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Agricultural Trade and Environmental Sustainability

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Abstract

Global agriculture consumes substantial resources and produces significant pollution. By shifting its production to new locations, and inducing changes in technology and input use, trade has a substantial impact on environmental sustainability of the world's food systems, but due to suboptimal environmental policy, the exact nature of these impacts is in dispute. We review the literature on agricultural trade and environmental sustainability, highlighting the different approaches taken in ecology versus economics. While useful in identifying environmental costs, much of the ecological literature does not compare these costs to a trade-free counterfactual and can therefore be misleading. Further, by moving production to places with more resources and increasing production efficiency, trade can reduce the environmental impact of food production. On the other hand, trade can also limit the effectiveness of domestic environmental policy because production can be shifted to countries with less stringent regulations. However, recently, consumers are leveraging trade policy to induce exporters to improve environmental sustainability. While such policies are gaining traction in wealthy countries, evidence suggests that such measures will not reach their potential without buy-in from decision makers in the countries where the environmental damages are occurring.

1. INTRODUCTION

Agriculture has a large resource footprint globally, occupying 40% of land and consuming 70% of freshwater (OECD-FAO 2020). It is one of the leading drivers of deforestation and habitat loss (Busch & Ferretti-Gallon 2017) and generates substantial pollution in the form of nitrogen and phosphorus runoff, air particulates from crop burning and dust, and more than 5 billion metric tons of CO_2 emissions (CO_2e) in greenhouse gas (GHG) emissions in the form of methane and nitrous oxide (Springmann et al. 2018). Meanwhile, trade in agricultural products has become increasingly important to the global food system. It has grown faster than global food production since 2000, spurred by lower trade barriers and strong economic growth in developing countries (OECD-FAO 2020). As a result, the location of the world's agricultural production is shifting. Eastern Europe, Latin America, and the Caribbean are strengthening their exports, while Asia and Africa are increasing their role as net importers. Given agriculture's inexorable link to natural resources, these trade-induced changes in agricultural production and the related increase in transportation activity raise concerns about their long-term effects on the environment.

In this article, we review the literature on the relationship between agricultural trade and environmental sustainability. This topic has been tackled by a range of disciplines, using a variety of different approaches. Much of the natural sciences and ecological research evaluates the cost of the trade-induced location of agriculture on natural resource use and environmental outcomes (e.g., Chaudhary & Kastner 2016, Konar et al. 2016, Lenzen et al. 2012). Although the economics research on this topic recognizes that agricultural trade can exacerbate the effects of suboptimal environmental regulation, it generally argues that the solution is not to limit trade, but to correct the market failures surrounding the negative externalities associated with pollution and (excessive) natural resource use at the location of production (Bulte & Barbier 2005).

Furthermore, economic research recognizes that environment and natural resource policy is endogenous. Income growth from trade may increase demand for policies to produce environmental goods, and trade can provide the incentives for regulators to manage their resources more carefully (Copeland & Taylor 2004, Swanson 1994). Economists also note that trade can enhance productivity, reducing resource consumption and environmental externalities. Meanwhile, the ecological research highlights the heterogeneity of the environmental effects of agricultural production and the costs of land-use transition, and it incorporates more detailed modeling of weather and resource shocks (e.g., He et al. 2019, Lenzen et al. 2012, Searchinger et al. 2008). Both literatures recognize the need for international coordination, through regulations as well as by incentivizing production of environmentally friendly agricultural products (Walker et al. 2009). In pursuit of such incentives, private firms and civil society have implemented initiatives involving eco-labeling and sustainability standards in supply chains. This has given rise to a flurry of new studies assessing their effectiveness. In this review, we synthesize recent research to get a more comprehensive picture on the relationship between agricultural trade and environmental sustainability.

We begin by reviewing the theory from the broader literature on trade, environment, and natural resource use, identifying what these findings might imply for agricultural trade and environmental sustainability. Second, we review the empirical literature that estimates the effects of agricultural trade on the environment. Third, we discuss policy interventions to improve the sustainability of agricultural trade. We conclude by identifying gaps in the existing literature, highlighting promising directions for future research.

2. INSIGHTS FROM TRADE THEORY

By changing relative output prices, agricultural trade can affect the location and amount of natural resources used and pollution produced. Second, trade can also alter production processes, thereby changing input use, as well as facilitate technology transfer among countries. Third, trade can induce changes in consumption, by changing both output prices and incomes. Those changes in income can also induce changes in the demand for environmental goods and thus the demand for regulations over pollution and natural resources (Copeland & Taylor 2004). In this section, we walk through a simple model of trade, natural resource use, and externalities, using this to discuss recent theoretical findings and their implications for agricultural trade and sustainability.

2.1. Basic Model

Figure 1 illustrates a standard Heckscher–Ohlin model of trade, with the production of two goods, x and y, that are a function of natural resources, R, and a composite of labor and capital, K. Environmental degradation in our model can come both from pollution, z, associated with production of good, x, and from consumption of the natural resource, R, as this pulls resources from the production of a nonmarket environmental good e, such as habitat, carbon sequestration, or water quality. Pollution can be either local, such as nitrous oxide, or globally mixed, like carbon dioxide. Goods x and y are tradable, but e is not. Let y be the numeraire good, where p is the price of x relative to the price of y. While the literature tends to model one or the other of these effects (pollution and encroachment on natural resources), we include both because agricultural production produces both types of externalities, and these externalities and their policies likely interact.

2.2. Environmental Policies

Agricultural production does not occur in a policy vacuum, and countries often have pre-existing policies to regulate the environment. Consider the case where the government taxes pollution at a rate of τ per unit. As the tax on pollution increases, firms will lower their emissions intensity, using more of either resources R, the composite input K, or both, depending on whether the other input is a substitute or complement to pollution (Fullerton & Heutel 2007). If the pollutant were manure effluent, the farmer's best response may be to use more of the resource (land) to allow manure to be spread less intensively. In other settings, the best response might be to invest in capital-intensive mitigation measures, such as storage lagoons or anaerobic digesters. Thus, the effect of increased stringency on emissions (i.e., an increase in τ) could be to use either more K or more R.

Now introduce a second government policy that subsidizes the production of the environmental good at σ per unit. This policy could take the form of a direct subsidy to production, or, more likely, dedicate some minimum level of the resource (R_e) to produce the environmental good, for example, the ecological focus area in the EU Common Agricultural Policy. This policy will increase the cost of natural resources in the production of x and y, inducing firms to use more of the other input K in production and reduce the production of the capital-intensive good.

2.3. Introducing Trade

Standard results from the Heckscher–Ohlin model suggest that each region will have a comparative advantage in the good that intensively uses the resource the region has in relative abundance. **Figure 1*a*** displays two regions: South (S) and North (N). If South is resource-rich (compared to its endowment of K) relative to its trading partner (North), it will have a comparative advantage in the production of the good that uses resources intensely in production.[1] In the absence of trade,

[1]A region is defined as being resource abundant if its ratio or resources to other inputs is higher than that in its trading partner, denoted by asterisks: i.e., $\frac{R}{K} > \frac{R^*}{K^*}$. A good is defined as using resources intensively in production if for all input prices, it uses a higher ratio of resources to capital than the other good: $\frac{R_x}{K_x} > \frac{R_y}{K_y}$.

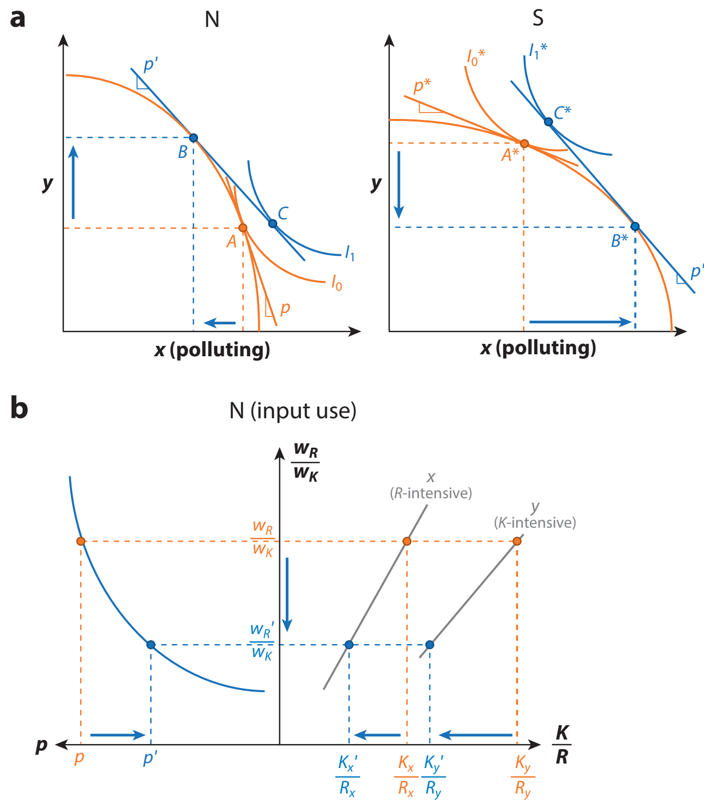

Figure 1

A simple model of trade and the environment. (*a*) The production and consumption of two goods, x and y, in two regions, N and S, before and after trade, where the production of good x is polluting. The before-trade equilibrium is illustrated in orange and the after-trade equilibrium in blue. Region N is illustrated in the left panel and region S in the right, and production, consumption, prices, and in difference curves in region S are denoted with asterisks. Before trade, both regions consume where their indifference curves (I_0 and $I_0{}^*$) are tangent to the production possibility frontier, illustrated by points A and A^* and relative prices p and p^* in regions N and S, respectively. After trade, relative prices converge to p', leading each region to produce at the tangency point between the new world prices and their production possibility curve, illustrated by points B and B^*. This causes N to reduce production of x and increase production of y, while S reduces production of y and increases production of x (the shift in production is shown by *blue arrows*). Each region now consumes where the price line is tangent to its higher indifference curve (I_1 and $I_1{}^*$). (*b*) The change in input use is associated with this same trade-induced change in production in region N, where we assume the production of x uses resources intensely. The left side of the graph illustrates the link between output and input prices, and the right side illustrates the link between input prices and the ratio of inputs used in the production of each good. When the relative price of good x in region N decreases after trade (from p to p'; *blue arrow* on the left), the returns to resources falls relative to the returns to the other input, K, so that $\frac{w_R}{w_K}$ decreases to $\frac{w_R'}{w_K}$ (*blue arrow* on the vertical axis). This decrease in the relative cost to resources causes a decrease in the amount of other inputs relative to resources to be used in the production of each good, dropping from $\frac{K_y}{R_y}$ to $\frac{K_y'}{R_y}$ and from $\frac{K_x}{R_x}$ to $\frac{K_x'}{R_x}$ (*blue arrows* on the right).

the two regions N and S consume what they produce (at A and A^*), and relative prices differ, with p being lower in S, which has a comparative advantage in x. Under free trade, relative prices are equalized at p', as shown by the common slope of the blue lines, and the North begins to produce more of the clean good (y) and less of the polluting good (x), while the opposite is the case in the South. Consumers in both regions are able to reach a higher level of utility, consuming at point C and C^*, illustrating the gains from trade. Demand for the domestically abundant factor will increase (R in the South and K in the North), while demand for the scarce factor will decrease as production shifts to locations where the factor used intensively in production is in abundance.

Figure 1*b* shows the corresponding changes in relative input and output prices and relative input quantities used in the production of goods y and x for region N. The increase in the relative price of x in N will raise the relative price for the abundant factor (K), illustrated as the decrease in $\frac{w_R}{w_K}$.[2] This increase in the relative cost of K is accompanied by lower capital intensity in the production of both goods (**Figure 1*b***, *lower right*), as this factor must be freed up to allow for expansion of the industry that uses it intensively. In contrast, in S, we would expect R to increase in price and firms in the region to produce both goods using a higher ratio of K to R. In terms of agriculture, if land is the resource, this would mean S would use more land in agriculture but also farm each acre more intensively, while the opposite would be true for N.

Trade is also expected to affect income, which, assuming x and y are normal goods, will increase demand for both. As noted above, we expect trade to lower the relative price of the imported good, increasing its domestic consumption, while the effect on consumption of the exported good would depend on its elasticity of income versus price. Further, if environmental services are a normal good, demand for these services will also increase with income, generating pressure for more stringent policies surrounding the production of the environmental good and pollution (Copeland & Taylor 2004).

2.4. Trade Impacts on Externalities

Standard trade theory suggests that the production of pollution will shift to the location that has a comparative advantage in producing the polluting good x. But the effect of trade on pollution also depends on the environmental policies in place that may mitigate the effect of an increase in production of x on a country's emissions. (The **Supplemental Appendix** provides a more detailed discussion based on Copeland & Taylor 2004.). In terms of externalities from natural resource use, the reallocation of production induced by trade would suggest that the presence of trade results in more efficient use of those resources in the production of x and y. The effect on the cost of producing the environmental good e, however, depends on how trade affects the price of R and the nature of the policy surrounding its production. In the model outlined here, if a country is resource abundant, trade will increase the relative price of resources and increase the cost of producing the nonmarket environmental good. Conversely, trade will decrease the relative price of resources in the resource-scarce country, making production of e relatively cheaper.

Higher prices for the resource-intensive good do not necessarily translate into a lower quantity of environmental goods. Barbier & Schultz (1997) model the environmental good as generated by the resource stock (land under forest cover) and show that higher timber prices driven by trade lead to an increase in the resource extraction (logging) and draw more of the resource into forests and out of other uses, such as agriculture.

2.5. Trade Impacts on Welfare

In the presence of externalities, we enter the world of the second best where removing the distortion of trade barriers is no longer guaranteed to improve welfare (Lipsey & Lancaster 1956).

[2]The relative price of the input used intensively in production of the export good will go up more than the relative price of the export good itself. Similarly, the relative price of the input used intensively in production of the import good will fall relative to the other prices; this is known as the Stopler–Samuelson theorem.

Consumers are confronted by three distinct consequences stemming from a decrease in trade barriers: the traditional gains from trade, the induced changes in pollution, and the induced changes in the production of the environmental good e. The latter two effects depend on how far domestic environmental policy is from incorporating the true costs of pollution or benefit of the environmental good. If the domestic environmental policies capture the true marginal cost (of z) and marginal benefit (of e), then trade will be welfare enhancing. If domestic environmental policies are suboptimal, then both the distance from optimality and the country's comparative advantage come into play. As above, if the country has a comparative advantage in the polluting or resource-intensive good, trade will increase the production of pollution or reduce the production of the environmental good, offsetting the gains from trade. On the other hand, if the country has a comparative advantage in the production of the clean good, or the capital-intensive good, they could reap a double dividend by benefiting from both the gains in trade and the reduction of pollution or increase in the production of the environmental good.

Trade can decrease welfare with suboptimal resource management when the country with the comparative advantage in resource extraction opens up to trade and the mobile factor shifts into resource production, exceeding the carrying capacity of the stock (Brander & Taylor 1997 and Bulte & Barbier 2005 show this resulting from extra extraction effort). Even if neither country has a distinct comparative advantage in producing the resource-intensive good, the lack of property rights for a common-property resource in one country could lead it to export resource-intensive goods in the steady state (Chichilnisky 1994). In this setting, Karp et al. (2001) demonstrate that trade can decrease welfare.

Polasky et al. (2004) model the interaction between trade and biodiversity and find that if species are specific to each country, the resulting specialization can lead to an overall loss in global biodiversity, which in turn can lead to net welfare losses from trade. Bellora & Bourgeon (2019) model the effect of trade on pesticide regulations and the resulting biodiversity. They argue that trade increases agricultural specialization, which in turn increases vulnerability to pest infestation. They conclude that optimal pesticide taxes are higher with trade, reducing the gains from trade.

2.6. The Role of New Technologies

Trade can play a role in facilitating spillovers of the technology used in production. Technology can be transferred directly by the trade in knowledge-embedding inputs, such as machinery or seed technology, or as trade in final outputs where the importer can learn the technology. A related literature notes that technology transfer is facilitated by foreign direct investment, which is often a mechanism to circumvent tariffs applied on final goods. Blomström & Kokko (1999) and Saggi (2002) review these issues.

What is the effect of new technology on resource use and degradation? This debate goes back to the economist William Jevons, who noted that increased efficiency of coal use during the Industrial Revolution increased, rather than decreased, coal consumption. The Jevons paradox is frequently cited in the context of agricultural innovation and cropland expansion (Rudel et al. 2009). Hertel et al. (2014) develop the conditions under which Jevons's paradox is likely to arise in the context of a two-region, single-sector model of agricultural trade. In this framework, the elasticity of excess demand is a sufficient statistic for determining what happens to land use in the innovating region following an increase in farm total factor productivity. If elastic, the expansion in sales will dominate the input savings, and land use in the innovating region will expand, whereas if inelastic, the opposite will result. Importantly, in addition to the global price elasticity of demand, this excess demand elasticity depends on both the supply response in the rest of the world and the relative size of the innovating region. If the rest of the world is large and has some supply response, increased productivity is expected to expand cropland in the innovating region, a result found in many single-country case studies. However, this ignores the response in the rest of the world.

Whether Jevons's paradox arises at a global scale is a more challenging question. Holding all else constant, agricultural production and land use in the rest of the world will fall due to lower world prices. Provided that cropland in the innovating region rises, the global outcome is the net of two opposing forces. Which will dominate? Hertel et al. (2014) show that, if crop yields in the innovating region are low, the increase in productivity could indeed lead to Jevons's paradox arising at the global scale, as the cropland expansion in the innovating region comes at the expense of higher yield production in the rest of the world. If, however, the innovation can itself be traded, and productivity improvements spill over to other producing regions, and given the inelastic nature of demand for most foods, we would expect global land use to decrease.

2.7. Environmental Policy in the Presence of Trade

How does trade affect the incentives for environmental policy? In as much as a country imposes a higher tax on pollution, it makes the production of x more costly (for a given technology). Similarly, the higher the subsidy on the environmental good, the more (relatively) costly natural resources become, increasing the cost of producing the resource-intensive good. This induced change in production cost has spawned the pollution haven hypothesis, which suggests that the relative severity of environmental regulation drives countries' comparative advantage and the location of production after trade, potentially lowering economic welfare. However, Copeland & Taylor (2004) show that, when environmental policies are chosen in response to changes in local demand for the environment, income-driven changes in demand for regulation can mitigate the pollution haven effect.

Similarly, if resource policy and institutions are endogenous to resource prices, higher prices for resource-intensive goods can improve resource management (Copeland & Taylor 2009). For example, a trade ban on certain types of resource trade may remove any legitimate use of the good and thus remove the incentive for property owners to pay to enforce their property rights (de Meza & Gould 1992) or to invest in the resource stock (Barbier & Schulz (1997).

Closely related to the pollution haven hypothesis is leakage: If a country imposes more stringent environmental standards on a global pollutant, like GHGs, its trading partners may increase the production of the polluting good, offsetting the impact of the emissions reduction. The concept of leakage has also been applied to resource use, where stricter resource protections in one location move extracting activities elsewhere. We review the empirical literature that explores this phenomenon and other interactions between policies, trade, and the environment in Section 4. But first we assess the evidence on trade and environmental externalities in Section 3.

3. TRADE AND EXTERNALITIES

We have organized discussion of the interplay between trade and externalities around different classes of externalities that have been widely addressed in the empirical literature, namely those associated with land use change, GHG emissions and related climate change impacts, biodiversity, water, and technological change.

3.1. Trade and Land Use Change

Telecoupling has become a widely used term in the sustainability literature describing bidirectional linkages—both market (i.e., trade) and nonmarket—between distant regions (Liu et al. 2013). Geographers, ecologists, and natural scientists have discovered the relevance of international trade, and this has led to an explosion of empirical research, often focusing on the displacement of land use change from wealthy countries to the developing world. Yu et al. (2013) use a multiregion input-output analysis to estimate the share of land in other countries driven by domestic consumption. In the United States, this figure is 33%, whereas it is 50% in the European Union and 92% in land-scarce Japan. An economist looks at these figures and sees comparative advantage at work (see Section 2). However, ecologists and geographers often associate such land displacement with the destruction of tropical forests and other natural areas rich in biodiversity and carbon. Meyfroidt et al. (2010) study seven countries that recently shifted from declining to growing forest cover and conclude that additional global land use change embodied in their net wood products trade offset three-quarters of the total domestic reforested area in these countries. As foreshadowed by the models of Chichilnisky (1994) and Karp et al. (2001), much of this overseas deforestation offset occurred in countries with weak governance, including Brazil and Indonesia.

The expansion of soy production in Brazil has garnered considerable attention as a driver of land use change and deforestation. From 2004–2011, China increased its soy imports from Brazil by over 200%, which Yao et al. (2018) suggest is driven by changes in demand and comparative advantage. China's rising incomes and meat consumption increased both agricultural demands and increasing competition for farm labor from manufacturing, thereby expanding domestic agricultural production costs. At the same time, they highlight the extraordinary growth in Brazilian soy productivity. In contrast, Torres et al. (2017) emphasize the role of property rights and institutions in fostering this rapid growth in soybean trade. China's Rural Land Contracting Law, implemented in 2002, ensured stability in agricultural land, with longer-term, written contracts and less-frequent adjustments in land allocations. This, they argue, accounts for the relatively stable production of soybeans in China over this period of rapid import growth. China's collective land ownership stands in sharp contrast to Brazil where rural property rights give priority to production over conservation, providing a strong incentive to cut forested lands and immediately establish a productive use. Torres et al. (2017) argue that these production-based property rights coupled with cheap credit, expansion of roads, and new technologies allowing for the expansion of soy production into the soil-challenged Cerrado biome positioned Brazil to respond to the growing soy import demand from China.

The linkage between international trade and land use change is quite naturally viewed within the broader lens of globalization (Wiedmann & Lenzen 2018), with global forces driving local land use change (Hertel et al. 2019). Hertel & Baldos (2016) use a global partial equilibrium model to decompose the drivers behind global cropland change from 1961 to 2006. They find that population growth was the most important driver of cropland expansion, with income growth a distant second. Improved agricultural technology offset about half of the pressure for cropland conversion over this period. (We explore the role of technological change in land use change in Section 3.6 below.)

3.2. Trade and Biodiversity

Agricultural land use is strongly associated with biodiversity loss (Crenna et al. 2019), and the findings reviewed above suggest trade is an important driver of agricultural land use. However, some authors seek to establish a direct link between trade and biodiversity. Lenzen et al. (2012) link 25,000 animal species threat records with 15,000 commodities produced across the world, evaluate over 5 billion supply chains, and conclude that 30% of global species threats can be linked to international trade. In a similar vein, Chaudhary & Kastner (2016) link trade data for 170 crops with biodiversity maps and calculate the likely species loss due to food trade. They conclude that 83% of total species loss is due to the conversion of natural lands to agriculture, and 17% of total losses are due to production for export. An important limitation of this work is that these studies do not compare these impacts to a counterfactual, begging the question: What would happen in the absence of trade (see Section 2.4)?

Biodiversity can also be viewed as a resource endowment. How does the presence of resource-rich biodiversity alter a region's comparative advantage and hence economic activity around the world? Roxburgh et al. (2020) explore this linkage for six key natural ecosystem services, including pollination services, coastal protection, water regulation, forestry, fisheries, and carbon storage. They find that protection of these natural ecosystem services in the future could add $10 trillion to cumulative GDP over the period 2011–2050, when compared to a baseline without protection. From the perspective of the world's poorest economies, which feature a large GDP share from agriculture, pollination services provided to agriculture are the most valuable of the six natural ecosystem services being conserved.

3.3. Trade and Greenhouse Gas Emissions

International trade influences GHG emissions in many ways, perhaps the most obvious being the energy needed to transport goods from one country to another. Cristea et al. (2013) find that international transport is responsible for one-third of worldwide trade-related emissions and more than three-quarters of GHG emissions for manufacturing. In about one-quarter of product categories, differences in emissions from production more than offset the transport-related emissions, suggesting that trade reduces global GHG emissions for those goods.

Whether or not increased trade reduces or raises GHG emissions is fundamental to the food miles debate about the local food movement. Sim et al. (2007) compare the life cycle energy footprint of domestic fresh bean consumption in the United Kingdom versus consuming beans flown in from Kenya or Guatemala. They find that these bean imports entail a global warming impact more than 20 times greater than consumption of domestic green beans. However, in a more comprehensive analysis of local sourcing of food in countries around the world, Avetisyan et al. (2014) find that differences in domestic emissions intensities are dominant (relative to transport-related emissions savings) in driving the GHG consequences (both positive and negative) of domestic sourcing of foods for 90% of the country/commodity pairs in their study of food trade.

3.4. Trade and Climate Impacts

GHG emissions give rise to climate impact externalities. These impacts are expected to be geographically diverse, with low-income, tropical countries being harder hit than higher-latitude, wealthy temperate countries (Carleton & Hsiang 2016). Therefore, international trade is expected to play an important role in climate change adaptation, moderating the impacts on consumers by smoothing the impacts across the globe. In some of the first research on agricultural impacts and trade, Reilly & Hohmann (1993) concluded that interregional adjustments in both production and consumption are important adaptations to the global climate impacts on agriculture. Janssens et al. (2020) use the GLOBIOM economic model and the EPIC agronomic model to analyze the value of international agricultural trade with a changing climate. They find that, under the current level of trade integration, climate change would result in up to 55 million additional undernourished people in 2050 compared to a baseline with no climate change, while in the absence of trade adaptation, that number could rise up to 73 million. The combination of trade facilitation and tariff elimination may fully compensate the hunger effect of climate change for all but the most extreme climate scenario. They find that the value of trade adaptation is greatest for import-dependent regions with the highest incidence of hunger.

Costinot et al. (2016) challenge the importance of trade in adaptation to climate change. They develop a general equilibrium model with 1.7 million grid cells, based on the FAO-GAEZ database. In each grid cell, they consider the potential for 10 different crops to be cultivated, even where the crop is not currently grown. This allows for adaptation to climate change by altering the mix of crops grown in any given grid cell. They conclude that the most important margin of adjustment is not international trade but rather changes in local crop production.

Picking up on this surprising finding, Gouel & Laborde (2018) replicate and extend Costinot et al.'s (2016) study, exploring the sensitivity of results to the model parameterization as well as the counterfactual experiment used to understand the role of trade in adaptation to climate change. They find that the most important factor driving Costinot et al.'s finding is the way in which trade is restricted under the counterfactual "no trade adaptation" scenario. In their paper, Costinot et al. achieve this counterfactual by fixing export shares in the model. However, Gouel & Laborde (2021) find that this is not the margin of adjustment that matters for trade. When instead they restrict import shares to be unchanging in the counterfactual experiment, they find that the role of trade rivals the role of changing crop mix in importance. In summary, it appears that the ability to change the sourcing of agricultural imports is a key element of adaptation to climate change.

Hertel et al. (2019) explore the mechanisms through which international trade mediates the impacts of climate change. They leverage a meta-analysis of more than 1,000 impact estimates of the Intergovernmental Panel on Climate Change (IPCC) (Moore et al. 2017). This allows them to isolate the spatial pattern of climate impacts owing to (*a*) differences in temperature under the current climate (cold regions are likely to benefit from warming), (*b*) differences in the pattern of warming (polar amplification), and (*c*) differences in the temperature sensitivity of crops grown. The combined impact of these factors results in damages concentrated across the tropics due to the dominance of factors *a* and *c*. The authors explore how these direct, biophysical impacts are transmitted across regions through changes in regions' terms of trade. They find that this biophysical heterogeneity reinforces the geographic heterogeneity embodied in bilateral trade patterns, doubling the effect of climate change impacts on countries' terms of trade.

Dingel et al. (2019) argue that studies of future climate impacts on agriculture that omit the spatial correlation of climate shocks will be misleading. They find that the gains from trade in cereals over the last half century were larger for more-productive countries and smaller for less-productive countries when cereal productivity was more spatially correlated. Importantly, incorporating the spatial correlation of productivity shocks into projections of future climate impacts increases the welfare losses in Africa.

Climate change is also expected to shift the distribution of year-on-year weather shocks to agriculture. Verma et al. (2014) explore the implications of trade liberalization for year-on-year price volatility in the US corn market under future climate conditions. They find that trade liberalization reduces this future price volatility by about 8%.

3.5. Trade and Water

In some areas of the world, current irrigated agriculture is not sustainable. Suboptimal resource management, missing property rights, and inefficient prices have led to the depletion of groundwater (Scanlon et al. 2012) and surface water (Wine & Laronne 2020) and increasing soil salinity (Butcher et al. 2016). Trade can exacerbate or alleviate these sustainability challenges by allowing the import of water-intensive products into water-scarce regions. Substantial research has developed in this area over the past two decades.

One popular approach has been to explore global water footprints and virtual water trade, i.e., the water content embodied in goods trade. By importing wheat, countries are implicitly importing the water embodied in growing the wheat, thereby satisfying their water requirements virtually (Allan 1996), which also results in a wider water footprint (Hoekstra & Chapagain 2007). With the increasing availability of global input-output databases, quantifications of the pattern and extent of virtual water trade have become ever more sophisticated and spatially resolved (Marston et al. 2015). Dalin et al. (2012) map the growth of virtual water trade embodied in agricultural products between 1986 and 2007 and find that the number of trade linkages and the virtual water trade volume more than doubled over this period, while the water content per unit of weight decreased. The authors also document a marked shift toward Asia, and especially China, as an importer of virtual water owing to the soy imports from Brazil. Graham et al. (2020) use the Global Change Analysis Model (GCAM) to project future growth in virtual water trade and find that trading of renewable water may triple by the end of the twenty-first century.

Authors employing the concept of virtual water trade often point to the water savings achieved by such trade (Mekonnen & Hoekstra 2010) and advocate for virtual water trade as a vehicle for enhancing the global efficiency of water use in food production. However, the concept of virtual water does not take into account the opportunity cost of the water at its place of use. Therefore, using virtual water as a guide for economic policy related to resource conservation and sustainability is likely to be misleading. Wichelns (2015) provides a thorough economic critique of the policy prescriptions based on the concept of virtual water trade. Three of his criticisms warrant discussion here. First, he argues that virtual water trade should not be used as a basis for modifying trade flows. Economic theory argues that trade based on a country's comparative advantage is beneficial. But comparative advantage for the production and export of certain goods does not relate to the abundance of a single resource like water. Note that even in our simple two-factor model discussed in Section 2, comparative advantage is driven by the relative availability of both factors. Numerous examples exist of water-scarce countries successfully exporting individual water-intensive products. Thus, comparative advantage needs to consider the multiple inputs used in production and their opportunity cost in other uses. Kumar & Singh (2005) analyze data on renewable freshwater availability across 146 countries and find that virtual water trade is not driven by availability but rather by efficiency of use. Debaere (2014) takes a more comprehensive look at water availability, comparative advantage, and trade patterns. As predicted in our model, he finds that water abundance is a source of comparative advantage. However, it contributes significantly less to explaining the pattern of exports than the more dominant factors of production, namely labor and physical capital.

Wichelns' (2015) second point relates to the lack of a counterfactual under which domestic water is used in place of the imported virtual water. By way of example, Wichelns notes that given its limited land base, Japan, one of the countries with the largest water savings from virtual trade according to Chapagain et al. (2006), could not possibly produce the crop and livestock products it consumes. Therefore, the virtual water embodied in Japan's food imports cannot be viewed as water savings.

Wichelns' (2015) third point is that consumers in one country are unlikely to solve water scarcity problems in another country via their consumption choices. While a marked shift in consumer choices can affect price, he argues that the ultimate decision about how local resources are exploited—and overexploited—are fundamentally local decisions to be determined in the context of local opportunity costs, property rights, political and market power.

Nonetheless, international trade remains a key vehicle for adaptation to local water scarcity. Liu et al. (2014) examine the economic effects of changes in irrigation outlook for 126 river basins globally. They find that irrigation water supply reliability is likely to fall by 30–60% in key river basins between 2000 and 2030. Incorporating these shortfalls into a global economic model, the authors find that, although local agricultural production is sharply reduced in these basins, food prices are only modestly affected due to increased imports from other river basins.

3.6. Trade, Technology, and Externalities

Over the past century, technological change in agriculture has been largely driven by public investments in research and development (Fuglie 2018). These investments can be viewed as generating positive externalities by boosting total factor productivity (TFP) in the food sector, both in the source region and in spillover regions where the new technologies are adopted. However, such innovations have also been accused of generating negative externalities, particularly in terms of deforestation, as increasingly profitable agriculture expands into natural areas to meet the demands of global markets (Angelsen & Kaimowitz 2001). The question of whether or not agricultural innovation spares land and benefits the environment is central to support for such agricultural research and development activities, particularly at the international level (Borlaug 2007, Stevenson et al. 2013).

Recall from Section 2 that the question of whether agricultural innovation leads to environmental degradation depends on the excess demand elasticity facing producers in the innovating region. Villoria (2019) estimates a partial equilibrium econometric model of agricultural land use that allows for imperfect product substitution (following the Armington approach). He finds that, in most countries across the world, the excess demand elasticity facing producers is not less than one. Again, referring to Section 2, this means that domestic TFP growth will lead to increased domestic land use in the innovating region. At larger scale, however, Villoria finds that productivity growth in major world regions such as developing Asia, sub-Saharan Africa, and South Asia leads to reductions in global cropland area. He estimates that, without TFP growth between 1991 and 2010, global agriculture would have required an additional 173 million hectares of land.

Just as it can spare land for nature, technological change in agriculture can yield other positive externalities, such as reduced terrestrial GHG emissions, depending on the relative emissions intensity of the adopting region (Hertel et al. 2014). Burney et al. (2010) estimate the net effect of agricultural intensification (not the same as TFP growth) on GHG emissions between 1961 and 2005. They conclude that each dollar invested in input intensification resulted in a 249-kgCO_2 reduction in emissions relative to 1961 technology, or a cost of about \$4/tCO_2e, which is quite favorable relative to other mitigation strategies. In a related study, Lobell et al. (2013) ask how successful agricultural adaptation to climate change might help mitigate further GHG emissions. They explicitly model the link between R&D spending and TFP growth. Their scenario of global adaptation to offset negative yield impacts of climate change by mid-century requires cumulative R&D spending of \$225 billion to spare 61 million hectares of land conversion, reducing GHG emissions by 15 gigatonnes, a mitigation cost of between \$11–22/tCO_2e.

Hertel et al. (2020) explore the linkages between trade and technology in the context of food security and environmental outcomes in sub-Saharan Africa. The authors find that domestic R&D investment to bolster productivity was the dominant vehicle for lowering food prices in the sub-Saharan African region over the 1991–2011 period. Little evidence exists for technological innovations elsewhere spilling over into sub-Saharan Africa, but the authors suggest that it might grow in the future as other tropical countries—in particular Brazil, China, and India—develop their R&D infrastructure. Technology may also benefit consumers in Africa through virtual technology trade: importing the fruits of improved technology (i.e., the farm products) instead of importing the technology itself. In their projections to the mid-century, this virtual technology trade is expected to be the most important technology transfer mechanism for reducing nonfarm undernutrition in Africa. The authors also find that greater trade integration of sub-Saharan Africa into the global economy could result in less cropland being required in that region in 2050.

However, if other major producing regions were to use their TFP growth to withdraw resources from agriculture in favor of the environment, as has been the case in northern Europe (Heisey & Fuglie 2018), this would put considerably more pressure on cropland conversion, and hence environmental degradation, in sub-Saharan Africa.

4. SUSTAINABILITY POLICIES AND PRIVATE SECTOR ACTIVITIES

In this section we focus on policies or interventions that can improve environmental sustainability in the context of trade. We first review the literature that evaluates domestic environmental regulation and its effect on international competitiveness and the environment. Then we examine evidence on the role of border adjustment tariffs in reducing the environmental footprint of agriculture. Finally, we look at nontariff measures, specifically sustainability standards and their potential to mitigate sustainability impacts of externalities in the presence of international trade.

4.1. Domestic Environmental Regulation and Trade

As noted in Section 2, domestic environmental regulation can decrease competitiveness, leading production to shift to other locations with less stringent regulations (pollution havens). Levinson & Taylor (2008) find evidence from North American trade that those industries that saw their abatement costs increase the most saw the largest increase in competing imports. Levinson (2010) notes that much of the literature using panel data tends to find that the United States seems to import more of those goods facing increasing environmental abatement costs at home. Candau & Dienesch (2017) show with both a structural and reduced-form regression approach that lower environmental standards explain the location of polluting affiliates of European firms. Corruption lowers environmental standards, thereby also attracting polluting firms. The carbon import taxes necessary to stop relocation are found to be quite high, although heterogeneous across countries.

Dechezleprêtre & Sato (2017) review recent empirical evidence on the pollution haven effect for a wide set of countries and industries and confirm the earlier result of Jaffe et al. (1995) for US manufacturing that environmental regulation can increase costs, but its effect is small compared to other determinants of competitiveness "such as transport costs, proximity to demand, quality of local workers, availability of raw materials, sunk capital cost, and agglomeration" Dechezleprêtre & Sato (2017, p. 201). The cost burden is largest in energy-intensive sectors and more strongly affects industries that cannot pass through abatement costs to consumers. The authors also find strong evidence that environmental regulation induces innovation in cleaner technologies. They conclude that the induced innovation, where it exists, does not generally offset the full compliance cost so that little empirical support exists for the more far-reaching interpretation of the Porter hypothesis (Porter & van der Linde 1995). Shapiro & Walker (2018) show that environmental regulation is responsible for a large share of the 60% reduction in pollution by US manufacturing over the period 1990 to 2008 and is driven less by productivity developments and trade (Dechezleprêtre & Sato 2017).

Turning to the agricultural and food industry, a recent OECD report by DeBoe (2020) reviews 160 empirical papers analyzing the environmental and economic performance of environmental regulations in agriculture. They distinguish between regulatory instruments (e.g., standards defining fertilizer restrictions, maximum stocking densities, and other restrictions on agricultural practices), hybrid instruments (cross compliance), voluntary agri-environmental schemes, public investment in structural adjustment toward greener agricultural systems, environmental taxes and charges, and tradable allowances. DeBoe highlights the effects of these interventions on environmental outcomes and cost, both of which can be affected by trade (not explicitly considered by them).

DeBoe (2020) finds that agri-environmental regulation such as restrictions on stocking densities or input use can be an effective, but costly and inefficient, mechanism to achieve policy goals. A crucial factor that determines these economic impacts is the degree to which the firm can pass along increased costs. Here, trade plays a role, potentially limiting the amount of cost pass-through to consumers and thereby raising their cost. Conversely, trade might facilitate access to alternative technologies, lowering the costs of these environmental taxes or regulations.

Both the United States and European Union have many voluntary agri-environmental programs that encourage reducing the intensity of agricultural production, but they can also induce trade-related spillovers by increasing land use elsewhere. Specifically, Pelikan et al. (2015) find the EU cropland set-asides for ecologically sensitive areas result in increased crop intensification within the European Union as well as cropland expansion in non-EU regions. In general, DeBoe finds that effective implementation of environmental policies is crucial; as noted above, if environmental policy or natural resource management is suboptimal, trade can exacerbate these market failures. We summarize the results of DeBoe (2020) in more detail and add trade implications in **Supplemental Table 1**.

We found little research on the question of whether domestic sustainability policies affect technological innovation and productivity in the agricultural and food sectors. In a recent cross-country analysis, Lankoski & Thiem (2020) analyze the effect of agricultural support policies on sustainable productivity. A qualitative comparative analysis shows, among other things, that either a low level of coupled support or a high share of support payments with environmental constraints is important for achieving a high level of sustainable productivity. The analysis is short term, as production intensities and structures are taken as given, and the identification of the policy effects may be confounded with other factors.

In an analysis of environmental regulations in aquaculture, Abate et al. (2016) use a cross-country regression analysis and find that stricter environmental regulations in developed countries contribute to lower growth rates in the sector compared to developing countries with more lenient environmental standards. In a detailed analysis of a single country, Koch et al. (2019) use a difference-in-difference panel approach to estimate the causal effect of Brazil's anti-deforestation strategy of priority municipalities on the production and productivity of beef, dairy, and crops. They find these priority municipalities reduced deforestation by about 50% compared to nonpriority municipalities. Beef stocking rates also rose (36%), along with higher production value per hectare (14.8%). These land- and capital-based intensities themselves say little about the effects of the anti-deforestation policy on international competitiveness, but Nepstad et al. (2014) show that public and policy interventions can slow down Amazon deforestation, even while beef and soy production increase as a result of intensification on existing farm land.

As with EU land set-asides for biodiversity, domestic policies aimed at mitigating GHG emissions also spill over to other countries. In the United States, corn-based ethanol received a big boost from the enlarged renewable fuel standard passed in 2007. Life cycle analysis promised that the displacement of 10% of gasoline with ethanol additives would lower GHG emissions significantly (Farrell et al. 2006). However, when the response of producers overseas to higher corn and soybean prices was included, a 20% GHG savings turned into a large emission increase due to the induced cropland change in places like Brazil (Searchinger et al. 2008; Hertel et al. 2010). Since then, many other studies have evaluated the land use impacts of US and EU biofuel programs (Al-Riffai et al. 2010, Garcia & You 2018).

The pattern of these international spillovers from domestic environmental policies depends critically on the economic geography of international trade. Assuming fully integrated global markets, Searchinger et al. (2008) predicted that the largest cropland response to US biofuels expansion would occur in countries with the largest agricultural sectors such as China, India, and Brazil.

Subsequent empirical work rejected the integrated markets hypothesis in favor of nationally differentiated products following the Armington model (Villoria & Hertel 2011). Those authors find that the pattern of US biofuels–induced cropland change is heterogeneous (e.g., larger impacts in Canada and smaller in India), and the ensuing increase in GHG emissions is less than half as large as predicted using the integrated markets model.

In summary, domestic policies to promote environmental sustainability can successfully mitigate both domestic and global environmental externalities. However, they may also shift domestic production to trading partners, mitigating or exacerbating externalities overall. One way to mitigate leakage is through border adjustments of tariffs, which is the subject of the next section.

4.2. Tariffs and the Sustainability Impact of Trade

The economist's standard solution to the externalities is to internalize them through Pigouvian taxes or tradable permits, which, as noted above, may affect the location of production. Optimally, to avoid a pollution haven effect, these policies should be coordinated across countries. For example, a coordinated GHG policy would reduce the consumed quantities of emission-intensive products and relocate production activities toward countries with lower emission intensities (Avetisyan et al. 2011). But to work, such policies require trading countries to agree on consistent pricing of externalities. This is rarely possible. One exception is offered by the emission trading system of the European Union, which could move industry to locations with cleaner production (Dyrstad et al. 2019). However, management of this system has been criticized in that it has resulted in carbon prices that are often below the true cost of carbon and insufficient to transition the European energy system away from fossil fuels (Ellerman et al. 2016). Based on their analysis with a dynamic, computable general equilibrium (CGE) model, Brink et al. (2016) conclude that tighter caps on emissions could provide a more robust system in the short term, but the addition of a floor price system would better address volatility issues and support long-term investments in cleaner energy technologies.

In the absence of an international agreement on environmental externalities, researchers have explored the potential for border taxes (import tariffs) to account for the embedded externalities of the imports, particularly carbon. Critically, optimal border adjustments are usually calculated assuming no pre-existing tariffs. However, this is rarely the case. In a remarkable recent paper, Shapiro (2020) documents how the current structure of tariffs and nontariff barriers creates an implicit subsidy to CO_2 emissions of several hundred billion dollars globally (between \$80 and \$120 per t/CO_2e). This follows from comparatively higher tariffs placed on cleaner downstream industries than on dirtier traded inputs. This pattern of protection has a political economy explanation, because industrial lobbies seek cheaper inputs, while consumers are comparatively less organized, resulting in higher tariffs on finished goods. Shapiro finds that an equal burden of border measures on polluting and clean industries would lower emissions without much change in income. Any changes in border measures reflecting the emissions intensity of traded goods would have to overcome this considerable implicit subsidy before resulting in an overall positive sustainability effect. The analysis by Shapiro does not look at the agricultural sector specifically. But manufactured food products, including sugar, pork and beef, belong to the list of the five cleanest products showing a multiple of tariff and nontariff protection rates compared to the five dirtiest products, which include nitrogen and phosphorus fertilizer (Shapiro 2020, table 1, p. 46)[3] . So, the

[3] To have meat production as a clean product seems strange at first (Eshel et al. 2014), but the Shapiro's (2020) distinction of intermediate from final goods for meat separates the dirty cattle and livestock raising industry from the clean slaughtering and packing industry.

global food sector seems to support Shapiro's hypothesis of higher tariffs applying to the cleaner products.

Border carbon adjustments (BCAs) typically have three objectives: (*a*) to reduce emissions leakage, (*b*) to preserve the competitiveness of domestic industry, and (*c*) to pressure trading partners with less-stringent policies to upgrade their regulation of carbon emissions (Morris 2018). In practice, these schemes face implementation challenges involving the measurement of carbon intensities and perverse incentives (e.g., exporters have no incentive to mitigate emissions and would be encouraged to export their most carbon intensive products). A number of authors have used CGE models to calculate the degree of leakage associated with carbon taxes without BCAs. Estimates range from 10% (Paltsev 2001) to 130% (Babiker 2005). More recent estimates of leakage tend to fall at the lower end of this range, such as the 20% figure reported by Elliott et al. (2010). Recent studies suggest that the cost savings from applying BCAs are modest and would entail significant distributional impacts across countries (Böhringer et al. 2012). For the agricultural sector, one recent study evaluates the potential of carbon regulations coupled with border taxes in the European Union. Using a detailed CGE model of EU agriculture and trade, Nordin et al. (2019) find that while BCAs limit the resulting leakage, increased emissions elsewhere still offset 92% of the emissions reduction within the EU. The primary driver of this leakage is that the unilateral BCAs cannot stop EU exports from largely being supplanted by production in less-GHG-efficient countries.

Border interventions have also been proposed as a means of mitigating environmental damages from tropical deforestation. The United Kingdom, Netherlands, Norway, and France have all enacted demand-side restrictions on the purchase of high deforestation commodities. However, a recent study by Taheripour et al. (2019) highlights the challenges associated with market-mediated spillovers into related product and factor markets. The authors focus on the case of an EU-wide ban on imports of palm oil from Malaysia and Indonesia. They conclude that, without active forest conservation incentives, such an import ban would do little to slow deforestation in the source countries because much of the palm oil would be diverted to other destinations and any reduction in oil palm area would be converted to other crops.

4.3. Voluntary Sustainability Standards in Trade

Following consumer pressure, many companies have adopted sustainability standards to improve social and environmental practices in their international supply chains. These standards range from ensuring basic human rights, worker health, and fair prices, along with mitigating the environmental impacts of production. Tayleur et al. (2017) found records of certified cropland in 133 countries and estimated annual increases of 11% in certified crop area from 2000 to 2012. However, the certification mostly relates to heavily traded commodities like coffee, cocoa, tea, and palm, each with around 10% or more of their total global production area certified. The coverage is much lower for staple crops such as maize, rice, and wheat, which explains the low-level certified area overall, just 1.1% of global cropland in 2012 (Tayleur et al. 2017, Waldman & Kerr 2014).

Sustainability standards attempt to internalize externalities by creating a market for conservation- and eco-friendly production practices in traded goods. In her brief section on trade certification, Fischer (2010) notes that although eco-labeling for agricultural and forest products can increase prices for more sustainable goods, it also creates additional transaction costs to monitor, certify, and track the sustainable practices along the complex international supply chains. Such costs may be prohibitive, thereby slowing down the establishment of certification. Moreover, market feedbacks may change relative prices between sustainably and less-sustainably produced goods, dampening the overall positive effect on the environment. Meemken (2020) reviews 95 studies and finds that smallholder farmers certified by some sustainability standards receive 20–30% higher prices and earn 16–22% higher income than their noncertified counterparts. Effects of standards on production costs and yields are mixed and vary considerably across standards.

The definition of sustainability standards often involves nongovernmental organizations (NGOs), but private companies are crucial for their implementation, and governments may assist in providing information systems (e.g., on land use) to ensure traceability. In their recent review on the interaction between private actors, civil society, and governments in sustainability standards, Lambin & Thorlakson (2018) find that public and private environmental governance rarely operate independently. They observe a proliferation of parallel standards developed by different stakeholder groups, which compete with each other for market share (e.g., *Fair Trade* versus *The Rainforest Alliance*, each of which take social and environmental issues into account). Governments react to the development of private standards and may seek to complement and correct the voluntary standards when they are not in line with public sustainability goals. For example, Clark & Martínez (2016) argue that provincial governments in Ecuador broadened access to agricultural certification for marginalized producers by providing it as a public service. The authors argue that rigorous empirical studies on the influence of these interactions on the effectiveness of sustainability standards are still lacking. Other recent reviews on standards and certifications in the context of agricultural value chains focus on other impacts (for the impact on the poor, see Swinnen 2007; on the political economy, see Swinnen et al. 2015; on inclusive value chains, see De Janvry & Sadoulet 2019; on structural transformation and economic development, see Barrett et al. 2019).

Turning to the more specific impact of standards and certification on environmental sustainability, Fischer (2010) states that the evidence for environmental benefits of eco-labeling was still scarce, which could be related to the cost (and interdisciplinarity) involved in measuring environmental impacts. Since her review, some new empirical evidence has emerged. Without any specific trade or supply chain context, Meemken & Qaim (2018) review existing evidence on organic versus conventional agriculture with respect to food security and environmental effects. They find considerable positive environmental effects stemming from organic agriculture (e.g., about one-third lower GHG emissions per hectare, lower nutrient leaching per hectare, especially for nitrogen, and about one-third higher species richness per hectare), but these per hectare gains often vanish or turn negative when measured per unit of output due to the lower yields in organic farming. According to the authors, the biodiversity impact of indirect land use change has not been evaluated in this context. They conclude that organic agriculture may help address local environmental problems, but it does not resolve the global ones.

DeFries et al. (2017) ask if voluntary certification of tropical (and typically traded) commodities achieve economic, social, and environmental sustainability goals for small-scale producers. Their review selects 16 papers (mostly on coffee, but two on bananas and none on cocoa or palm oil) out of 2,600 originally satisfying their criteria for a low risk of bias in estimating the treatment effect. They conclude that results are moderately positive for economic and environmental impact. In **Supplemental Table 2**, we summarize a few more recent papers not covered by DeFries et al. (2017), but which according to our assessment would meet their inclusion criteria (proper control groups for treatment identification). Notably, very few studies directly estimate environmental outcomes and instead measure the adoption of sustainable practices, likely due to the difficulty in measuring environmental outcomes.

5. CONCLUSIONS AND DIRECTIONS FOR FUTURE RESEARCH

Trade theory demonstrates that the effect of international trade on externalities can be ambiguous—it can either reduce or increase environmental costs, depending on comparative advantage, demand, and supply elasticities both at home and abroad, property rights, and the transferability of technologies across countries. Another key insight from economic theory is that the effect of trade on environmental externalities depends on domestic environmental policy; if this policy is suboptimal, trade can reduce welfare. Further, differences in policies (including property rights and other institutions that affect resource management) can affect comparative advantage, in which case, trade may well exacerbate these market failures, a fact that has also been found in several case studies. Understanding this interplay between trade and domestic institutions is a high priority for future research and one to which geographers and political scientists have much to contribute.

An important feature of the trade and environment landscape has been the emergence of private and civil society–driven sustainability solutions, in the form of eco-labeling and implementation of sustainability standards in supply chains. These solutions show some success in encouraging more sustainable production practices, but the evidence on environmental impacts directly measured with appropriate indicators is still scarce. Effective sustainability solutions will also require active engagement by local decision makers in the communities where these certified commodities are produced.

A research topic worthy of further investigation relates to the environmental consequences of current distortions to agricultural trade. The findings of Shapiro (2020) with respect to the existing manufacturing tariff structure and its implications for GHG emissions are extremely interesting. How does this play out for a broader set of agricultural policies and environmental metrics?

Agricultural trade and sustainability is a topic that is ripe for collaboration between economists and ecologists as well as other natural scientists. However, the absence of counterfactual experiments in much of the natural science literature in this area has led to two significant misunderstandings. The first is the role of technological change in land conversion. Absent a counterfactual, it is not possible to tease out this linkage. The same is true when it comes to valuing resources (water, biodiversity) used in current agricultural trade. In many cases, the implied counterfactual in which all agricultural production is produced domestically is infeasible.

More generally, much of the existing ecological work attempts to estimate the cost of the current location of agricultural production facilitated by trade. However, we know from trade theory that while trade can move production to new locations, it also changes the cost and use of inputs, as well as the technology employed. Much of the current literature ignores these effects. Conversely, the ecological literature highlights the heterogeneity associated with the environmental impacts of production location and processes, which are vital to evaluating the effect of trade, particularly on outcomes like biodiversity, but which are often missing in the economic analyses. Further, the economics literature often ignores the cost associated with the shift in the location of production; e.g., clearing new land for agriculture is not immediately offset by the gains in abandoning agricultural production elsewhere. There are important ecological dynamics and irreversibilities that must be taken into account in order to properly assess the environmental impacts of agricultural trade. In summary, we see substantial gains from interdisciplinary trade in ideas and approaches to understanding the interrelation between agricultural trade and environmental sustainability.

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