration of production in countries where the opportunity costs of inputs and factors of production are lower. As a result, the virtual export of natural resources, being water or land, is very concentrated, suggesting that just a few countries have increasingly specialized in the provision of agricultural products to world markets. While most economists would consider this fact a simple outcome of the theory of comparative advantages, in the natural science and ecology literature, this is viewed as evidence of the presence of structural imbalances in world trade, and it represents a major source of concern.

The second piece of circumstantial evidence brought against trade concerns is increasing groundwater depletion. Almost 50 percent of the world's population lives in places where aquifers are overexploited, with the main driver being crop irrigation, which accounts for 70 percent of groundwater use (Pastor *et al*., 2019). In fact, almost 40 percent of the food comes from irrigated land, 30 percent of which is unsustainable (Pastor *et al*., 2019). Yet, a water-centric approach that associates trade with the globalization of pollution and the externalization of water use (see, for instance, O'Bannon *et al*., 2014) is partly misleading, as water is often not the main driving force behind trade flows. Moreover, as forcefully noted by Wichelns (2015), there is no clear counterfactual against which one can assess the current level of market integration. What happens if trade suddenly halts, and each country produces domestically everything it needs? Besides being simply unfeasible for many countries, a notional scenario in which international flows are banned would not reduce the material footprint of the food system by the amount usually attributed to trade, but rather change the location of production in ways that may well increase pressure on natural resources.

Despite the overall water saving associated with international trade (Hoekstra and Chapagain, 2008; Dalin and Rodrìguez-Iturbe, 2016), Dalin *et al*. (2017) note that efficiency and sustainability do not always go hand-in-hand: soybean imports in China are water and land efficient but contribute to unsustainable water depletion in the United States of America and is associated with biodiversity loss and deforestation in Asia and Brazil. Hence, there are possible trade-offs among competing environmental objectives. Moreover, domestic production is often not a viable alternative or, at least, not one that would reduce the impact on natural resources.

Higher crop yields, which are instrumental in lowering the environmental pressure of the food system, are associated with higher pollution from fertilizer use and the intensification of agriculture. The trade-off between competing claims is very evident in this respect, and research on the subject is inconclusive (Dalin and Rodrìguez-Iturbe 2016). A similar claim is advanced by Liu *et al*. (2018) in the context of virtual water flows, noting that very little is known about gray water, which is linked to environmental damage and pollution.

One explanation for the lack of a prominent role for trade in promoting efficiency is the well-known fact that the marginal cost of water and land does not reflect environmental costs so negative externalities can occur and land-rich countries with large, unprotected areas are likely to supply a lot of land-intensive products. Moreover, agricultural production embeds a host of complementary inputs, not just land (or water, or fertilizer), and there are possible trade-offs across different natural resources, whose binding role will depend on local conditions.

As mentioned in the Introduction, international trade can play an important role in adapting to climate change. Market integration allows the diversification of sourcing patterns, making the food system more resilient to weather shocks, the adverse effect of rising temperatures on agricultural production, or increased water scarcity and soil degradation.

A last indirect channel through which trade can positively affect the conservation of natural resources is via its impact on income. As long as environmental protection is a normal good (and even if it behaves like a luxury good), rising incomes generate pressure for more stringent policies, and trade openness can have a beneficial effect on the environment (Copeland *et al*., 2021). Because this mechanism is not directly related to trade in agricultural commodities, it cannot be developed further.

CHAPTER 3

Negative environmental impacts of trade

3 Negative environmental impacts of trade

Agricultural production is a key driver of resource use and environmental pressure, and it can lead to unsustainable water withdrawals, water and soil pollution, deforestation, and degradation of natural habitats (Foley *et al*., 2005). Because market integration creates incentives to expand crop production in some countries, a number of scholars (Lenzen *et al*., 2012; Wiedmann and Lenzen, 2018; Rosa *et al*., 2019) postulate a link between international trade and environmental degradation (Baylis *et al*., 2021), although direct evidence about a causal relationship between trade and environmental damage remains limited.

Advocates of consumption-based accounting (aka footprints, see, for instance, Wiedmann and Lenzen, 2018) stress the need to hold consumers more accountable for their choices and suggest importing countries are responsible for the depletion of natural capital experienced by producing countries. Besides the difficulty of allocating the costs and benefits of food production across consumers and producers, a further complication stems from the fact that footprints cannot inform policymakers of the consequences of trade restrictions so long as it does not incorporate precise information on local conditions.

This Section reviews the main arguments on the negative consequences of food trade, following the tripartite structure used in Section 2 and looking at water, land, and emissions.

In addition to possible detrimental effects on specific natural resources, which can be traced down to the presence of externalities due to poorly defined property rights, there are two general concerns put forward in the natural sciences literature. The first question is whether trade can improve resource efficiency, and the second is whether the global food system is more prone to shocks.

According to Wiedmann and Lenzen (2018), over the last 30–40 years, the globalization of agriculture has not led to a significant reduction in the material footprint of advanced countries, once their domestic and external footprints are lumped together. As such, trade would affect the location of production without contributing to improving efficiency. Similarly, Wood *et al*. (2018) note that over time the per-capita environmental footprint of humanity has increased, although their analysis is not confined to agricultural trade. The lack of a well-defined counterfactual against which it is possible to gauge the role of trade and other drivers of environmental pressure somewhat weakens the argument.

The observation that many advanced countries have an external footprint larger than their domestic one is often considered a sign of malaise and evidence of the pernicious effects of trade on the environment. For instance, Lenzen *et al*. (2012) claim that "30 percent of global species threats are due to international trade". The loss of biodiversity and natural habitats are critical issues and are often driven by land use changes and deforestation, which, in turn, respond to economic incentives and market failures (there are no property rights for biodiversity, so that its loss is not internalized by markets and there are negative spillover effects). Yet, trade restrictions would not, for instance, curb domestic consumption, which often represents the largest share of food demand in any given country.

Contrary to the notion that trade can act as a useful adaptation strategy to cope with climate change, some scholars express concerns about the vulnerability of a global food system that relies on unsustainable practices (e.g., Dalin *et al*., 2017). The working hypothesis is that by de-coupling consumption from production, countries become less aware of and more vulnerable to

climate-related shocks and/or the depletion of natural resources. For this effect to be relevant, one needs to make several assumptions.

The first is that the presence of a border blurs perceptions about the environmental footprint of the food system, above and beyond the separation between agricultural production and food consumption that is present even within countries, making consumers less aware of the effects of their choices.

Second, markets must not convey proper signals on natural resource scarcity, so that resource depletion does not lead to higher prices that would stimulate resource-saving investment. This is, unfortunately, not far from reality in many countries. Chang *et al*. (2016) emphasize that ecosystem services are not priced and therefore subject to true externalities, and it is well known that irrigation prices seldom reflect scarcity. As a result, too many resources are used for human activities, undermining long-term sustainability.

Third, if a negative shock hits an exporting country, it must be more troublesome to replace imports than to compensate for a shortfall in domestic production. In this respect, there is little evidence that imports are inherently riskier than domestic production, unless the benchmark is a crisis situation in which a government may be able to commandeer crop distribution and/or impose price controls. Sartori and Schiavo (2015) find that the global food system has not become inherently more vulnerable or unstable despite its complexity has increased substantially in the past decades. However, unfettered markets may be more volatile, especially if there are low reserve stocks (Marchand *et al*., 2016) and specific measures to guarantee food access and affordability are necessary for some contexts (although this is not related to environmental issues).

Of course, incomplete markets and uneven rules on the exploitation of natural resources imply that the globalization of agriculture may increase the environmental footprint if it leads to the relocation of production to countries with laxer standards (the pollution haven hypothesis) or weaker governance of natural resources.

3.1 Water stress

Mekonnen and Hoekstra (2020) focus on the blue water footprint of food, which comprises surface water and groundwater, highlighting the risks associated with unsustainable water practices. In fact, more than 50 percent of the blue water footprint comes from places where the environmental flow requirements (the amount of freshwater necessary to sustain aquatic ecosystems and, as a result, support sustainable livelihoods) are not respected.

Agriculture accounts for 70 percent of water withdrawals, reaching higher shares in Africa and Asia and food production is responsible for 96 percent of the infringements, with a growing share being outside the country of final consumption and two-thirds of the total footprint located in just five countries (China, India, Islamic Republic of Iran, Pakistan and the United States of America). Moreover, a small number of internationally traded crops (cotton, rice, wheat, sugarcane and soybean) account for around two-thirds of unsustainable virtual water flows (Mekonnen and Hoekstra, 2020).

According to D'Odorico *et al*. (2019), excessive water extraction accounts for roughly 20 percent of irrigation, and the overuse of groundwater represents a serious challenge in some countries and areas, including rich parts of the world such as the United States of America.

Food consumption that relies on these sources is therefore at risk in the medium- long-run, and this is true irrespective of whether final consumers are located a short distance from where crops are grown or thousands of kilometers away.

Shifting the burden of resource use to other countries may reduce the perception of water scarcity and thus postpone a reckoning that may be necessary. Yet, the focus on water as the main bottleneck to food production provides policymakers with only a partial and somehow distorted perspective. Food is produced by a bundle of inputs whose use is determined by their opportunity cost. In fact, D'Odorico *et al*. (2019) recognize that trade is not driven by water needs, while Wiedmann and Lenzen (2018) concur that income is the most important driver of virtual water trade.

Dalin and Rodrìguez-Iturbe (2016) notice that water productivity does not amount to sustainability, so virtual water trade may increase efficiency, while simultaneously putting additional pressure on scarce water resources. Along the same lines, Wichelns (2015) stresses that concepts like virtual water or water footprint are of limited policy relevance because they do not account for the opportunity cost of water and for local conditions, which are critical to assessing the merit of alternative water uses.

3.2 Land use change, deforestation and biodiversity loss

In the last 30 years, the world has lost approximately 178 Mha of forest area (FAO, 2020). Land appropriation by agricultural production not only exerts a negative effect on the environment by contributing to GHG emissions and reducing carbon storage, but also because deforestation is associated with biodiversity loss and environmental degradation. For instance, Green *et al*. (2019) find significant species losses driven by land conversion and appropriation by agriculture in the Brazilian cerrado, while Ortiz *et al*. (2021) highlight that biodiversity is 40 percent lower in cropland relative to areas covered by primary vegetation. This, in turn, triggers a feedback loop as the loss of biodiversity negatively affects agriculture by reducing ecosystem services such as pollination and environmental resistance. Chang *et al*. (2016) emphasize that ecosystem services are not priced and therefore subject to true externalities. As a result, too much land ends up being used for human activities.

Although the domestic market is often responsible for the largest share of impact than any foreign country, even in export-oriented agricultural systems such as Brazil (Green *et al*., 2019), new market opportunities created by trade liberalization may increase the incentive for agricultural expansion and land appropriation, with negative effects on deforestation and the preservation of natural habitats (Dalin and Rodrìguez-Iturbe, 2016). Hence, while the expansion of cropland in areas previously not dedicated to agriculture can enhance efficiency, it may also threaten fragile environments and generate global spillovers (an increase in GHG emissions from deforestation would feed a vicious circle by hastening climate change and leading to further environmental degradation elsewhere). This is especially the case when land governance is weak, either because of ill-defined property rights or prioritization of agricultural production over conservation (Torres *et al*., 2017). In fact, uncertainties about the impact of trade on deforestation have become a major stumbling block in the ratification of the EU-Mercosur trade agreement (Abman *et al*., 2021), although evidence of a direct link between trade and biodiversity loss remains limited.

In an early contribution that aims at determining the causal effect of trade on the environment, Frankel and Rose (2005) find little evidence that openness has any significant adverse effect on

deforestation (or pollution), controlling for income or other relevant factors.[3] One of the few examples where a trade shock has had a direct and sizable impact on species conservation is a study by Taylor (2011), using historical information to draw a causal link between the surge in demand for leather triggered by a British industrial innovation and the collapse in the buffalo population in North America in the late 19th century. Similarly, Eisenbarth (2018) finds that demand shocks that increase exports can explain the depletion of fisheries around the world. These works suggest that a surge in foreign demand may determine the over-exploitation of poorly-regulated natural resources. However, Ortiz *et al*. (2021) make clear that a more local food system *per se* is unlikely to be beneficial to biodiversity, mainly because the use of more suitable locations to grow food (as induced by comparative advantages), reduces the required amount of inputs such as land, water and fertilizers.

Chen *et al*. (2018) emphasize that the impact of food production depends heavily on local conditions, and even in a critical context such as Brazil, Green *et al*. (2019) find that the production of soy for exports has a very different environmental footprint depending on regional agricultural practices. In general, unless appropriate measures to protect natural habitats are put in place in producing countries –which help farmers integrate the trade-off between short term supply considerations versus longer-term sustainability issues– reducing international trade does not guarantee that food production takes place where environmental pressures are minimal.

A further channel through which the international flow of goods can affect biodiversity is the spread of invasive alien species (Westphal *et al*., 2008). Interestingly, it is not the type of trade that matters, such as the share of agricultural imports over total trade, but rather the sheer amount of international transactions.

3.3 Greenhouse gas emissions and climate change

West *et al*. (2010) estimate that deforestation and conversion to cropland contribute between 12–20 percent of global emissions yearly. While not all the increased production is destined for international markets, in some areas (e.g., Brazil and Indonesia) and for some crops (soybeans and palm oil), the opportunities generated by market integration rank high among the determinants of land use change. When combined, food accounts for roughly 30-35 percent of GHG emissions (Poore and Nemecek, 2018; Crippa *et al*., 2021), with strong heterogeneity across both products and countries. Consequently, the location of agricultural activities matters a great deal. In fact, the environmental impact of food production can vary 50-fold among producers of the same good, even in similar geographic regions, with trade-offs between emissions and usage of natural resources. For instance, aquaculture saves on land, but generates far more GHG emissions than vegetable proteins, whose production is more land intensive.

Differences in agricultural practices, and the different effects that even the best practices have in different regions, imply that specialization and international trade may not always lead to more efficient use of natural resources or a reduced environmental impact (even if one abstracts from transport-related emissions and pollution). Intensive systems, an outcome of specialization, have a lower per unit impact, although the overall pressure they put on local ecosystems is stronger and could be unsustainable in some cases. If current resource scarcity

3 Frankel and Rose (2005) find no evidence that trade increases air pollution; on the contrary they report a causal link between trade openness and lower concentrations of sulphur dioxide in the air when looking at a group of 40 countries in the early 1990s.

and considerations about stock depletion are not factored into prices, then efficiency and sustainability may not proceed in parallel, and trade-offs may emerge.

Significant cross-country differences in GHG emissions suggest that the relocation of agricultural production triggered by trade integration can substantially impact the food system's carbon footprint, and this heterogeneity has important implications on the net effects of the local versus global sourcing of food. While the consumption of domestically-produced food seems an obvious way to reduce a country's carbon footprint, once differences in production practices and emissions are combined, the picture is far less clear. In fact, the GHG emissions due to the transport of traded goods are the most evident (and global) negative externality directly linked to trade, but their magnitude is small. While the direct emissions from transport are relatively small, in some cases they more than offset the gains due to higher agricultural productivity (Cristea *et al*., 2013). Avetisyan *et al*. (2014) find that, for some food items, in particular those of animal origin, the fall in transport-related emissions are dwarfed by the increase that would take place if all countries were to re-shore their agricultural production. In fact, domestic emissions dominate the contribution of the food system to global emissions in about 90 percent of the country-product pairs they examine.

The relatively small effect of transportation and shipping is consistent with results from more general works that do not focus on agricultural goods. Cristea *et al*. (2013) and Shapiro (2016) both find that a shift from autarky to free trade "only" increases overall CO_2 emissions by 3–5 percent, although there are very large differences across industries and trading partners. Maritime shipping in bulk carriers tend to be more fuel efficient than other means of transportation lowering the overall impact of some product-country-pair combinations.

The world has witnessed a decoupling of population growth and food-related emissions, with the latter growing more slowly than the population in the last 40 years. This, together with a reduction in CO_2 intensity and CO_2 per capita emissions over time, in a period of rapid expansion of international trade, is consistent with the notion of specialization lowering the environmental impact of the food system at a global level, even if Crippa *et al*. (2021) find a number of specific countries where the trend is reversed. Production, land use, and land use change are responsible for the bulk of the GHG emissions associated with the food systems, and account for more than 70 percent of the total. Amid later (beyond the farm gate) stages, distribution is less relevant than packaging, with "food miles" accounting for less than 5 percent of GHG emissions and the bulk of it due to local or regional road transport rather than international shipping. Of course, there is large heterogeneity, with some specific products, such as bananas and sugar cane, for which transport accounts for 40 percent of the total carbon footprint.

West *et al*. (2010) highlight the tension between the need to increase food production and the role of forests as carbon sinks; the trade-off is particularly adverse in tropical areas, which feature lower agricultural yields (up to −50 percent) and higher carbon storage potential (up to +100percent) with respect to temperate zones.[4] Conservation and reforestation of the tropics is only possible if more trade is allowed, as the amount of food that is needed will not diminish simply by imposing export restrictions.

4 The opposite holds for arid regions, where low vegetation implies low carbon storage. In these areas, on the other hand, increased agricultural production would put additional pressure on possibly scarce water resources.

CHAPTER 4

Policy implications

4 Policy implications

Despite the complexities that link agricultural trade and natural resources, there are at least two broad lessons can be drawn from the discussion. The first is that unless appropriate measures to protect natural habitats are in place at the production stage, trade restrictions do not guarantee that food production takes place where environmental pressures are minimal. Second, the need to recognize trade-offs and tensions among competing environmental claims and realize that actions aimed at mitigating pressure on a specific resource, like water, may well exacerbate tensions in other dimensions of the ecosystem. Vos *et al*. (2019) find that competing perspectives on water use, although this can be easily generalized to natural resources, do not account for existing trade-offs among water and land-use, blue and gray water, short-term productivity, and long-term sustainability, and so on.[5] This, together with the lack of well-defined counterfactuals limits the policy relevance of many of the works that address the relationship between agricultural trade and natural resources.

Still, it is possible to distill some relevant policy implications or at least dispel some common misconceptions.

4.1 Trade policy

From a theoretical point of view, trade policy remains a second-best (that is, sub-optimal) solution, because tariffs and non-tariff barriers to trade do not address the source of externalities and cannot target domestic consumption.

Ideally, one would like a system of free trade –so that comparative advantages can allocate crop productions where natural resources have the lowest opportunity costs and are used most efficiently– combined with local conservation measures to ensure the protection of fragile environments and the elimination of negative externalities.

Abman *et al*. (2021) find that regional trade agreements with specific provisions aimed at limiting deforestation and biodiversity loss are an effective tool to limit the negative effects trade can have on the environment. This effect mainly works through a reduction in land use change following trade liberalization. However, the global impact of such measures is unclear, as deforestation could simply shift to areas or countries not covered by such provisions. Hence, multilateral coordination should be preferred to a host of overlaying bilateral or regional agreements.

Coordinated trade policy can be used to achieve environmental effects in other countries, by forcing upon them part of the costs of protection. The idea behind the notion of climate clubs (Nordhaus, 2015) informs the carbon border adjustment mechanism recently proposed by the European Union as part of its strategy to counter climate change. Global coordination is key as even relatively large countries or "clubs" may achieve little on their own (Copeland *et al*., 2021).

For trade to properly allocate production where resources are more efficiently used, subsidies that prop up specific crops or sectors should be eliminated. Not only do they reduce efficiency and distort the allocation of resources across countries and sectors, but they can have adverse environmental effects. For instance, cotton production, which absorbs 33 percent of unsustainable irrigation (Rosa *et al*., 2019), is heavily subsidized in the United States of America and prominently

5 Grey water represents the amount of freshwater required to assimilate a load of pollutants based on natural background concentrations and existing quality standards.

among American exports.

Along the same lines, production externalities can be reduced by combining local conservation measures and adequate pricing of natural resources, reflecting the scarcity and intertemporal sustainability considerations. Kumar and Singh (2005) highlight that charging a price for (blue) water used in irrigation or setting quantity limits can be effective to increase water efficiency.

4.2 Global vs. local governance

Effects of agricultural production on natural resources are eminently local and therefore best dealt with at the local level. Because most of the negative effects of the food system occur at the production stage, where the final consumers are located is immaterial to environmental conservation.

Hoekstra (2011) has been a vocal advocate of global water governance, suggesting that as virtual water transfers shift environmental pressures beyond national borders, global factors such as climate change affect local conditions, and multinational corporations play an increasing role, the world is slowly moving toward the privatization of water. The counterargument is the subsidiarity principle, whereby any issue should be addressed at the lowest possible level of governance in order to guarantee solutions that are tailored to specific local needs and conditions. The main question then becomes whether it is possible to solve issues related to the unsustainable use of natural resources at a level that is lower than global or, in other words, whether the globalization of agriculture necessarily calls for global solutions?

In fact, global externalities are very few. Deforestation, with the associated GHG emissions, is the foremost example because the effects of climate change may well occur very far away from where GHGs have been released into the atmosphere. Moreover, emissions can feed a vicious circle since they hasten climate change and thus lead to further environmental issues. The loss of biodiversity and ecosystem services is another channel through which deforestation can have global negative effects by increasing the opportunity for animal-human interactions and thus facilitating the transmission of zoonotic diseases (Johnson *et al.*, 2020).[6]

On the other hand, environmental degradation or increasing pressure on water resources are not inherently global. Because environmental impacts heavily depend on local conditions, policy interventions should be tailor-made to the specific context and a one-size-fits-all approach is misguided.

The limited policy guidance offered by the concept of virtual water is stressed by Gawel and Bernsen (2013) and Wichelns (2015). These scholars emphasize that a large water footprint may not be problematic under some conditions and comparing WFs across countries is pointless unless we have precise information on production sites and on the opportunity cost of water. Wichelns (2015) stresses that the savings associated with VW trade is only notional and that efficiency and abundance cannot be combined. Sharp cross-country differences in water footprints do not, by themselves, make water scarcity a global issue. Water saving in Europe (a large sink of virtual resources) does not have beneficial effects in arid or semi-arid regions of Africa. Nor does a ban on trade in water-intensive goods necessarily benefit water-scarce regions, as water is often not the main constraint to agricultural production in food-importing countries.

6 The argument is akin to the result of the optimal tariff rate for a large country in international trade theory

On the other hand, local issues may become international under some circumstances. If water deficits or environmental degradation led to migration (Borgomeo *et al*., 2021), it makes sense to tackle the issue at the international or regional level. In this case though, restricting trade is likely to exacerbate problems, as areas featuring severe water scarcity can benefit from access to food produced elsewhere.

One argument in favor of global, or at least internationally coordinated, policies is the possibility that national conservation efforts have unintended consequences in third countries. In this case, the problem is not that action by a single country would not be enough to solve a problem, or that there might be a problem of free-riding. Rather, the argument is similar to the "pollution heaven" hypothesis, whereby the combination of stringent domestic regulation plus international trade shifts the environmental burden onto other countries where agricultural practices have a larger footprint, thus making the world worse off. This phenomenon is labeled the "illusion of preservation" by Berlik *et al*. (2002).

4.3 Suggestions

One of the main challenges facing humanity is to increase food production to match the population growth, while lowering the associated environmental pressure.

Access to advanced technology and innovation, which can be facilitated by international trade, will play an important role in helping developing countries, where the agricultural sector plays a larger role, promote intensification and resource efficiency while limiting adverse, local and global, effects on the planet.

Along with technical change to reduce the amount of natural resources needed to produce a given amount of food, policies that nudge people toward diets with a lower environmental footprint can also limit the over-exploitation of natural resources. Roux *et al*. (2021) estimate that 19 percent of the global harvested biomass is used for food, while 71 percent feeds livestock. As such, dietary changes that steer consumption away from animal-based products have the potential to lower the impact of the food system.

The heterogeneity in the impact of different policy measures and agricultural practices, together with a lack of clear-cut evidence on the relationship between agricultural productivity and pollution (Copeland *et al*., 2021) suggest policy experimentation will be crucial to develop a set of effective tools to reconcile increasing food demand with the need to protect the environment.

One of such areas of interventions concerns schemes offering payments for environmental or ecosystem services, which have been attracting attention and resources from both public and private donors. However, evidence on their actual effects is still limited and somehow controversial (Miteva *et al*., 2012). One problem is that these instruments often are assigned multiple objectives ranging from environmental protection to local development. Moreover, results seem to depend on local conditions, most notably enforcement and the presence of comprehensive conservation and development strategies (Costedoat *et al*., 2015). Direct support to farmers engaging in environmental protection to compensate for foregone revenues or increasing costs stemming for environment-friendly agricultural practices can help lower the tension between income support and conservation, but more evidence on the effectiveness of such schemes is needed (see Jayachandran *et al*., 2017, for a pilot study in Uganda, which has delivered positive results).

Non-state market-driven (NSMD) governance, such as certification schemes or labeling, have also become increasingly popular. The assumption is that by increasing consumers' awareness of the environmental, or social footprint of specific products (timber, cocoa, palm oil, to cite a few) it may be possible for "certified" crops to command a premium price, thus rewarding lower yields and environmental protection. Yet, the actual effectiveness of such schemes is disputed both in the general press (Whoriskey, 2019) and by scholarly research (Kroeger *et al*., 2017). On the one hand, issues such as mismanagement, weak monitoring, capture, corruption and even fraud have emerged as critical limitations. On the other hand, scientific research on the topic is still scant. Kroeger *et al*. (2017) find that deforestation continues despite NSMD rules aimed at prohibiting the conversion of forested land to agriculture, and this appears to hold for different institutional settings (Brazil, Indonesia, Côte d'Ivoire) and crops (soy, palm oil, cocoa). Studying soy production in the Brazilian cerrado, Green *et al*. (2019) find that certifications are not always effective in preventing biodiversity losses in vulnerable areas. Responsibility for this outcome lies mainly with a lack of market uptake so the premium received by farmers for sustainable agricultural practices is too small (van der Ven *et al*., 2018). Chang *et al*. (2016) estimate that a five percent increase in the price of Indonesian palm oil would be enough to internalize the value of lost ecosystem services driven by forest conversion and appropriation by agriculture, but the current premium fetched by certified palm oil is just one percent. Moreover, the existence of regulatory loopholes and the fragmentation of environmental governance also represent a problem. van der Ven *et al*. (2018) stress how cocoa and palm oil production rests on a large number of smallholder farmers, who lack the financial and technical capacity to implement necessary reforms. On the other hand, the presence of multiple certification schemes with different criteria and standards creates sourcing problems for large cocoa traders who control a large fraction of the market and would be in the position to steer the sector toward more sustainable practices.

CHAPTER 5

Conclusions

5 Conclusions

Agricultural trade can enhance global efficiency in the use of natural resources. At the same time, it may exacerbate the negative effects of externalities in contexts marked by weak governance. Moreover, efficiency and sustainability cannot go hand-in-hand. Local policy measures are needed to account for this trade-off, as well as to account for possible negative externalities that lead to the over-exploitation of the environment.

Trade restrictions are the second-best solution as they do not affect domestic demand and do not address the source of externalities. Moreover, global coordination is necessary to avoid bilateral or regional agreements simply displacing environmental damage to areas that enjoy a lower degree of protection.

Yet, trade is not "unfair" or problematic merely because it allows countries to consume more than could be domestically produced. While such an argument clashes with the very notion of gains from trade, the notional scenario in which each country produces domestically all the food that it needs is simply unfeasible. Moreover, trade restrictions do not guarantee that crops are grown where natural resources are more efficiently used and are likely to increase the global pressure the food system puts on the environment.

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