Received: 30 June 2021 | Accepted: 1 March 2022
DOI: 10.1002/aepp.13279

FEATURED ARTICLE

Sustainable agricultural production, income, and eco-labeling: What can be learned from a modern Ricardian approach?

Kari E. R. Heerman[1] | **Ian M. Sheldon**[2]

[1]Washington, District of Columbia, USA
[2]Department of Agricultural, Environmental, and Development Economics, Ohio State University, Columbus, Ohio, USA

Correspondence
Ian M. Sheldon, Department of Agricultural, Environmental, and Development Economics, Ohio State University, Columbus, OH, USA.
Email: sheldon.1@osu.edu

Editor in charge: Stefano Boccaletti

Abstract

In this article, trade-in sustainably produced agricultural products with eco-labeling are modeled using a modern Ricardian framework. Based on this approach, expressions are derived for the share of products importers purchase from specific exporters for low-cost unsustainable and high-cost sustainable production technologies, assuming consumers have non-homothetic preferences. The consumer and sustainability gains from eco-labeling are also analyzed, along with a discussion and comparison of the effects of mutual recognition versus harmonization of countries' eco-labeling regimes.

KEYWORDS
eco-labeling, income, trade, trade costs

JEL CLASSIFICATION
F11, F14, F15, Q17, Q56

Article originally prepared for presentation at EAAE Seminar 175: “The Wind of Change of Sustainability Standards: Sailing Economics, Governance, and Policy Perspectives.” May 12–15, 2021. Ian Sheldon acknowledges financial support from USDA/ERS Cooperative Agreement 58-3000-3-0058: “Complementarities in Commodity and Environmental Goods Trade: Implications for Analysis of Food and Agricultural Trade Liberalization.” We would also like to thank two anonymous reviewers for their helpful comments on earlier versions of the article. The views expressed here are those of the authors and may not represent the views of or be attributed to either the U.S. Trade Representative's Office (USTR) or the Council of Economic Advisers (CEA).

Over recent decades, there has been an increase in demand for the provision of a range of attributes in food products (Sexton, 2013). These attributes reflect a spectrum of consumer preferences for product characteristics covering, inter alia: food safety (pesticide residues), ethical production (animal welfare), right-to-know (genetic modification), location (geographic indicators), and sustainability (environmental impact) of food production methods. With respect to the latter, an OECD survey indicates there has been rapid growth in total eco-labeling since the 1970s, with a significant proportion relating to food and agricultural products, the labels covering characteristics such as waste, energy, natural resources, climate change, biodiversity, and chemical control (Gruére, 2013).

In the context of the current article, the International Organization for Standardization (ISO) has published an international standard laying out principles, requirements, and guidelines for quantification of a water footprint (ISO 14046, 2014), which is intended to support water footprint labeling (Ridoutt & Hodges, 2017). Although water footprint labeling of agricultural and food production is not currently the norm, there is some empirical evidence for consumers in high-income countries who are willing to pay a price premium for water-saving food production methods (Grebitus et al., 2016; Krovetz et al., 2017; Pomarici et al., 2018), as compared to consumers in low-income countries (Okpiaifo et al., 2020). Specifically, the latter study analyzed preferences for sustainable rice practices in Nigeria, the results indicating consumers placed very little weight on efficient water use as compared to food safety.

Considerable progress has been made in incorporating vertical product differentiation into trade models; for example, see Amiti and Khandelwal (2013), Baldwin and Harrigan (2011), Crinò and Epifani (2012), Curzi et al. (2015), Eum et al. (2021), Gaigné and Larue (2016), and Kugler and Verhoogen (2012). As noted by Gaigné and Gouel (forthcoming 2022) the international economics literature typically assumes away information failure: consumers are unable to verify claimed environmental or other benefits of how a product was produced both before and after consumption, such claims being termed *credence* attributes of the product (Dulleck & Kerschbamer, 2006). Eco-labeling in conjunction with a mechanism for certification of environmental/sustainability claims is regarded as key in resolving this type of information asymmetry (Roe & Sheldon, 2007; Sheldon, 2017; Sheldon & Roe, 2009). In addition, in an international setting, the choice by trading partners between mutual recognition and harmonization of their eco-labeling standards becomes an important policy issue (Sheldon & Roe, 2009; Swinnen, 2016).

Trade-in products with credence attributes may also generate environmental/sustainability gains. If production generates such benefits, this should be explicitly incorporated into trade analysis and the associated evaluation of trade liberalization and any international harmonization of eco-labeling standards. In this article a modern Ricardian trade model is developed, drawing on Eaton and Kortum (2002), and other contributions by Costinot et al. (2012), Fieler (2011), and Levchenko and Zhang (2014). This class of model has already been applied to evaluating trade and trade liberalization in the agricultural sector (Heerman et al., 2015; Heerman & Sheldon, 2018a; Heerman and Sheldon, 2018b; Heerman, 2020; Reimer & Li, 2010; Sotelo, 2020), as well as analysis of virtual water use and trade (Reimer, 2014), and evaluation of the impact of climate change on comparative advantage in the agricultural sector (Costinot et al., 2016; Gouel & Laborde, 2021).

Eaton and Kortum (2002) assume comparative advantage, is a function of a random productivity variable, independently distributed across products in the sector. Specifically, no two countries are more likely to compete against each other by exporting the same products than any other country. Extensions of Eaton and Kortum (2002) to a multisector analysis by, for example, Chor (2010), Costinot et al. (2012), Caliendo and Parro (2015), Tombe (2015), and Kerr (2018) implicitly recognize the limitation of this assumption, allowing average productivity, and in some cases the dispersion of productivity to vary across sectors, generating non-random patterns of trade specialization across sectors and sub-sectors.

However, these models still maintain the assumption of random heterogeneity within each sector or sub-sector. Therefore, a first departure in this article is the introduction of systematic heterogeneity in the agricultural sector. Specifically, the likelihood a country has a comparative advantage in a set of products depends not only on a randomly drawn technological productivity-augmenting parameter but also on a set of country and product-specific characteristics including land and climate. Fally and Sayre (2018) also allow heterogeneous natural resource productivity in commodities to influence comparative advantage. In contrast to the current approach, which explicitly links a product's productivity in a common factor, namely, a composite input consisting of land, labor, and water, to country and product characteristics, in Fally and Sayre (2018) each commodity is produced with a specific natural resource.

Allowing for intra-sector heterogeneity in agricultural productivity also has important implications for empirical analysis (Heerman, 2020; Heerman et al., 2015). The model described in the current article predicts that countries with similar land and climate characteristics will systematically tend to specialize in the same products. Estimated trade flow elasticities then depend on comparative advantage as opposed to absolute advantage, with larger magnitude predicted trade flow responses among countries more likely to specialize in similar products and thus compete head-to-head in export markets. This approach has similarities to the "mixed constant elasticity of substitution (CES)" model introduced in Adao et al. (2017), the key difference being that they characterize trade as a system of demand for input services (Heerman & Sheldon, 2018a).

A second departure is allowing for non-homothetic preferences in demand. While modern trade models differ in their specifications of the supply-side of an economy, they are all based on a common demand structure (Costinot & Rodríguez-Clare, 2014), that is, a CES utility function. Importantly, CES preferences imply income elasticities do not vary across products and equal one, that is, homotheticity. In the case of consumer demand for say, agricultural products embodying water-saving production methods, this may be an unreasonable assumption, especially if income per capita has the potential to affect trade.

This idea has a long pedigree, going back to Linder (1961) who argued firms located in high per capita income countries that are spatially close, will have a comparative advantage in producing high-quality products, with trade volumes being larger across countries with similar income levels. Only a few trade models assume non-homothetic preferences, including Flam and Helpman (1987), Lewis et al. (2020), Markusen (1986), and Matsuyama (2000). In this article, Fieler's (2011) constant relative income elasticity approach to incorporating non-homothetic preferences is adopted, allowing for average per capita income to have an impact on trade. However, as noted later, this approach is somewhat restrictive, the ratio of income elasticities for two products being constant across income levels.

In summary, the contribution of this article lies in the application of a Ricardian-type model to trade in agricultural products that have credence attributes, with intra-sector heterogeneity in agricultural productivity, and non-homothetic preferences in demand. As a preview, the analysis presented generates four key results. First, with eco-labeling, the price of sustainable products falls, generating benefits to consumers willing to pay for them. Second, the introduction of eco-labeling increases the share of a composite input (land, labor, and water) allocated to sustainable products with associated environmental/sustainability benefits. Third, in terms of choice of eco-labeling regime, a policy of mutual recognition will unambiguously increase trade in eco-labeled products, resulting in gains to both consumers and the environment, while regulatory harmonization may result in an environmental/sustainability gain or loss, depending on the cost of harmonized eco-labeling relative to any environmental benefits, and its expected impact on trade. Fourth, under certain conditions, non-homothetic preferences imply production and trade in sustainable agricultural products will be most intense among high-income countries, except for those instances where the location of production in low-income countries is dictated by agroecological characteristics.

In what follows, sustainable water use in agricultural production and its relationship to trade is discussed, followed by the description of a simple illustrative model, highlighting the way in which eco-friendly products and labeling can be incorporated into a trade model. A more detailed model is then derived, followed by an analysis of the consumer and environmental gains from trade and eco-labeling, and the effects of alternative eco-labeling regimes. Finally, the article is summarized along with a discussion of the potential future direction of this type of research.

TRADE AND SUSTAINABLE WATER USE IN AGRICULTURAL PRODUCTION

In the past half-century, competition for scarce water resources has intensified with population growth and changes in diet (Molden, 2007). Although populations in many countries and regions perceive water as an abundant natural resource, fresh water is limited, over-consumption is having the potential to increase water stress, posing a threat to humans, ecosystems, and biodiversity (Rost et al., 2008; Vörösmarty et al., 2010; Weinzettel & Pfister, 2019). Balasubramanya and Stifel (2020) also emphasize the need to understand the connection between water, agriculture, and poverty, given an increase in demand for scarce water resources and increased climatic variability.

Scientists focused on planetary boundaries, have defined a "safe operating space" for the world based on biophysical processes affecting the stability of the planet, the processes including global freshwater use, along with others such as climate change and the rate of loss of biodiversity (Steffen et al., 2015). While the planet's environment has been quite stable for over 10,000 years, human activities have been the main cause of environmental change since the industrial revolution (Rockström et al., 2009). The risk is human activity will push the planet beyond the current stable state, hence the need for planetary boundaries. In the case of freshwater, Steffen et al. (2015) propose boundaries on both the amount of annual global water consumption, as well as water withdrawal from specific river basins based on average monthly river flow. Note that water consumed is the amount of water removed for use and not returned to its source, whereas water withdrawal is defined as freshwater taken from ground or surface water sources, either permanently or temporarily, and conveyed to a place of use.

Analysis in this article focuses on the interaction between agricultural trade and water scarcity in a world where consumers have incomplete information about the environmental/sustainability impact of production. In this context, it is important to understand the links between agricultural production and freshwater consumption, and how those links have been analyzed. The literature breaks down into three main areas of analysis (Liu et al., 2014). First, studies focusing on the "water footprint" of agricultural production for both domestic consumption and export (Hoekstra & Mekonnen, 2012; Mekonnen & Hoekstra, 2011) and the related concept of virtual water trade (Allan, 1997; Ansink, 2010; Dalin et al., 2012; Konar et al., 2013; Reimer, 2012, 2014). Second, a focus on water use in agriculture, and the set of factors that could either exacerbate or mitigate future availability for production (Gerten et al., 2011; Rosegrant & Cai, 2002), the emphasis being on the use of irrigation by agriculture and its impact on river basins (Vörösmarty et al., 2010), and groundwater depletion (Aeschbach-Hertig & Gleeson, 2012; Richey et al., 2015). Third, studies evaluating the impact of water scarcity due to irrigation stress and climate change, on global agricultural trade and economic welfare (Konar et al., 2016; Liu et al., 2014; Reimer, 2014).

Defining the water footprint concept is an important starting point for thinking about agricultural trade and water scarcity. The concept, originally due to Hoekstra and Chapagain (2003), is defined as the water volume per unit of product, which is equal to the sum of the *green* water footprint (rainwater consumed), the *blue* water footprint (volume of surface, and groundwater consumed), and the *gray* water footprint (volume of freshwater required to assimilate pollutant loads) (Mekonnen & Hoekstra, 2011). The main source of green water is rain falling on the earth's surface, with 56% being evapotranspired by various landscape uses such as forestry, and 4.5% being evapotranspired by rainfed agriculture, where evapotranspiration is evaporation from the land surface plus transpiration from plants. Globally, about 39% of rain contributes to blue water sources, with blue water withdrawals accounting for 9% of blue water sources, with 70% of withdrawals going to irrigation. Total evapotranspiration by irrigated agriculture is about 2% of rain, of which 30% is directly from green water, and the remainder from blue water (Molden, 2007).

Over the period 1996–2005, the annual global water footprint of crop production, broke down as 78% green, 12% blue, and 10% gray respectively (Mekonnen & Hoekstra, 2011), with wheat, rice, and corn having the largest annual footprints. Wheat and rice had the largest annual blue water footprint, accounting for 45% of the global blue water footprint, and wheat, corn, and rice had the largest annual gray water footprint due to nitrogen fertilizer use, accounting for 56% of the global gray water footprint (Mekonnen & Hoekstra, 2011). In terms of the water footprint of crop production at the country level, India, China, and the United States had the largest annual total and annual blue water consumption, respectively (Mekonnen & Hoekstra, 2011).

Beyond looking at the blue water footprint of agricultural production, it is critical to evaluate the extent to which water security is at risk with respect to rivers, the chief source of renewable water supply for humans and ecosystems. Vörösmarty et al. (2010) report 80% of the world's population live in areas where either water security or threat to biodiversity exceeds the 75th percentile, with regions of intensive agriculture and dense settlement showing a high threat of incident, specifically the United States, Europe, and large parts of central Asia, the Middle East, the Indian sub-continent, and eastern China. There are many factors contributing to both water security and biodiversity threat, with cropland being the dominant stressor, nutrient, and pesticide loads being key pollution sources.

In addition, given 90% of water consumption is for irrigation, and about 40% of irrigation water is derived from groundwater, water security also depends on the extent of groundwater depletion (Aeschbach-Hertig & Gleeson, 2012). Groundwater depletion occurs when water output from an aquifer exceeds input, driven by both hydrological and economic factors. Rates of groundwater extraction are mostly linked to irrigated agriculture, and the fact it is a common pool resource (Aeschbach-Hertig & Gleeson, 2012). Groundwater depletion not only lowers water tables, reducing discharge to streams and wetlands affecting ecosystems, but also results in land subsidence, and induced groundwater flow leading to salinization from saltwater intrusion, and the spread of other pollutants. The empirical evidence suggests global groundwater depletion has accelerated since the mid-19th century, contributing to the rate of sea-level rise, the rate of depletion being projected to accelerate (Wada et al., 2010; Wada et al., 2012). The largest rates of groundwater depletion are currently in northern India, Bangladesh, and parts of Pakistan and Nepal, covering the Indo-Gangetic Plain. India currently pumps twice as much groundwater as China and the United States, where the North China Plain, the High Plains, and the California Central Valley all represent over-exploited aquifers (Aeschbach-Hertig & Gleeson, 2012).

Given the water footprint of agriculture, how does this relate to trade? Allan (1997) coined the term "virtual water" to describe trade in products with a large water footprint. In their analysis of agriculture's water footprint, Hoekstra and Mekonnen (2012) also calculated international virtual water flows over the period 1996–2005. Again, this is dominated by trade in agricultural products, the top virtual water exporters being the United States, China, India, Brazil, Argentina, Canada, Australia, Indonesia, France, and Germany, accounting for over half of global water exports (Hoekstra & Mekonnen, 2012).

While the virtual water concept has been debated (Allan, 2003; Ansink, 2010; Merrett, 2003), Reimer (2012) shows it is no more than a restatement of Vanek's (1968) extension of the Heckscher-Ohlin model, analysis being in terms of the factor content of trade. The implication is trade in water-intensive products could alleviate water scarcity in say the Middle East. There is some empirical support for this argument: for example, using a gravity model based on a Ricardian-type structure, Reimer (2014) finds trade could help countries suffering from an irrigation shock, while Liu et al. (2014) using an extended version of the GTAP computable general equilibrium (CGE) model, find irrigation shortfalls would increase agricultural trade and change its geographical pattern.

However, as pointed out by Weinzettel and Pfister (2019), the role of agricultural trade in mitigating water scarcity is empirically ambiguous, their analysis showing arid regions such as the Middle East, Mexico, Portugal, and Spain benefiting from imports of water-intensive products, but their exports also embody their own scarce water. In addition, their empirical results show developed countries also tend to be importers of scarce water-intensive products from developing countries, even though they typically have no water scarcity problems of their own.

This latter result is perhaps not surprising given water typically has a zero price, ignoring both its scarcity value and any externalities generated in its use for agricultural production (Hoekstra & Mekonnen, 2012). Therefore, the jumping-off point of the current article is as follows: suppose water used in agricultural production is not formally priced, but farmers are willing to incur the cost of applying environmental services to conserving water, but the latter is not observed by consumers willing to pay for those services via higher product prices. Specifically, what are the potential benefits of the trade-in and certified eco-labeling of products that are environmentally friendly in terms of their utilization of scarce water resources?

AN ILLUSTRATIVE MODEL

The basic story of this article is as follows: trade offers consumers access to products from trading partners produced with least cost unsustainable (U) and high cost sustainable (S) technologies. Eco-labels allow consumers willing to pay a higher price for sustainable products to identify them, producers being compensated for higher costs of production. Eco-labels increase the gains from trade by expanding the market share of products produced with a more environmentally sustainable technology.

To illustrate, a simple two-country model can be described. Following Dornbusch et al. (1977), the world comprises two countries, $i = 1, 2$, with many representative buyers and a continuum of agricultural products, $j \in [0,1]$. Each country has a unique technology for producing each product in the continuum, all product markets being perfectly competitive. Unit costs of production for each country and product, $c_i(j)$, are plotted in Figure 1, products being organized in order of increasing unit costs for Country 1 producers and decreasing unit costs for Country 2 producers. In autarky, both countries produce every agricultural product in the continuum with a less-than-infinite unit cost of production. Country 1 consumers purchase products from 0 to j_1, and Country 2 consumers purchase products from 1 to j_2.

With trade, consumers purchase each product from the country with the lowest unit cost of production, consumers purchasing all products along the continuum. Country 1 specializes in producing and exporting products 0 to $\tilde{j}$, while Country 2 specializes from $\tilde{j}$ to 1, that is, the so-called "chain of comparative advantage" is broken at that product $\tilde{j}$ in the continuum where the unit costs of production are the same in each country. Advances in technology are easily captured in this framework: suppose country 1 is subject to a uniform reduction in its unit input requirement across the continuum, its unit cost schedule rotating down, Country 1 now specializing in producing more products in the continuum, $\tilde{j}$ to $\tilde{j}'$.

In this article, what matters from the standpoint of sustainability is the products in which a country has the lowest unit production costs require fewer inputs per unit of output. Therefore, if it is assumed fewer inputs imply a smaller environmental impact, there is an environmental gain E_1 from trade when products $\tilde{j}$ to j_1 in the continuum are no longer produced by Country 1, or $E_1{}'$ after the technological change has occurred in Country 1. Of course, these gains could be offset by the environmental impact of transporting the relevant products from Country 2, but this potential source of environmental loss is abstracted from here.

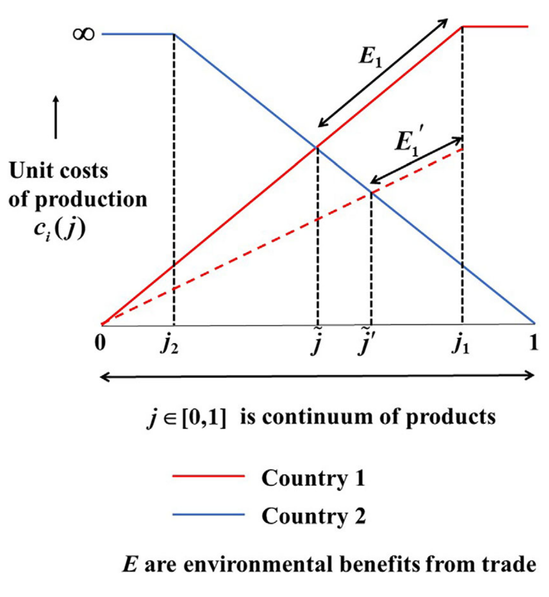

FIGURE 1 Comparative advantage in the continuum [Color figure can be viewed at wileyonlinelibrary.com]

Extending the analysis, suppose producers have access to a second set of more sustainable (S) technologies, unit costs of production for these products are higher because the inputs required are more costly. One subset of consumers is always willing to pay a higher price for S products, while another subset will purchase S products if the difference in price between the S product and the product produced with the less sustainable technology U is less than w. In this case, there is an environmental gain from trade that is a function of the share of consumers who always purchase sustainably produced products and those who purchase some sustainably produced products.

In terms of Figure 2, after opening to trade, Country 1, in addition to producing products from 0 to $\tilde{j}^U$ with U technology will specialize in products from $\tilde{j}^U$ to $\tilde{j}^S$, produced with S technology. Certified eco-labels allow consumers willing to pay a higher price for S products to identify them and allow producers to obtain compensation for using the S technology. Thus, eco-labeling provides Country 1 with the ability to capitalize on comparative advantage in S products from $\tilde{j}^U$ to $\tilde{j}^S$.

In this very simple two-country world, trade gives consumers access to the lowest cost and most sustainable technologies. The role of an eco-label in this model is to allow consumers to exercise their preference for the S over the U technology and allow producers to be compensated with a higher price. This story can be easily extended to a many-country world using the probabilistic approach originally developed by Eaton and Kortum (2002). The key is to model unit costs for each product in each country as a random variable.

FULL MODEL

As in the two-country example, there is a continuum of agricultural products, which can be produced in each country with country-specific unsustainable (U) and sustainable (S) technologies.

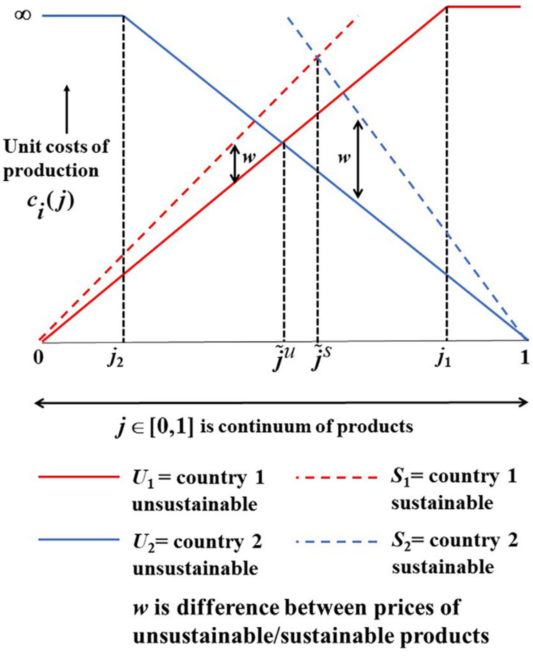

FIGURE 2 Sustainable products in the continuum [Color figure can be viewed at wileyonlinelibrary.com]

The production technology does not affect a product's intrinsic characteristics, that is, a banana produced with the S technology is indistinguishable from a banana produced with the U technology. As such, an eco-label is required for consumers to identify U and S products.

Production

Following Heerman (2020), the product j-specific U technology available in country i takes the following form:

$$q_i^U(j) = z_i^U(j)\left[\left(a_i^U(j)\Upsilon_i\right)\right], \tag{1}$$

where $z_i^U(j)$ is a productivity-enhancing random variable as in Eaton and Kortum (2002), Υ_i is a composite input consisting of land, labor, and water, and $a_i^U(j)$ is country i, product j-specific productivity of the composite input with technology U.

The product j-specific S technology is distinguished from the U technology by the additional input requirement of environmental services H_i. These would include drought-resistant production technology, less-intensive irrigation, and control of nutrient runoff:

$$q_i^S(j) = z_i^S(j)\left[\left(a_i^S(j)\Upsilon_i\right)^{\alpha} H_i^{1-\alpha}\right]. \tag{2}$$

For both technologies, following Eaton and Kortum (2002), $z_i^k(j)$ is assumed to be distributed independently following a Type II extreme value or Fréchet distribution:

$$F_i^k(z) = \exp\left\{-T_i z^{-\theta^k}\right\}, \tag{3}$$

where $T_i > 0$, and $\theta^k > 1$. The parameter T_i describes average agricultural productivity in country i, with higher values of T_i implying a country is more productive on average. This parameter can be thought of as capturing a country's absolute advantage in agriculture. The parameter θ^k describes the dispersion of agricultural productivity. Notice T_i does not vary across S versus. U technologies, whereas θ^k is assumed common across countries but may differ across technology types.

The input productivity parameter $a_i^k(j)$ is systematically linked to the suitability of exporter i's natural environment for producing j. This parameter links countries with similar climates, soil types, and access to water. The model predicts such countries will tend to specialize in the same agricultural products and be more likely to compete head-to-head in the international market (Heerman & Sheldon, 2018a). The parameter is assumed to follow a continuous density that is a deterministic function of exporter i's agroecological characteristics and product j's agroecological production requirements (Heerman, 2020; Heerman et al., 2015). For example, $a_i^k(j)$ will reflect relatively high input productivity of tropical products in countries with tropical climate. This approach has similarities to the literature explicitly incorporating land heterogeneity into trade models, for example, Costinot and Donaldson (2012), Costinot et al., 2016, Fally and Sayre (2018), Gouel and Laborde (2021), Gouel (2020), and Sotelo (2020).

Producers in country i face iceberg trade costs $\tau_{ni} \geq 1$ of exporting to market n. In addition, producers from country i using the S technology must also pay an eco-labeling cost ζ_{ni} allowing consumers in the market n to distinguish it from the same product produced with the U technology. In the absence of credible certification, ζ_{ni} will be infinitely high. Eco-labeling costs within a specific country are normalized, that is, $\zeta_{nn}=1$, so that ζ_{ni} can be interpreted as the additional eco-labeling cost(s) of exporting a sustainable product.

Perfectly competitive producers set prices equal to unit costs of production. Exporter i's price offers in market n are, therefore:

$$p_{ni}^{U}(j)=\frac{\tilde{a}_{i}^{U}(j)c_{i}^{U}\tau_{ni}}{z_{i}^{U}(j)} \qquad p_{ni}^{S}(j)=\frac{\tilde{a}_{i}^{S}(j)c_{i}^{S}\tau_{ni}\zeta_{ni}}{z_{i}^{S}(j)}, \tag{4}$$

where c_i^k is the cost of a product j input bundle in sector $k=U,S$. For cost-minimizing producers, $c_i^U=\upsilon_i$ and $c_i^S=\kappa\upsilon_i^{\alpha}h_i^{1-\alpha}$, where υ_i and h_i are the unit costs of the composite and environmental service inputs respectively (see Appendix A, Supporting information). The intuition behind (4) is straightforward: product prices vary inversely with a country's absolute advantage, they vary positively with a country's production costs conditioned on agroecological suitability, and they vary positively in transport and eco-labeling costs.

Fieler's (2011) extension to Eaton and Kortum (2002) appeals to the product life-cycle theory of Vernon (1966) also. According to this theory, when a product is first developed, it will be produced in a technologically advanced country and sold to its high-wage local consumers. Over time, the technology becomes standardized, that is, the dispersion of productivity declines, and any country can produce the product, including those with low wages. Therefore, in general equilibrium, low-wage (high-wage) countries will have a comparative advantage and thus specialize in products with a high (low) value of θ^k, given low average labor productivities (high average labor productivities).

In the current model which features productivity differences tied to systematic country and product characteristics, the latter result will not necessarily hold. To see this, consider the expectation of the price offered by an exporter relative to a domestic producer:

$$\frac{E\left(p_{ni}^{k}(j)\right)}{E\left(p_{nn}^{k}(j)\right)}=\left(\frac{T_i}{T_n}\right)^{-1/\theta^k}\times\frac{E\left(a_i^k(j)\right)c_i^k\tau_{ni}\zeta_{ni}}{E\left(a_n^k(j)\right)c_n^k}. \tag{5}$$

Notice relative price is a function of two factors: the ratio of the two countries' average agricultural productivity T_i/T_n, and the ratio of their unit costs, including input, trade, and eco-labeling costs. As θ^k increases, that is, the dispersion of productivity falls, the first term approaches one, and relative unit costs of production and delivery dominate the determination of relative prices.

Unlike Fieler (2011), $\theta^U>\theta^S$ does not necessarily imply high-income countries will be more likely to specialize in producing with the S technology and vice versa. With systematic heterogeneity in input productivity for agricultural products, even with high average agricultural productivity T_i, a country's potential for exporting product j with the S technology will be conditioned on it having a suitable environment for producing j. For example, despite the United States having high average agricultural productivity, the Mid-Western climate is wholly unsuitable for the production of sustainable coffee beans and pineapples, just as it is unsuitable for unsustainable production of these tropical products.

In other words, high-income countries may specialize earlier in a range of sustainable products, but here it is driven by preferences. Therefore, any general argument for Vernon's (1966) product life-cycle theory being applied to sustainable agricultural production technologies at the sector level is unlikely to stand up empirically. This proves important when considering the effect of income on trade-in sustainable products when evaluating eco-labeling.

Trade and prices

As in Eaton and Kortum (2002), trade is driven by buyers seeking to purchase their preferred bundle of U and S products from the source country with the lowest price offer. The probability the lowest price offer for product j comes from exporter i is the probability that all its competitors l, offer higher prices. This can be written for S products as:

$$\Pr(p_{nl}^S(j) > p_{ni}^S(j) \forall l \neq i = \frac{T_i\left(\tilde{a}_i^S(j) c_i^S \tau_{ni} \zeta_{ni}\right)^{-\theta^S}}{\Phi_n^S(j)} \equiv \pi_{ni}^S(j), \tag{6}$$

where $\Phi_n^S(j) = \sum_{l=1}^{I} T_l\left(\tilde{a}_l^S(j) c_l^S \tau_{nl} \zeta_{nl}\right)^{-\theta^S}$ (see Appendix B, Supporting information). The $\Phi_n^k(j)$ parameters play a key role describing how average agricultural productivity, agroecological suitability, input costs, trade, and labeling costs around the world, affect prices and thus consumption in each import market. These parameters reveal lowering trade and labeling costs increases the probability the lowest price offer in market i will be from a source country with higher average agricultural productivity T_l, and more suitable agroecological characteristics for the production of j, $\tilde{a}_l^k(j)$, and thus lower unit requirements for the composite input. To the extent, this higher efficiency implies a smaller negative environmental impact from production; trade enables consumption with a smaller environmental impact net of any transportation externalities, even if consumption is not reallocated to S products.

The unconditional probability exporter i offers the lowest price for an agricultural product in market n is:

$$\overline{\pi}_{ni}^S = \int \frac{T_i\left(\tilde{a}_i^S(j) c_i^S \tau_{ni} \zeta_{ni}\right)^{-\theta^S}}{\Phi_n^S(j)} dF_{a_n}\left(\tilde{\boldsymbol{a}}^S\right), \tag{7}$$

where $dF_{a_n}\left(\tilde{\boldsymbol{a}}^S\right)$ is the density of input productivities $\tilde{\boldsymbol{a}}^S = \left[\tilde{\boldsymbol{a}}_1^S, \ldots, \tilde{\boldsymbol{a}}_I^S\right]$ over agricultural products consumed in market n, and $\tilde{\boldsymbol{a}}_i^S$ is the vector of product-specific input productivities in country i. That is, the unconditional probability exporter i has the lowest price offer is the weighted average of the product-specific probabilities π_{ni}^S, where the weights reflect the importance of each product in n consumption. Using the law of large numbers $\overline{\pi}_{ni}^S$ is exporter i's market share in country n for the sustainable product (see Appendix B, Supporting information). Expression (7) can be interpreted as a gravity-like relationship between the market shares of an exporting country on the one hand and exporter characteristics and bilateral trade costs on the other.

Specifically, Expression (7) indicates that country i's market share in country n, increases with: higher average agricultural productivity T_i, a more suitable agroecological environment for the products consumed in n, $\tilde{\boldsymbol{a}}_{\boldsymbol{i}}$, lower input costs, υ_i, h_i, lower bilateral trade costs, τ_{ni}, and lower eco-labeling costs relative to market i, ζ_{ni}, for S products. While a policy of first-best water pricing is not analyzed here, if used by an exporting country i, it will necessarily work via increasing the unit cost of the composite input, υ_i.

Consumption

Consumers in country i choose quantities of agricultural products j, $\{q_i^k(j)\}$ to maximize a non-homothetic utility function following Fieler (2011):

$$\frac{\sigma^U}{\sigma^U-1}\left(\int_0^1 q_i^U(j)^{\frac{\sigma^U-1}{\sigma^U}}dj^U\right)+\frac{\sigma^S}{\sigma^S-1}\left(\omega_i^{\frac{1}{\sigma^S}}\int_0^1 q_i^S(j)^{\frac{\sigma^S-1}{\sigma^S}}dj^S\right), \tag{8}$$

where $\sigma^k>1$ for $k\in\{U,S\}$ and $\omega_i>0$ is a preference weight representing the value country i consumers place on sustainable production S. Note that the possibility of sub-optimal use of water resources in agricultural production is assumed not to directly enter the utility function as a local public bad. The consumer's budget constraint is defined by their income from the ownership of the composite agricultural input. Products using the S technology have higher costs of production and thus higher prices because their production requires the environmental services input in addition to the composite input. Therefore, consumers only choose S products if they are credibly labeled as such, that is, without a label, consumers will not be willing to pay a higher price for S products.

Total expenditure on S products relative to U products is:

$$\frac{X_i^S}{X_i^U}=\lambda_i^{\sigma^U-\sigma^S}\left(\frac{\omega_i P_i^{S^{1-\sigma^S}}}{P_i^{U^{1-\sigma^U}}}\right), \tag{9}$$

where P_i^k is the CES price index of products $k\in\{U,S\}$, and $\lambda_i>0$ is the Lagrange multiplier from the budget constraint, which Fieler (2011) notes is strictly decreasing in consumer income (see Appendix C, Supporting information). Relative expenditure on sustainable products increases with the consumer preference weight ω_i and decreases their price P_i^S.

The impact of changes in income is a function of the term $\lambda_i^{\sigma^U-\sigma^S}$. Suppose $\sigma^S>\sigma^U$, so relative expenditure on sustainable products is decreasing in λ_i, and thus increasing in income. Therefore, as in Fieler (2011), at all levels of income and prices, the income elasticity of demand for an S product relative to that for a U product is given by σ^S/σ^U, that is, consumers with higher incomes, increase the share of their budget allocated toward sustainable products. An important *caveat* should be noted here: as consumer incomes increase, their relative consumption of sustainable products increases, but their consumption of both types of product increases in absolute terms, that is, the way non-homotheticity is introduced does not allow for substitution over time from unsustainable to sustainable products.

TRADE AND ECO-LABELING

Consumer gains

Consumer gains from trade with the introduction of eco-labels on imported products arise to the extent they lower the price of S products. Introducing eco-labels can be represented as a decrease in ζ_{ni} from infinity. With eco-labeling and trade, the price of S products can be written (see Appendix D, Supporting information):

$$P_n^S = \gamma \left(\int \left(\overbrace{T_n \left(\tilde{a}_n^S(j) c_n^S \right)^{-\theta^S}}^{\text{Term1}} + \overbrace{\left(\sum_{l=1}^{I} T_l \left(\tilde{a}_l^S(j) c_l^S \tau_{nl} \zeta_{nl} \right) \right)^{-\theta^S}}^{\text{Term2}} \right)^{\frac{\sigma^S - 1}{\theta^S}} dF_{a_n}\left(\tilde{\boldsymbol{a}}^S \right) \right)^{\frac{1}{1-\sigma^S}}. \tag{10}$$

Without eco-labeling, that is, with ζ_{ni} set to infinity, the price of S products is fully determined by domestic production costs. That is, Term 1 in (10) determines the price because consumers effectively do not have access to imported S products. The introduction of eco-labels for imported S products, Term 2 in (10) provides consumers access to lower prices associated with products for which its trading partners have a comparative advantage.

Moreover, trade allows the price of S products to decline relative to U products because the latter U products are not affected by eco-labeling costs. This implies an increase in the share of expenditure allocated to S products (see Appendix C, Supporting information). In general equilibrium, S products increase their share of country i consumers' budgets to the extent their price falls more than U prices, which will depend on the distribution of adjustments to composite input costs, as well as trade and labeling costs around the world.

With a fully parameterized model, consumer gains from eco-labeling can be estimated by approximating the utility obtained with and without imported S products, holding expenditure fixed. The change in consumer welfare is defined as:

$$\mathrm{CW}_i = \left(\frac{X_i^{U'}}{P_i^{U'}} + \frac{\omega_i^{\frac{1}{\sigma^S}} X_i^{S'}}{P_i^{S'}} \right) - \left(\frac{X_i^U}{P_i^U} + \frac{\omega_i^{\frac{1}{\sigma^S}} X_i^S}{P_i^S} \right), \tag{11}$$

where $\left(\frac{X_i^{U'}}{P_i^{U'}} + \frac{\omega_i^{\frac{1}{\sigma^S}} X_i^{S'}}{P_i^{S'}} \right)$ is weighted real expenditure on agricultural products with the introduction of eco-labels on imported products, and total expenditure is constrained to equal expenditure without eco-labels on imports.

The magnitude of consumer gains from the introduction of eco-labeling with international trade will vary across countries depending on the value consumers place on environmentally friendly/sustainable production as well as trade and labeling costs.

Sustainability gains

The extent of sustainability gains from eco-labeling depends crucially on the objective of the eco-label. Only cases in which the eco-label signifies a specific production process was followed are considered here. The sustainability benefits of using a given S production process relative to the U production process are rarely if ever easy to quantify on a large scale. The interaction of natural resources and agricultural inputs for the purpose of producing crops or animal products always has some environmental impact. Calculating negative environmental cost(s) associated with that interaction at a given place and time requires very specific criteria and may yet be difficult or impossible to measure. Moreover, just as an identical input bundle will not produce the same output in Canada as it will in Spain; so the environmental impact from an identical production process will vary depending on the characteristics of the natural resource base across countries over time.

Since the sustainability gains from a given production technology cannot be directly calculated without much more information than is generally available, as in Larson (2003) the sustainability gains from eco-labeling and trade EW_i are measured as a function of the increase in the share of the composite input Υ_i allocated to S production:

$$\mathrm{EW}_i = f\left(\frac{\Upsilon_i^{S'} - \Upsilon_i^S}{\Upsilon_i}\right). \tag{12}$$

To see how introducing trade-in eco-labeled products provides sustainability gains in the exporting country, note the equilibrium conditions resulting in an optimal allocation of the composite input imply (see Appendix E, Supporting information):

$$\frac{\Upsilon_i^S}{\Upsilon_i^U} = \frac{\sum_n \overline{\pi}_{ni}^S X_n^S}{\sum_n \overline{\pi}_{ni}^U \left(X_n - X_n^S\right)}. \tag{13}$$

The numerator in (13) is the value of country i's total production of S products – exports plus domestic production. The denominator is the total value of U products production. With the introduction of eco-labels, that is, as ζ_{ni} falls from infinity, $\overline{\pi}_{ni}^S$ rises under general circumstances. Therefore, the numerator of (13) increases with the introduction of eco-labels. As noted earlier, $\left(X_n - X_n^S\right)$ is expected to decrease with the introduction of eco-labeling on imports under general conditions. Given markets must be clear, the introduction of eco-labels with trade increases the share of the composite input allocated to S products, providing a sustainability gain.

Alternative eco-labeling policies

While measuring the absolute level of sustainability gains from eco-labels and trade is complicated by the challenge of objectively measuring the relative environmental impact of two production processes, the model offers valuable insights into the relative gains from eco-labeling and trade under various policy regimes. Here the impact of two eco-labeling policy scenarios is examined when two separate economies choose to integrate through a regional trade agreement: mutual recognition and regulatory harmonization. The choice between these two labeling regimes has the potential to affect both consumer and sustainability gains from eco-labeling.

Before describing the results, it is important to place them in the context of the literature on standards and their impact on trade. Beghin et al. (2015) note the international economics literature has often focused on the extent to which standards and other non-tariff measures (NTMs) limit trade while ignoring the fact that such standards are typically targeted at market failures such as externalities and asymmetric information. More careful analysis indicates the expected impact of standards on trade is ambiguous. For example, Fischer and Serra (2000) show that if the policymaker, in setting a standard, deviates from the first-best level required to maximize global welfare, it may be protectionist. In contrast, Marette and Beghin (2010) find that maximizing domestic as opposed to global welfare is not necessarily protectionist, the outcome is depending on the relative efficiency of domestic versus foreign producers in complying with those standards.

Adopting the language of the literature: standards can be either a "barrier" or a "catalyst" to trade, a prediction that holds up in the analysis presented by Swinnen (2016, 2017), and Beghin and Schweizer (2021), even if standards are not set with protectionist motives in mind. Specifically, standards affect both domestic and export supply due to the burden of compliance costs, while demand may be affected as consumers react to the information they get from the standard and any associated labeling. As Beghin and Schweizer (2021) emphasize, it is important to disentangle these effects in evaluating the impact of standards.

Mutual recognition of eco-labels among countries implies products meeting domestically sufficient criteria for an eco-label may be sold with that eco-label in an import market without meeting additional criteria or providing additional proof domestically sufficient criteria have been met. For example, since 2012, the European Union (EU) and the United States have had a mutual recognition agreement for organic products: products meeting the criteria for an organic label in the United States may be exported and labeled as organic in the EU.

Under a policy of mutual recognition, labeling costs in the export market are identical to domestically sufficient labeling costs. That is, $\zeta_{ni} = \zeta_{in} = \zeta_{ii} = \zeta_{nn} = 1$, and mutual recognition lowers labeling costs in foreign markets from $\zeta_{ni}, \zeta_{in} > 1$. From (7) it is clear that holding all prices and all other countries' labeling costs constant, lowering ζ_{ni} increases $\bar{\pi}^S_{ni}$—an increase in bilateral trade in eco-labeled products.

The extent to which mutual recognition provides consumer and environmental/sustainability gains will depend on its effects on the prices of S and U products. Holding the prices of the composite input and environmental services constant, mutual recognition unambiguously lowers both, the absolute price of S products as well as the price of S relative to U products. To see this, suppose there is mutual recognition of eco-labels in countries n and i. Then, following (10), the price of S products in market n becomes:

$$P^S_n = \gamma \left(\int \left(\begin{array}{c} \overbrace{T_n\left(\tilde{a}^S_n(j) c^S_n\right)^{-\theta^S}}^{\text{Term1}} + \overbrace{T_i\left(\tilde{a}^S_i(j) c^S_i \tau_{ni}\right)^{-\theta^S}}^{\text{Term2}} \\ + \overbrace{\left(\sum_{l \neq n} T_l\left(\tilde{a}^S_l(j) c^S_l \tau_{nl} \zeta_{nl}\right)\right)^{-\theta^S}}^{\text{Term3}} \end{array} \right)^{\frac{\sigma^S - 1}{\theta^S}} dF_{a_n}\left(\tilde{\boldsymbol{a}}^S\right) \right)^{\frac{1}{1-\sigma^S}}. \tag{14}$$

In expression (14), Term 1 in parentheses is the contribution of domestic prices, which is unchanged under mutual recognition. Term 2 is importer i's contribution, which has increased from $T_i\left(\tilde{a}_i\left(j^S\right) c^S_i \tau_{ni} \zeta_{ni}\right)^{-\theta^S}$, lowering P^S_n. The contribution of all other countries who are not members of the regional trade agreement, that is, Term 3 is unchanged. Since P^U_n is not a function of ζ_{ni}, it is unchanged. Therefore, from (9), with $\sigma^k > 1$ the share of expenditure allocated to S rises with mutual recognition, which also implies an increase in consumer welfare in both countries. In addition, an increase in expenditure and bilateral trade in S products generates environmental/sustainability gains in both countries as the expanded export opportunity increases the share of the composite input allocated to S production.

Under a policy of *regulatory harmonization*, eco-labeling criteria are standardized across countries. Thus, as with mutual recognition, labeling costs are constant in the domestic and foreign markets. However, the cost of meeting agreed labeling criteria may differ from the cost of meeting domestically sufficient criteria. Let ζ_n' be the costs of meeting mutually agreed criteria, which are greater than the domestically sufficient criteria. Now:

$$P_n^S = \gamma \left(\int \left(\begin{array}{l} \overbrace{T_n\left(\tilde{a}_n^S(j)c_n^S\zeta_n'\right)^{-\theta^S}}^{\text{Term1}} + \overbrace{T_i\left(\tilde{a}_i^S(j)c_i^S\tau_{ni}\zeta_i'\right)^{-\theta^S}}^{\text{Term2}} \\ + \overbrace{\left(\sum_{l \neq n} T_l\left(\tilde{a}_l^S(j)c_l^S\tau_{nl}\zeta_{nl}\right)\right)^{-\theta^S}}^{\text{Term3}} \end{array} \right)^{\frac{\sigma^S-1}{\theta^S}} dF_{a_n}\left(\tilde{\boldsymbol{a}}^S\right) \right)^{\frac{1}{1-\sigma^S}}. \tag{15}$$

In Expression (15), Term 1 in parentheses is again the contribution of domestic prices, which have risen from $\int T_n\left(\tilde{a}_n\left(j^S\right)c_n^S\right)^{-\theta^S}$, increasing P_n^S. Term 2 reflects country i's contribution, which may be larger or smaller depending on whether ζ_i' is larger or smaller than ζ_{ni}, while Term 3 remains unchanged. In this case, the price of S products, and hence imports by n from i, may rise or fall, depending on the magnitudes of ζ_{ni}, and ζ_i', as well as i's average agricultural productivity T_i, its agroecological environment $\tilde{a}_i^S$, its input costs c_i^S, and the level of bilateral trade costs that it faces, τ_{ni}. If the prices of S products rise (fall), their share in total expenditure will fall (rise), reducing (increasing) consumer welfare. The conclusion to be drawn here is that the harmonization of eco-labeling can be either a “barrier” or “catalyst” to trade.

If mutually agreed criteria are more costly and not accompanied by sufficiently larger environmental/sustainability benefits, such an effort may reduce such gains, that is, with $\zeta_n' > 1$ domestic market share falls under mutual recognition:

$$\pi_{nn}^S = \frac{\int T_n\left(\tilde{a}_n^S(j)c_n^S\zeta_n'\right)^{-\theta^S}}{\Phi_N^S} < \frac{\int T_n\left(\tilde{a}_n^S(j)c_n^S\right)^{-\theta^S}}{\Phi_N^S}. \tag{16}$$

If this is manifest as a decline in production for the domestic market that is not offset by an increase in exports to market i, the share of the composite input allocated to S production in country n will decline, resulting in an environmental/sustainability loss.

Income and trade in sustainable products with eco-labeling

Drawing on (9), and the earlier discussion, if it is assumed $\sigma^S > \sigma^U$, relative expenditure on sustainable products is increasing in income. From this, and following Fieler (2011), it can be argued country n's imports from i relative to its domestic consumption will be a function of income, that is, for a high-income country, $X_{ni}/X_{nn} \approx X_{ni}^S/X_{nn}^S$, and by (7):

$$\frac{X_{ni}^S}{X_{nn}^S} = \frac{T_i}{T_n}\left(\frac{\tilde{a}_i^S(j)c_i^S\tau_{ni}\zeta_{ni}}{\tilde{a}_n^S(j)c_n^S\tau_{nn}\zeta_{nn}}\right)^{-\theta^S}. \tag{17}$$

Given $\tau_{nn} = \zeta_{nn} = 1$, the term in brackets will in general be greater than 1, but as θ^S becomes smaller, the impact of relative costs of sustainable production declines, and country n's imports from i increase, driven by differences in average agricultural productivity. The analytical logic here is, the production of and trade in sustainable agricultural products will be more intense among high-income countries when $\sigma^S > \sigma^U$, and $\theta^S < \theta^U$. This result also suggests, even if eco-labeling costs are significant, fundamental differences in average agricultural productivity can drive trade, that is, standards are not necessarily a "barrier" to trade.

However, this does not capture exports of, say tropical agricultural products produced in low-income countries, driven by their having the relevant agroecological characteristics, even if their average agricultural productivity is low. This sets up an interesting dynamic: low-income countries produce and trade a range of agricultural products using the unsustainable technology U, but demand for them to switch to production and export of the same range of products using the sustainable technology S comes from high-income country consumers willing to pay higher prices.

For this to be in equilibrium with the associated environmental benefits, the term in brackets in (17) will have to be less than 1, and the value of θ^S not too low. In other words, producers in low-income countries have sufficiently low unit costs of sustainable production, $\tilde{a}_i^S(j)c_i^S$, which mitigates any frictions created by transport costs and other barriers to trade τ_{ni}, as well as the costs of eco-labeling ζ_{ni}. This all assumes producers in low-income countries have access to the environmental services H_i necessary for sustainable production, and an ability to certify credence products for sale to consumers in high-income countries. The policy implication is that aid in the form of technology transfer(s) by developed countries may be necessary for developing countries to achieve their potential for sustainable production (Sheldon, 2012).

SUMMARY AND DISCUSSION

The key motivation for this article is consumers increasingly demand food characterized by credence attributes such as sustainable production methods, where eco-labeling and certification of any sustainability claims are critical in resolving the associated informational asymmetry. Importantly, trade-in of such products may generate environmental/sustainability gains. In this context, a Ricardian-type trade model with intra-sector heterogeneity in agricultural productivity and non-homothetic preferences is used to explore the potential gains to consumers and the environment of increased trade-in and eco-labeling of sustainably produced agricultural products. In addition, the alternatives of mutual recognition versus harmonization of different countries' eco-labeling regimes are compared. The key findings are that trade and eco-labeling can generate both consumer and sustainability gains; their extent being dependent on the labeling regime in place. In addition, production and trade in sustainable agricultural products will be most intense among high-income countries, unless the location of production in low-income countries is dictated by agroecological characteristics.

Ultimately, the extent to which trade in eco-labeled products benefits consumers and the environment is an empirical issue, calibrating the current model, and using it to conduct relevant policy simulations being the next step in this line of research. The methodology for applying this type of model has already been developed, the empirical strategy consisting of two key steps. First, parameters of the agricultural sector's productivity, trade and labeling cost distributions can be estimated and utilized in a gravity-like equation, from which estimates of the elasticity of trade flows with respect to changes in trade and eco-labeling costs can be derived

(Heerman, 2020; Heerman et al., 2015; Heerman & Sheldon, 2018a). This requires data on bilateral market shares, proxy variables for trade and eco-labeling costs, and country land, climate, and water footprint characteristics of agricultural production. Second, computing equilibrium in the model requires data on input endowments, values for parameters in the utility and production functions, and the elasticity of substitution (Heerman, 2020). Following the methodology suggested by Levchenko and Zhang (2016), the model can then be solved and used for policy simulation and analysis (Heerman, 2020) (see Appendix E, Supporting information).

A key finding of the earlier empirical work is that, given the estimated elasticities, lowering trade barriers highlights the importance of productivity-based comparative advantage, thereby intensifying competition between countries with similar agroecological characteristics that specialize more than proportionately in producing and exporting similar products (Heerman et al., 2015; Heerman & Sheldon, 2018a; Heerman & Sheldon, 2018b). The main empirical challenge in extending this framework to the analysis of water use and eco-labeling lies in the development of a proper and robust connection between trade, agricultural production, agroecological characteristics, and the water footprint of sustainable versus unsustainable production, and measuring consumer willingness to pay for sustainable agricultural products. The former is constrained by lack of data on bilateral trade in unsustainable versus sustainable products, while there is limited empirical evidence of consumers being willing to pay for water-saving agricultural production methods. In addition, Soregaroli et al. (2021) find that consumer wine choices, given carbon footprint information and an additional price for carbon emissions, are very sensitive to the design of the information policy. Therefore, understanding the impact of eco-labeling is crucial in evaluating consumer willingness to pay for sustainability.

Several other standout issues also need addressing. First, the focus of the model is entirely on trade in agricultural products and the potential for eco-labeling, ignoring their use as intermediate inputs in traded processed food products. In principle, the current model could be adapted following Heerman (2020), where traded agricultural and processed food products are produced using labor allocated across all sectors, a composite input including land and water specific to agricultural production, and an aggregate of intermediate inputs including environmental services, the latter being combined in the manner suggested by Caliendo and Parro (2015). However, the additional complexity means solving for equilibrium would likely be analytically challenging, and evaluating it empirically faces the same data constraints noted earlier. An alternative might be to apply the approach of Adao et al. (2017), where trade is modeled as an exchange in input services, the impact of eco-labeling costs working through changes in the input content of trade and input prices, given a reduced form input demand system. While a detailed discussion of this methodology lies beyond the scope of the current article, it should be noted estimation of the input demand system requires accurate measurement of the factor content of trade, which is potentially a problem given the level of aggregation of input-output matrices (Burstein & Vogel, 2017).

Second, the model as currently structured lacks an explicit vertical market structure, that is, it ignores linkages between agricultural producers and downstream food processors and retailers, which parties set sustainability standards, and the potential for post-contractual bargaining over any available economic surplus. Following Antràs (2003), it would be interesting to allow for incomplete contracts between agricultural producers and food processors. Specifically, food processors may seek to sell an eco-labeled food product but are unable to sign ex-ante enforceable contracts specifying the production of sustainably produced agricultural inputs, the quality of the latter only being revealed ex-post, and which may not actually be verifiable. In this setting, agricultural producers, and food processors bargain over the surplus after sustainable inputs have been produced, distribution depending on whether there is arm's length contracting or vertical control. To avoid the hold-up problem faced by agricultural producers, food processors may contribute to relationship-specific investments in sustainable production, thereby increasing their exposure to opportunistic behavior by the agricultural producer, which in turn provides an incentive for vertical integration.

Third, finding a more appropriate and tractable way of capturing non-homothetic preferences is critical, especially if the model is to be tied more closely to the existing literature on vertical product differentiation, that is, one that predicts, with increasing incomes, consumers substitute away from unsustainable products (low-quality) toward sustainable products (high-quality). While Gaigné and Gouel (forthcoming 2022) have a useful discussion relating to the issue of non-homotheticity and why it matters in thinking about agricultural trade, they conclude it is an open question on how to relate increasing incomes to consumption of higher-quality products.

Finally, the discussion of policy in this article focuses solely on the eco-labeling regime countries choose when integrating through a trade agreement. Obviously, other policy instruments could be analyzed in this setting, including first-best water pricing schemes and subsidies targeted at sustainable production, but from a practical policy viewpoint, given the choice of an eco-labeling regime ultimately implies a water footprint standard, it is useful to consider at what level the standard could be set and the potential implications for trade. This matters in terms of Article 2.4 of the Technical Barriers to Trade (TBT) Agreement of the World Trade Organization (WTO, 1995), which specifies that any required technical regulation should draw on existing international standards. As noted earlier, ISO 14046 is an international standard laying out principles, requirements, and guidelines for the quantification of a water footprint. The key to this international standard is its focus on water use from a life cycle assessment (LCA) perspective, but it is not prescriptive in terms of what water footprint indicator should be used when conducting such an assessment. Importantly, in LCA, the focus is on accounting for both water use and evaluating the potential environmental impact of that water use (Pfister et al., 2017).

As Ridoutt and Hodges (2017) show, alternative indicators can generate substantial differences in values for water scarcity footprints in agricultural production. Necessarily if different metrics are used, it may be hard for consumers to make comparisons across privately certified water footprint programs, and the policymaker's choice of eco-labeling programs is made more complex. There is also the possibility that government-sponsored labeling programs are in some sense inefficient and may not be compliant with the TBT, that is, the standard and associated labeling program either have the potential to negatively affect trade if they are set too high relative to the first-best policy of achieving sustainable production, or even if the standard is efficient, developing countries are unable to meet the standard if they lack access to environmental services.

However, this latter conclusion should clearly be tempered by the earlier discussion of eco-labeling regimes which suggests that the expected impact on trade of a certified water footprint standard is ambiguous a priori, an observation also supported by a recent meta-analysis of empirical research on NTMs and agri-food trade (Santeramo & Lamonaca, 2019). Therefore, beyond the conceptual approach to production and trade in sustainable agricultural products described and analyzed in this article, much applied work is required in developing an optimal standard for their water footprint and whether that standard acts as a “barrier” or a “catalyst” to trade.

REFERENCES

Adao, Rodrigo, Arnaud Costinot, and Dave Donaldson. 2017. "Nonparametric Counterfactual Predictions in Neoclassical Models of International Trade." *American Economic Review* 107(3): 633–89.

Aeschbach-Hertig, Werner, and Tom Gleeson. 2012. "Regional Strategies for the Accelerating Global Problem of Groundwater Depletion." *Nature Geoscience* 5(11): 853–61.

Allan, J. Anthony. 1997. "Virtual Water: A Long-Term Solution for Water Short Middle Eastern Economies?" Occasional Paper No. 3, Water Issues Study Group, School of Oriental and African Studies, University of London.

Allan, J. Anthony. 2003. "Virtual Water-the Water, Food, and Trade Nexus: Useful Concept or Misleading Metaphor?" *Water International* 28(1): 106–13.

Amiti, Mary, and Amit K. Khandelwal. 2013. "Import Competition and Quality Upgrading." *Review of Economics and Statistics* 95(2): 476–90.

Ansink, Erik. 2010. "Refuting Two Claims about Virtual Water Trade." *Ecological Economics* 69(10): 2027–32.

Antràs, Pol. 2003. "Firms, Contracts, and Trade Structure." *Quarterly Journal of Economics.* 118(4): 1375–418.

Balasubramanya, Soumya, and David C. Stifel. 2020. "Viewpoint: Water, Agriculture and Poverty in an Era of Climate Change: Why Do We Know So Little?" *Food Policy* 93(4): 101905.

Baldwin, Richard, and James Harrigan. 2011. "Zeros, Quality, and Space: Trade Theory and Trade Evidence." *American Economic Journal: Microeconomics* 3(2): 60–88.

Beghin, John C., and Heidi Schweizer. 2021. "Agricultural Trade Costs." *Applied Economic Perspectives and Policy* 43(2): 500–30.

Beghin, John C., Miet Maertens, and Johan Swinnen. 2015. "Nontariff Measures and Standards in Trade and Global Value Chains." *Annual Review of Resource Economics* 7: 425–50.

Burstein, Ariel, and Jonathan Vogel. 2017. "International Trade, Technology, and the Skill Premium." *Journal of Political Economy* 125(5): 1356–412.

Caliendo, Lorenzo, and Fernando Parro. 2015. "Estimates of the Trade and Welfare Effects of NAFTA." *Review of Economic Studies* 82(1): 1–44.

Chor, Davin. 2010. "Unpacking Sources of Comparative Advantage: A Quantitative Approach." *Journal of International Economics* 82(2): 152–67.

Costinot, Arnaud, and Dave Donaldson. 2012. "Ricardo's Theory of Comparative Advantage: Old Idea, New Evidence." *American Economic Review* 102(3): 453–8.

Costinot, Arnaud, Dave Donaldson, and Ivana Komunjer. 2012. "What Goods Do Countries Trade? A Quantitative Exploration of Ricardo's Ideas." *Review of Economic Studies* 79(2): 581–608.

Costinot, Arnaud, Dave Donaldson, and Cory Smith. 2016. "Evolving Comparative Advantage and the Impact of Climate Change in Agricultural Markets: Evidence from 1.7 Million Fields around the World." *Journal of Political Economy* 124(1): 205–48.

Costinot, Arnaud, and Andrés Rodríguez-Clare. 2014. "Trade Theory with Numbers: Quantifying the Consequences of Globalization." In *Handbook of International Economics*, Vol 4, edited by Gita Gopinath, Elhanan Helpman, and Kenneth Rogoff, 197–261. Amsterdam: Elsevier.

Crinò, Rosario, and Paolo Epifani. 2012. "Productivity, Quality and Export Behavior." *Economic Journal* 122(565): 1206–43.

Curzi, Daniele, Valentina Raimondi, and Alessandro Olper. 2015. "Quality Upgrading, Competition and Trade Policy: Evidence from the Agri-Food Sector." *European Review of Agricultural Economics* 42(2): 239–67.

Dalin, Carole, Megan Konar, Naota Hanasaki, Andrea Rinaldo, and Ignacio Rodriguez-Iturbe. 2012. "Evolution of the Global Water Trade Network." *PNAS* 109(16): 5989–94.

Dornbusch, Rudiger, Stanley Fischer, and Paul A. Samuelson. 1977. "Comparative Advantage, Trade, and Payments in a Ricardian Model with a Continuum of Goods." *American Economic Review* 67(5): 823–39.

Dulleck, Uwe, and Rudolf Kerschbamer. 2006. "On Doctors, Mechanics, and Computer Specialists: The Economics of Credence Goods." *Journal of Economic Literature* 44(1): 5–42.

Eaton, Jonathan, and Samuel Kortum. 2002. "Technology, Geography, and Trade." *Econometrica* 70(5): 1741–79.

Eum, Jihyun, Ian Sheldon, and Stanley R. Thompson. 2021. "Product Quality in Food and Agricultural Trade: Firm Heterogeneity and the Impact of Trade Costs." *Journal of Agricultural and Resource Economics* 46(1): 1–19.

Fally, Thibault, and James Sayre. 2018. "Commodity Trade Matters." NBER Working Paper, 24965.

Fieler, Anna C. 2011. "Nonhomotheticity and Bilateral Trade: Evidence and a Quantitative Explanation." *Econometrica* 79(4): 1069–101.

Fischer, Ronald, and Pablo Serra. 2000. "Standards and Protection." *Journal of International Economics* 52(2): 377–40.

Flam, Harry, and Elhanan Helpman. 1987. "Vertical Product Differentiation and North-South Trade." *American Economic Review* 77(5): 810–22.

Gaigné, Carl, and Christophe Gouel. 2022. "Trade in Agricultural and Food Products." In *Handbook of Agricultural Economics*, Vol 6, edited by Christopher B. Barrett and David R. Just. Amsterdam: Elsevier. Forthcoming

Gaigné, Carl, and Bruno Larue. 2016. "Quality Standards, Industry Structure, and Welfare in a Global Economy." *American Journal of Agricultural Economics* 98(5): 1432–49.

Gerten, Dieter, Jens Heinke, Holger Hoff, Hester Biemans, Marianela Fader, and Katharina Waha. 2011. "Global Water Availability and Requirements for Future Food Production." *Journal of Hydrometeorology* 12(5): 885–99.

Gouel, Christophe. 2020. "The Impact of Global Warming on Agriculture: A Critique of the Ricardian Approach from a General Equilibrium Perspective." Unpublished working paper, INRAE.

Gouel, Christophe, and David Laborde. 2021. "The Crucial Role of Domestic and International Market-Mediated Adaptation to Climate Change." *Journal of Environmental Economics and Management* 106: 102408.

Grebitus, Carola, Bodo Steiner, and Michele M. Veeman. 2016. "Paying for Sustainability: A Cross-Cultural Analysis of Consumers' Valuations of Food and Non-Food Products Labeled for Carbon and Water Footprints." *Journal of Behavioral and Experimental Economics* 63: 50–8.

Gruére, Guillaume A. 2013. "Characterization of Environmental Labeling and Information Schemes." OECD Environment Working Papers, No. 62, Paris: OECD Publishing.

Heerman, Kari E. R. 2020. "Technology, Ecology and Agricultural Trade." *Journal of International Economics* 123(2): 1–11.

Heerman, Kari E. R., Shawn Arita, and Munisamy Gopinath. 2015. "Asia-Pacific Integration with China Versus the United States: Examining Trade Patterns under Heterogeneous Agricultural Sectors." *American Journal of Agricultural Economics* 97(5): 1324–44.

Heerman, Kari E.R., and Ian M. Sheldon. 2018a. "Gravity and Comparative Advantage: Estimation of Trade Elasticities for the Agricultural Sector." NBER Working Paper 24772.

Heerman, Kari E.R., and Ian M. Sheldon. 2018b. "Increased Economic Integration in the Asia-Pacific Region: What Might Be the Potential Impact on Agricultural Trade?" Paper Presented at Annual Meetings of the Agricultural and Applied Economics Association, Washington, DC.

Hoekstra, Arjen Y., and Ashok K. Chapagain. 2003. *Globalization of Water: Sharing the Planet's Freshwater Resources*. Oxford: Blackwell Publishing.

Hoekstra, Arjen Y., and Mesfin M. Mekonnen. 2012. "The Water Footprint of Humanity." *PNAS* 109(9): 3232–7.

ISO 14046. 2014. *Environmental Management – Water Footprint – Principles, Requirements and Guidelines*. Geneva: International Organization for Standardization.

Kerr, William R. 2018. "Heterogeneous Technology Diffusion and Ricardian Trade Patterns." *The World Bank Economic Review* 32(1): 1–20.

Konar, Megan, Zekarias Hussein, Naota Hanasaki, Denise L. Mauzerall, and I. Rodriguez-Iturbe. 2013. "Virtual Water Trade Flows and Savings under Climate Change." *Hydrology and Earth System Sciences* 17(8): 3219–34.

Konar, Megan, Jeffrey J. Reimer, Zekarius Hussein, and Naota Hanasaki. 2016. "The Water Footprint of Staple Crop Trade under Climate and Policy Scenarios." *Environmental Research Letters* 11(3): 035006.

Krovetz, Hannah, Rebecca Taylor, and Sofia Villas-Boas. 2017. "Willingness to Pay for Low Water Footprint Food Choices during Drought." NBER Working Paper 23495.

Kugler, Maurice, and Eric Verhoogen. 2012. "Prices, Plant Size, and Product Quality." *Review of Economic Studies* 79(1): 307–39.

Larson, Bruce A. 2003. "Eco-Labels for Credence Attributes: The Case of Shade-Grown Coffee." *Environment and Development Economics* 8(3): 529–47.

Levchenko, Andrei A., and Jing Zhang. 2014. "Ricardian Productivity Differences and the Gains from Trade." *European Economic Review* 65(1): 45–65.

Levchenko, Andrei A., and Jing Zhang. 2016. "The Evolution of Comparative Advantage: Measurement and Welfare Implications." *Journal of Monetary Economics* 78: 96–111.

Lewis, Logan, Ryan Monarch, Michael Sposi, and Jing Zhang. 2020. "Structural Change and Global Trade." Federal Reserve Bank of Chicago, Working Paper No. 2020–25.

Linder, Staffan B. 1961. *An Essay on Trade and Transformation*. New York: John Wiley and Sons.

Liu, Jing, Thomas W. Hertel, Farzad Taheripour, Tingju Zhu, and Claudia Ringler. 2014. "International Trade Buffers the Impact of Future Irrigation Shortfalls." *Global Environmental Change* 29: 22–31.

Marette, Stéphan, and John Beghin. 2010. "Are Standards Always Protectionist?" *Review of International Economics* 18(1): 179–92.

Markusen, James R. 1986. "Explaining the Volume of Trade: An Eclectic Approach." *American Economic Review* 76(5): 1002–11.

Matsuyama, Kiminori. 2000. "A Ricardian Model with a Continuum of Goods under Non-homothetic Preferences: Demand Complementarities, Income Distribution, and North-South Trade." *Journal of Political Economy* 108(6): 1093–120.

Mekonnen, Mesfin M., and Arjen Y. Hoekstra. 2011. "The Green, Blue and Grey Water Footprint of Crops and Derived Products." *Hydrology and Earth System Sciences* 15(5): 1577–600.

Merrett, Stephen. 2003. "Virtual Water and Occam's Razor." *Water International* 28(1): 103–5.

Molden, David. 2007. *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*. London: Earthscan/International Water Management Institute.

Okpiaifo, Glory, Alvaro Durand-Morat, Grant H. West, Lawton L. Nalley, Rodolfo M. Nayga, and Eric J. Wailes. 2020. "Consumers' Preferences for Sustainable Rice Practices in Nigeria." *Global Food Security* 24: 100345.

Pfister, Stepan, Anne-Marie Boulay, Markus Berger, Michalis Hadjikakou, Masaharu Motoshita, Tim Hess, Brad Ridoutt, et al. 2017. "Understanding the LCA and ISO Water Footprint: A Response to Hoekstra (2016). 'A Critique on the Water-Scarcity Weighted Water Footprint in LCA'." *Ecological Indicators* 72: 352–9.

Pomarici, Eugenio, Daniele Asioli, Riccardo Vecchio, and Tormod Næs. 2018. "Young Consumers' Preferences for Water-Saving Wines: An Experimental Study." *Wine Economics and Policy* 7(1): 65–76.

Reimer, Jeffrey R. 2012. "On the Economics of Virtual Water Trade." *Ecological Economics* 75: 135–9.

Reimer, Jeffrey R. 2014. "Water in the International Economy." *Journal of Agricultural Trade and Development* 14(4): 21–51.

Reimer, Jeffrey R., and Man Li. 2010. "Trade Costs and the Gains from Trade in Crop Agriculture." *American Journal of Agricultural Economics* 92(4): 1024–39.

Richey, Alexandra S., Brian F. Thomas, Min-Hui Liu, John T. Reager, James S. Famiglietti, Katalyn Voss, Sean Swenson, and Matthew Rodell. 2015. "Quantifying Renewable Groundwater Stress with GRACE." *Water Resources Research* 51(7): 5217–38.

Ridoutt, Bradley, and Danni Hodges. 2017. "From ISO14046 to Water Footprint Labeling: A Case Study of Indicators Applied to Milk Production in South-Eastern Australia." *Science of the Total Environment* 599-600: 14–9.

Rockström, Johan, Will Steffen, Kevin Noone, F. Åsa Persson, I. I. I. Stuart Chapin, Eric F. Lambin, Timothy M. Lenton, et al. 2009. "A Safe Operating Space for Humanity." *Nature* 46: 472–5.

Roe, Brain, and Ian M. Sheldon. 2007. "Credence Labeling: Efficiency and Distributional Implications of Several Policy Approaches." *American Journal of Agricultural Economics* 89(4): 1020–33.

Rosegrant, Mark W., and Ximing Cai. 2002. "Global Water Demand and Supply Projections, Part 2: Results and Prospects to 2025." *Water International* 27(2): 170–82.

Rost, Stefanie, Dieter Gerten, Alberte Bondeau, Wolfgang Lucht, Janine Rohwer, and Sibyll Schaphoff. 2008. "Agricultural Green and Blue Water Consumption and its Influence on the Global Water System." *Water Resources Research* 44(9): W09405.

Santeramo, Fabio G., and Emilia Lamonaca. 2019. "The Effects of Non-tariff Measures on Agri-Food Trade: A Review and Meta-Analysis of Empirical Evidence." *Journal of Agricultural Economics* 70(3): 595–617.

Sexton, Richard. 2013. "Market Power, Misconceptions, and Modern Agricultural Markets." *American Journal of Agricultural Economics* 95(2): 209–19.

Sheldon, Ian M. 2012. "North-South Trade and Standards: What Can General Equilibrium Analysis Tell Us?" *World Trade Review* 11(3): 376–89.
Sheldon, Ian M. 2017. "Certification Mechanisms for Credence Attributes of Foods: Does it Matter Who Provides Diagnosis?" *Annual Review of Resource Economics* 9: 33–51.
Sheldon, Ian M., and Brian Roe. 2009. "Public *Vs.* Private Eco-Labeling of Environmental Credence Goods: Maximizing the Gains from International Integration." *Journal of Agricultural and Food Industrial Organization* 7(2): 1–29.
Soregaroli, Claudio, Elena C. Ricci, Stefanella Stranieri, Rodolfo M. Nagya, Ettore Capri, and Elena Castellari. 2021. "Carbon Footprint Information, Prices, and Restaurant Wine Choices by Customers: A Natural Field Experiment." *Ecological Economics* 186: 1–13.
Sotelo, Sebastian. 2020. "Domestic Trade Frictions and Agriculture." *Journal of Political Economy* 128(7): 2690–738.
Steffen, Will, Katherine Richardson, Johan Rockström, Sarah E. Cornell, Ingo Fetzer, Elena M. Bennett, Reinette Biggs, et al. 2015. "Planetary Boundaries: Guiding Human Development on a Changing Planet." *Science* 347: 1259855.
Swinnen, Johan. 2016. "Economics and Politics of Food Standards, Trade and Development." *Agricultural Economics* 47(S1): 7–19.
Swinnen, Johan. 2017. "Some Dynamic Aspects of Food Standards." *American Journal of Agricultural Economics* 99(2): 321–38.
Tombe, Trevor. 2015. "The Missing Food Problem: Trade, Agriculture, and International Productivity Differences." *American Economic Journal: Macroeconomics* 7(3): 226–58.
Vanek, Jaroslav. 1968. "The Factor Proportions Theory: The n-Factor Case." *Kyklos* 21(4): 749–56.
Vernon, Raymond. 1966. "International Investment and International Trade in the Product Cycle." *Quarterly Journal of Economics* 80(2): 190–207.
Vörösmarty, Charles J., Peter B. McIntyre, Mark O. Gessner, David Dudgeon, Alexander Prusevich, Pamela Green, Stanley Glidden, et al. 2010. "Global Threats to Human Water Security and River Biodiversity." *Nature* 467: 555–61.
Wada, Yoshihide, Ludovicus P. H. van Beek, Frederiek C. Sperna, Benjamin F. Weiland, Yun-Hao Wu Chao, and Marc F. P. Bierkens. 2012. "Past and Future Contribution of Global Groundwater Depletion to Sea-Level Rise." *Geophysical Research Letters* 39(9): L09402.
Wada, Yoshihide, Ludovicus P. H. van Beek, Cheryl M. van Kempen, Josef W. T. M. Reckman, Slavek Vasak, and Marc F. P. Bierkens. 2010. "Global Depletion of Groundwater Resources." *Geophysical Research Letters* 37(20): L20402.
Weinzettel, Jan, and Stephan Pfister. 2019. "International Trade of Global Scarce Water Use in Agriculture: Modeling on Watershed Level with Monthly Resolution." *Ecological Economics* 159(5): 301–11.
World Trade Organization (WTO). 1995. *Agreement on Technical Barriers to Trade*. Geneva: WTO.

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: Heerman, Kari E. R., and Ian M. Sheldon. 2022. "Sustainable Agricultural Production, Income, and eco-Labeling: What Can Be Learned From a Modern Ricardian Approach?" *Applied Economic Perspectives and Policy* 1–23. https://doi.org/10.1002/aepp.13279