Theoretical and Empirical Developments, and Future Issues in Agricultural Trade

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Agricultural trade has been steadily increasing since the 1960s. Consequently, agricultural trade has become an important field in agricultural economics since the 1970s. This special issue article presents an overview of key trade theories, empirical trade models, the current status of multilateral trade negotiations, major disputes, and key forces that can shape future commodity trade. Agriculture was brought into global trade negotiations under the Uruguay Round; however, the Doha Round negotiations are beset with disagreements among WTO member countries. Further, with Trump's unilateral tariff policies, global trade negotiations are under siege, disrupting trade and potentially slowing economic growth worldwide.

Key words: agricultural trade, theory, empirical model, trade war

Introduction

World trade in agricultural commodities has been increasing steadily since 1967 (Figure 1). Agricultural exports rose from $6.4 billion in 1967 to $175.9 billion in 2024, and agricultural imports expanded from $4.2 billion in 1967 to $214.1 billion in 2024. These increases are attributed to globalization, liberalization of agricultural trade, greater demand for farm products due to population growth and economic growth across the globe, and increased supply of agricultural products due to new and improved varieties, technologies, and cultivation practices. Consequently, though agricultural trade was not a major field of study in agricultural economics in the 1960s, it became an important area starting in the 1970s, and most of agricultural economics departments in the United States currently employ at least one faculty member specializing in agricultural trade.

This article provides smorgasbord coverage of developments in trade theories, empirical trade models, the status of agricultural trade liberalization, various major trade disputes and trade wars, and forces influencing future global agricultural trade.

Trade Theories

Countries engage in trade because of price differences across borders. Importing countries with higher prices tend to import from exporting countries with lower prices. Prices differ across countries because of the supply and demand differences. An importing country's demand generally exceeds its supply, and an exporting country's supply generally exceeds its demand. Supply differences arise
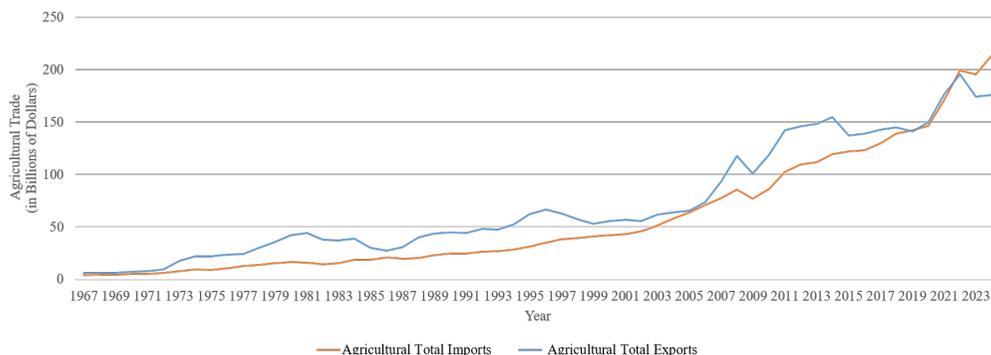
Figure 1. World Agricultural Exports and Imports

due to technology and endowment differences. Demand differences arise due to differences in tastes and preferences, population size, and per capita income.

Markusen et al. (1995) posit the following conditions for no trade: (i) all countries have identical production functions, (ii) all countries have the same relative endowments, (iii) production functions exhibit constant returns to scale, (iv) markets operate under perfect competition, (v) all countries have identical and homogeneous taste, and (vi) no countries have domestic and/or trade distortions. Violations of conditions (i) and (ii) lead, respectively, to Ricardian theory and Heckscher–Ohlin theory. Relaxation of conditions (iii) and (iv) provides impetus for New Trade theory. Differences in tastes, preferences, and consumption patterns can also lead to trade (as put forth by the Linder Hypotheses, Linder, 1961, also see Markusen, 1986). Finally, domestic and trade policy interventions can also cause trade (Bhagwati, 1969). In the interest of brevity, I focus on four standard trade theories that are widely considered in the trade literature: the Ricardian theory of comparative advantage, the Heckscher–Ohlin theory, new trade theory, and firm-level trade theory.[1] Since Devadoss and Luckstead (2018a) present a detailed summary of these theories, below I briefly explain these theories and their applications to agricultural trade.

The Ricardian Theory of Comparative Advantage

The 19th-century British economist David Ricardo developed the theory of comparative advantage, which posits that a country will export goods in which it has a comparative advantage. This theory was later refined by 20th-century economist Gottfried Haberler, who incorporated opportunity cost to clarify the law of comparative advantage. Specifically, differences in relative productivity among commodities are a key determinant of countries' trade patterns.

The original Ricardian theory used two countries, two commodities, and one input, which was later extended to many countries, many goods, and many inputs. A pioneering article by Dornbusch, Fischer, and Samuelson (1977) modified the basic Ricardian model to include a continuum of goods with two countries and one input, thus relaxing the two-good Ricardian model. Since this article, numerous studies have incorporated a continuum of goods in their models to analyze various aspects of trade theory and policies. A seminal paper by Eaton and Kortum (2002) further extended the Ricardian model to study productivity differences across sectors in many countries to develop a gravity equation from the supply side.

Trade economists have developed a formula to quantify the comparative advantage. The most common and widely used index for measuring comparative advantage is Balassa's (1965) Revealed

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[1] Readers interested in related trade theories are referred to Bernard, J. Bradford Jensen, and Schott (2007).

Comparative Advantage (RCA) index:

$$(1) \qquad \mathrm{RCA}_{i,t}^k = \frac{E_{i,t}^k / E_{i,t}}{E_t^k / E_t},$$

where $E_{i,t}^k$ is the value of country i's exports of commodity k in year t, $E_{i,t}$ is the value of country i's total exports of all commodities, E_t^k is the value of total world exports of commodity k, and E_t is the value of total world exports of all commodities. Thus, RCA computes a commodity's share of a country's total exports relative to the commodity's share of total world exports. $\mathrm{RCA}_{i,t}^k$ greater than one indicates that country i exports more of commodity k because the ratio $E_{i,t}^k / E_{i,t}$ is greater than commodity k's share of total world exports E_t^k / E_t. Larger values of RCA imply country i possesses a comparative/competitive advantage in exports of commodity k. As observed by French (2017), RCA is generally used to infer a country's comparative advantage in a commodity. RCA can give a broad overview and preliminary assessment of a country's export capabilities. Although it is difficult to detect productivity differences directly, the RCA measure may be used to infer these disparities using trade data. Gnidchenko and Salnikov (2021) found in a review of 131 studies conducted between 2013 and 2019 that Balassa's RCA index is the most common method used for analyzing the competitiveness of particular products and sectors.

However, Boffa, Bolatto, and Zanetti (2010) observed that the Balassa index focuses only on exports and does not consider imports and other policy-induced effects arising from trade barriers and domestic policies. In addition, the Balassa index cannot assess a country's export competitiveness of a particular product to a specific region or country. Lafay (1992) developed the Lafay Index (LFI) to emphasize bilateral trade links by computing the normalized trade balance of specific goods relative to the total normalized trade balance (Amable, 2000; Zaghini, 2003; Caselli and Zaghini, 2005). Thus, the LFI measures the comparative advantage of a country in a particular product vis-a-vis an individual nation or groups of nations. The LFI is

$$(2) \qquad LFI_{ij}^k = 100 \left[\frac{X_{ij}^k - M_{ij}^k}{X_{ij}^k + M_{ij}^k} - \frac{\sum_{k=1}^K \left(X_{ij}^k - M_{ij}^k \right)}{\sum_{k=1}^K \left(X_{ij}^k + M_{ij}^k \right)} \right] \frac{X_{ij}^k + M_{ij}^k}{\sum_{k=1}^K \left(X_{ij}^k + M_{ij}^k \right)},$$

where X_{ij}^k is the export of commodity k from country i to country j, M_{ij}^k is the import of commodity k by country i from country j, and K is the number of commodities. The LFI equation consists of three components: LFI_1, LFI_2, LFI_3.

$$(3) \qquad LFI_1 = \frac{X_{ij}^k - M_{ij}^k}{X_{ij}^k + M_{ij}^k}$$

measures the net export ratio of country i in commodity k to its partner country j, which captures how much country i exports the commodity k relative to how much it imports from country j.

$$(4) \qquad LFI_2 = \frac{\sum_{k=1}^K \left(X_{ij}^k - M_{ij}^k \right)}{\sum_{k=1}^K \left(X_{ij}^k + M_{ij}^k \right)}$$

measures the ratio of total net exports to total trade between countries i and j. Finally,

$$(5) \qquad LFI_3 = \frac{X_{ij}^k + M_{ij}^k}{\sum_{k=1}^K \left(X_{ij}^k + M_{ij}^k \right)}$$

measures commodity k's share in the total trade of country i, which represents the significance of commodity k in country i's total trade. A greater positive value of the LFI signifies a greater level

of competitiveness in commodity k. Conversely, negative values of the LFI represent a lack of specialization, indicating a competitive disadvantage (Zaghini, 2005). The advantage of the LFI is that it incorporates the trade competitiveness (TC) index,

$$(6) \qquad TC_{ij} = \frac{\left(X_{ij} - M_{ij}\right)}{\left(X_{ij} + M_{ij}\right)},$$

a method to measure the level of the export competitiveness of particular products.

Reimer and Li (2010) use the Ricardian framework of technology-based productivity differences and yield variability to study the pattern of trade in cereal grains and oilseeds for 21 countries. Heerman, Arita, and Gopinath (2015) utilize Eaton and Kortum's (2002) gravity framework to study comparative advantage from agro-ecological characteristics in determining bilateral trade. Costinot, Donaldson, and Smith (2016) apply the comparative advantage framework by utilizing crop-specific micro-level productivity data for 10 crops and 1.7 million fields in the world to study the effects of climate change on trade. Devadoss, Ugwuanyi, and Ridley (2022) find that cross-country productivity differences, which are influenced by institutional factors and gravity variables, determine bilateral trade (also see Ridley and Devadoss, 2023).

The Heckscher–Ohlin Theory

The Ricardian theory postulates that relative productivity differences are the basis for comparative advantage. By contrast, the Heckscher–Ohlin (H–O) theory illustrates that differences in factor endowments and the resulting relative cost differences across countries are the source of comparative advantage. This theory states that a country will export a commodity that uses its relatively abundant factor intensively. The H–O theory is also known as the factor proportion theorem or Heckscher–Ohlin–Samuelson theorem because of Samuelson's extensive contribution to this theory. Since the original H–O theory is based on two factors, two commodities, and two countries, this theory is also known as the $2 \times 2 \times 2$ model. For graphical and mathematical analyses of this theorem, see Bowen, Hollander, and Viaene (1998).

The insight of the H–O theory was that factor prices and commodity prices would be affected by differences in the availability of factors of production. Specifically, a relatively large supply of a particular factor of production will have a relatively low price, and goods that use this relatively low-priced factor intensively in their production will have low prices as well. Thus, a nation will have a comparative advantage in the goods and services which use the nation's abundant factor of production intensively. A by-product of the H–O theorem is the Stolper–Samuelson theorem, which states that a rise in the price of a commodity increases the nominal, relative, and real earnings of the factor that is used intensively in the production of that commodity but decreases the nominal, relative, and real earnings of the other factor.

Dornbusch, Fischer, and Samuelson (1980) extended the H–O model to include a continuum of goods with two factors and two countries. However, the complexity of this extension to a continuum of goods made the model more complex; consequently, this model was not as widely followed as Dornbusch, Fischer, and Samuelson (1977). The basic $2 \times 2 \times 2$ model is extended to a multi-factor, multi-commodity, and multi-country framework, which is known as Heckscher–Ohlin–Vanek.

A few studies have applied H–O theory to agricultural trade. Arnade (1994) concludes that relative factor endowment differences explain agricultural exports in Latin American countries. Clements (1987) confirms the validity of the H–O theorem by observing that labor-abundant Brazil exports labor-intensive agricultural products. Gopinath and Kennedy (2000) show evidence that factor endowments are key determinants of US state-level agricultural exports. Along this vein, Li (2012) applies the H–O theorem and demonstrates that factor intensities play a key role in determining Chinese regional agricultural exports. Reimer (2012) employs a two-input model (i.e., capital and water) to show that countries with abundant water resources will export agricultural

commodities that use water intensively. Devadoss, Ugwuanyi, and Ridley (2022) find evidence for the H–O theorem that land-abundant countries export more land-intensive goods.

New Trade Theory

The Ricardian and H–O theories determine trade patterns on the basis of comparative advantage due to technology and endowment differences, respectively. However, developed countries with fairly comparable technologies and endowments trade a large number of commodities. In addition, Ricardian and H–O theories treat commodities as homogeneous; however, developed countries engage in large volumes of trade covering differentiated goods and intra-industry trade. Economists realized these developments in the late 1960s and early 1970s and began to work on new trade theories. Grubel and Lloyd (1975) comprehensively examined intra-industry trade. Relaxation of the third and fourth conditions of trade (i.e., constant returns to scale production functions and perfect competition) can lead to trade.

Since the 1970s, a large number of studies under the umbrella of new trade theory have examined these trade patterns. Since imperfect competition covers monopoly, oligopoly, and monopolistic competition, there is no single unified trade theory proposition under new trade theory; rather, a large array of literature covered potential trade arising from different market structures in both partial and general equilibrium frameworks. Furthermore, the impacts of trade policies under new trade theory are explored under the topic of strategic trade theory. A good starting point for beginners to learn new trade theory is chapters 11, 12, 17, and 22 in Markusen et al. (1995). With this background, researchers can read graduate-level textbooks (e.g., Bowen, Hollander, and Viaene, 1998; Feenstra, 2015) and journal articles in trade theory to undertake research in this area. Also see Devadoss and Luckstead (2018a) for a synthesis of new trade theories and their applications to agricultural trade.

Though numerous general economics studies applying new trade theory have proliferated since the late 1970s, only a few studies in agricultural economics have utilized new trade theory. Sexton et al. (2007) find that any benefits from government liberalization are absorbed by intermediary firms who have the market power along the supply chain. Studies in apple export competition by Luckstead, Devadoss, and Mittelhammer (2014), the US–Chinese apple juice market by Luckstead, Devadoss, and Dhamodharan (2015), US–Brazil–EU orange juice trade by Luckstead, Devadoss, and Mittelhammer (2015), and the orange juice market by Dhamodharan, Devadoss, and Luckstead (2016) have utilized strategic trade policies to analyze the impact of trade barriers under imperfect competition models. A pair of studies by Sabala and Devadoss (2021a) for the sorghum market and Sunil and Devadoss (2025) for the cardamom market utilize the spatial equilibrium model with duopoly imperfect competition.

Firm-Level Trade Theory

It is firms, not countries, that trade. Recognizing this fact, firm-level trade theory emphasizes the productivity differences across firms and their implications for trade. For instance, exporting firms are generally larger, more productive, more skilled, and capital-intensive. Melitz (2003) combines Krugman's (1980) monopolistic competition model and Hopenhayn's (1992) firm-level heterogeneity with endogenous entry and operating decision model to study the firm-level trade. Several of Melitz's (2003) key findings are that exporting firms are more productive to survive international competition, firms with large fixed costs compete effectively in the overseas market, and resource reallocation from low productivity firms to high productivity firms generate additional gains from trade. Since Melitz (2003), many studies examining firm-level trade theory have proliferated. Melitz and Ottaviano (2008) extend Melitz (2003) to model firm heterogeneity through marginal cost differences and show market size and trade impact the toughness of competition, which endogenously determines the producers and exporters. They use this model to derive the gravity equation.

In agricultural economics literature, a few studies have applied firm-level trade theory to agricultural trade. Luckstead and Devadoss (2016) apply the Melitz model to examine the effects of the then-proposed Transatlantic Trade and Investment Partnership on prices, production, bilateral trade, firm numbers, productivity, and welfare in the processed food sector. Devadoss and Luckstead (2018b) utilize firm-level trade theory to analyze the effects of the Comprehensive Economic and Trade Agreement (CETA) between Canada and the European Union on these two countries. Luckstead and Devadoss (2019) extends firm-level trade theory by incorporating domestically operating, exporting, and multinational enterprise (MNE) firms to quantify the effects of trade liberalization, fixed trade cost reduction, and foreign direct investment (FDI) cost reduction under CETA on the processed food sector. Zhao, Luckstead, and Devadoss (2022) develop a multiregion heterogeneous-firm trade model to decompose intensive and extensive margins in volumes and values of domestic sales, bilateral trade, production, and consumption. This study presents *ex ante* predictions on gains and losses at the margins arising from trade liberalization. Luckstead, Devadoss, and Zhao (2024) formulate a gravity trade model of heterogeneous firms to study the effects of firms' endogenous choice between exporting or foreign direct investment on the proportion of exporting firms and bilateral trade.

Empirical Trade Models

Models used for empirical analyses of domestic and trade policies can be broadly classified into (i) the nonspatial equilibrium model, (ii) the spatial equilibrium model, (iii) the gravity model, and (iv) the computable general equilibrium model.

Nonspatial Equilibrium Model (NSEM)

This class of models contains supply and demand functions for single or multiple commodities for n exporting countries and m importing countries. Suppose the United States is one of the exporting countries with the following supply and demand functions:

$$(7) \qquad S_U = h_U(P_U, Z_U)$$

$$(8) \qquad D_U = f_U(P_U, X_U),$$

where S_U is the supply of the United States, P_U is the price in the United States, Z_U is the vector of supply shifters, D_U is the demand by the United States, and X_U is the vector of demand shifters. Similarly, the supply and demand functions of the remaining $n - 1$ exporters are defined as

$$(9) \qquad S_i = h_i(P_i, Z_i) \quad \forall\, i = 1, \cdots n - 1$$

$$(10) \qquad D_i = f_i(P_i, X_i) \quad \forall\, i = 1, \cdots n - 1.$$

The supply and demand functions for all m importing countries are given by

$$(11) \qquad S_j = h_j(P_j, Z_j) \quad \forall\, j = 1, \cdots m$$

$$(12) \qquad D_j = f_j(P_j, X_j) \quad \forall\, j = 1, \cdots m.$$

In Figure 1, the top left panel plots the US supply and demand functions. The excess supply of the United States is

$$(13) \qquad ES_U = h_U(P_U, Z_U) - f_U(P_U, X_U).$$

The individual exporter supply function is plotted next to the US diagram titled "World Market." The supply and demand functions of the remaining $n - 1$ exporters are plotted in the bottom right
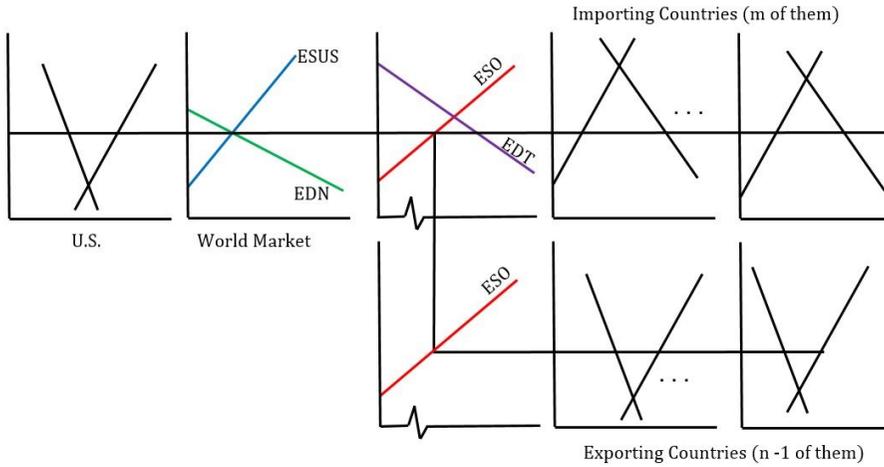
Figure 2. Graphical Analysis of Nonspatial Equilibrium Model

panels. Each of these exporter's excess supply function is

$$(14) \qquad\qquad ES_i = h_i(P_i, Z_i) - f_i(P_i, X_i),$$

which are summed to obtain the total excess supply of all other exporters,

$$(15) \qquad\qquad ES_O = \sum_{i=1}^{n-1} \left[h_i(P_i, Z_i) - f_i(P_i, X_i) \right],$$

which is plotted in the leftmost diagrams of the bottom panel and translated to the middle diagram in the top panel. The supply and demand functions of all the importers are plotted in the rightmost diagrams in the top panel. Each of these importer's excess demand functions is

$$(16) \qquad\qquad ED_j = h_j(P_j, Z_j) - f_j(P_j, X_j),$$

which are summed to obtain the total excess demand of all other importers,

$$(17) \qquad\qquad ED_T = \sum_{j=1}^{m} \left[f_j(P_j, X_j) - h_j(P_j, Z_j) \right],$$

which is plotted in the middle diagram of the top panel. The net excess demand facing the United States is

$$(18) \qquad\qquad ED_N = ED_T - ES_O,$$

which is plotted in the world market diagram. The world market equilibrium is at the intersection of ES_U and ED_N.

   The domestic supply policies enter in the supply shifters or domestic supply price and domestic demand policies enter in the demand shifters or domestic demand price. Domestic prices can be linked to the world market price. Trade policies impact the price linkages between the world price and domestic price or import quantity in the case of quantity restrictions. The model is solved simultaneously to obtain the world market equilibrium price and quantity traded. The equilibrium price can be substituted into each country's supply and demand functions to obtain their quantity supplied and demanded. This model is called the nonspatial equilibrium model because we cannot determine the bilateral trade flow from the ith exporter to jth importer. Examples of applications of NSEM include Devadoss, Helmar, and Meyers (1990) and Meyers, Devadoss, and Helmar (1991).

Spatial Equilibrium Model

The spatial equilibrium model (SEM), which was pioneered by Samuelson (1952) and popularized by Takayama and Judge (1971), maximizes an objective function subject to a set of constraints. For SEMs that incorporate *ad valorem* tariffs, the objective function is the net revenue function (also known as the social revenue or net social monetary gain function), and the constraints are (i) no excess demand, (ii) no excess supply, (iii) optimal consumption, (iv) optimal supply, and (v) location price equilibrium to obtain the global maximum and economic equilibrium (Devadoss, 2013). The objective function is

(19)
$$\mathscr{L} = \sum_{i=1}^{N} \left(\alpha_i - \beta_i Q_i^D \right) Q_i^D - \sum_{i=1}^{N} \left(\gamma_i + \delta_i Q_i^S \right) Q_i^S - \sum_{i=1}^{N} \sum_{j=1}^{N} T_{ij} X_{ij}$$
$$- \sum_{i=1}^{N} \sum_{j=1}^{N} X_{ij} \left(\rho_j^D - \rho_i^S \right) + \sum_{i=1}^{N} \sum_{j=1}^{N} X_{ij} \left(\frac{\rho_j^D}{\left(1 + \tau_{ij} \right)} - \rho_i^S \right).$$

The components of the objective function are the sum of each country's total revenue,

(20)
$$\sum_{i=1}^{N} \left(\alpha_i - \beta_i Q_i^D \right) Q_i^D ,$$

minus total cost,

(21)
$$\sum_{i=1}^{N} \left(\gamma_i + \delta_i Q_i^S \right) Q_i^S ,$$

minus total transport costs,

(22)
$$\sum_{i=1}^{N} \sum_{j=1}^{N} T_{ij} X_{ij} ,$$

minus the monetary loss arising from the price wedge created by the tariff,

(23)
$$- \left[\sum_{i=1}^{N} \sum_{j=1}^{N} X_{ij} \left(\rho_j^D - \rho_i^S \right) - \sum_{i=1}^{N} \sum_{j=1}^{N} X_{ij} \left(\frac{\rho_j^D}{\left(1 + \tau_{ij} \right)} - \rho_i^S \right) \right] .$$

This objective function is maximized subject to the constraints:

(24)
$$\text{No excess demand: } \left(\sum_{i=1}^{N} X_{ij} \geq Q_j^D \right), j = 1, \dots, N,$$

which states that the demand in region j must be met by domestic production in j and imports from all other regions i;

(25)
$$\text{No excess supply: } \left(Q_i^S \geq \sum_{j=1}^{N} X_{ij} \right), i = 1, \dots, N,$$

which entails that the supply in region i should be at least as much as domestic sales in i plus exports to all other regions j;

(26)
$$\text{Optimal consumption: } \left(\rho_i^D \geq \alpha_i - \beta_i Q_i^D \right), i = 1, \dots, N,$$

which indicates that the market demand price, ρ_i^D, must be on or above the demand curve to ensure an interior or corner solution;

(27) $\qquad\qquad\qquad$ Optimal supply: $\left(\gamma_i + \delta_i Q_i^S \geq \rho_i^S \right), i = 1, \ldots, N,$

which constrains that the market supply price, ρ_i^S, must be on or below the supply curve to ensure an interior or corner solution;

(28) $\qquad$ Location price equilibrium: $\left[\left(\rho_i^S + T_{ij} \right) * \left(1 + \tau_{ij} \right) \geq \rho_j^D \right], i, j = 1, \ldots, N,$

which states that the market supply price of region i, transport costs, and tariffs should be greater than or equal to the market demand price in region j;

(29) $\qquad\qquad$ Nonnegativity constraints: $\left(Q_i^D, Q_i^S, \rho_i^D, \rho_i^S, X_{ij} \geq 0 \right), i, j = 1, \ldots, N,$

which denotes that the endogenous variables in each region (quantity demanded, quantity supplied, market demand price, market supply price, bilateral trade flows) should be nonnegative.

The above mathematical representation is for a single commodity but can be readily expanded to accommodate multiple commodities (see Baryshpolets, Devadoss, and Sabala, 2022, for an example). SEM is widely used in several areas of economics: transportation, water allocation, commodity distributions, and trade policy analysis. Studies that used SEM for trade policy analyses include Boyd and Krutilla (1987), Devadoss and Aguiar (2006), Liu and Devadoss (2013), Ridley and Devadoss (2014), Sabala and Devadoss (2019), Devadoss and Sabala (2020), Baryshpolets and Devadoss (2021), and Sabala and Devadoss (2021b).

Gravity

The gravity model was originally proposed by Tinbergen (1962) based on Newton's Law of Universal Gravitation. Specifically, bilateral trade from country i to country j (X_{ij}) is positively related to i's value of production (Y_i) and j's value of domestic consumption (E_j) and negatively related to the value of world production (Y) and trade cost between i and j (T_{ij}):

(30) $$X_{ij} = \frac{Y_i E_j}{Y T_{ij}}.$$

The above gravity equation is atheoretical, and Anderson (1979) established a theoretical foundation for the gravity equation using a constant elasticity of substitution utility function which allows for product differentiation based on origins. A theoretical basis for the gravity equation was further developed by Eaton and Kortum (2002) from the supply side using Ricardian theory and by Anderson and Van Wincoop (2003) from the demand side using Armington–CES preferences, which has become a structural gravity model. Yotov et al. (2016) provide a lengthy and detailed discussion of the gravity model, estimation procedures with STATA code, and counterfactual simulation analysis. Here, we briefly present the basic structural gravity model and the estimable equation.

The canonical structural gravity model for several commodities is

(31) $$X_{ijt}^k = \frac{Y_{it}^k E_{jt}^k}{Y_t^k} \left(\frac{\phi_{ijt}^k}{\Pi_{it}^k P_{jt}^k} \right)^{1-\sigma^k},$$

where X_{ijt}^k is the value of exports from i to j of commodity k in year t, $Y_{it}^k = \sum_j X_{ijt}^k$ is the ith exporter's total value of production equal to the sum of exports to all countries, $E_{jt}^k = \sum_i X_{ijt}^k$ is the jth importer's total value of consumption equal to the sum of imports from all exporters, both Y_{it}^k

and E_{jt}^k contain domestic sales (X_{ijt}^k with $i = j$), $Y_t^k = \sum_i Y_{it}^k = \sum_j E_{jt}^k$ is the total world output, ϕ_{ijt}^k is the trade cost terms reflecting bilateral trade barriers, and Π_{it}^k is the inward multilateral resistance and P_{jt}^k is the outward multilateral resistance, which are defined as

$$(32) \qquad \Pi_{it}^{k\,1-\sigma^k} = \sum_j \left(\frac{\phi_{ijt}^k}{P_{jt}^k} \right)^{1-\sigma^k} \frac{E_{jt}^k}{Y_t^k} \quad \text{and} \quad P_{jt}^{k\,1-\sigma^k} = \sum_i \left(\frac{\phi_{ijt}^k}{\Pi_{it}^k} \right)^{1-\sigma^k} \frac{Y_{it}^k}{Y_t^k},$$

where Π_{it} denotes the consumption-weighted average of all bilateral trade barriers experienced by exporter i and P_{jt} represents the production-weighted averages of all bilateral trade costs imposed by importer j in the global trading system (Anderson and Van Wincoop, 2003). Changes in bilateral trade costs for a given pair i and j will generate impacts on the i to j trading relationship (through the direct impacts on ϕ_{ijt}^k) as well as all other trading relationships in the trading system (via the indirect impacts mediated by changes in P_{it}^k and Π_{jt}^k). Finally, σ^k is the commodity-specific elasticity of substitution of imports across commodities and various sources.

The trade cost ϕ_{ijt}^k term is generally expressed as an exponential function of time-varying trade policy variables and time-invariant factors:

$$(33) \qquad \phi_{ijt}^k = \exp \left\{ \log \left(1 + \tau_{ijt}^k \right) + \alpha^k WTO_{ijt} + \gamma^k PTA_{ijt} + \lambda_{ij}^k \right\}.$$

Here, τ_{ijt}^k is the *ad valorem* tariff rate imposed by importer j on commodity k from exporter i, WTO_{ijt} is a binary variable equal to 1 if i and j are WTO members in year t and 0 otherwise, PTA_{ijt} is an indicator variable equal to 1 or 0, reflecting i and j's common membership in a preferential trade agreement (PTA), λ_{ij}^k is the country-pair fixed effects to account for both observable (e.g., the geographical distance, common language, and contiguous border between i and j) and unobservable time-invariant determinants of bilateral trade costs.

Baier and Bergstrand (2007) note that λ_{ij}^k also addresses potential endogeneity/reverse causality in the τ_{ijt}^k and PTA_{ijt} variables because countries that trade with one another are more likely to maintain low tariffs or enter into a preferential trade agreement. We include WTO and preferential trade agreements (PTAs) as they may impact both bilateral trade barriers and trade volumes, and omitting them can cause biased estimates of the relationship between trade and trade barriers (Anderson, Larch, and Yotov, 2018).

Substitute the trade cost equations (33) and (32) into the gravity equation (31), and include the stochastic error term to obtain the empirical gravity equation:

$$(34) \qquad X_{ijt}^k = \exp \left\{ \beta_{0,t}^k + \beta_1^k \log \left(1 + \tau_{ijt}^k \right) + \beta_2^k WTO_{ijt} + \beta_3^k PTA_{ijt} + \gamma_{it}^k + \delta_{jt}^k + \eta_{ij}^k \right\} + \epsilon_{ijt}^k,$$

where $\beta_{0,t}^k = -\log(Y_t^k)$ is an intercept term equal to world output Y_t^k; $\beta_1^k = (1 - \sigma^k)$, $\beta_2^k = (1 - \sigma^k)\alpha^k$, and $\beta_3^k = (1 - \sigma^k)\gamma^k$ are coefficients; $\gamma_{it}^k = \log(Y_{it}^k) - (1 - \sigma^k)\log(\Pi_{it}^k)$ and $\delta_{jt}^k = \log(E_{jt}^k) - (1 - \sigma^k)\log(P_{jt}^k)$ are fixed effects that capture the Y_{it}^k, E_{jt}^k, Π_{it}^k, and P_{jt}^k terms; $\eta_{ij}^k = (1 - \sigma^k)\lambda_{ij}^k$ is a country-pair fixed effect; and ϵ_{ijt}^k is a mean-zero error. Santos Silva and Tenreyro (2006) have shown that log-linearized versions of equation (34) estimated using ordinary least squares (OLS) produce inconsistent parameter estimates under heteroskedasticity and log of trade flows on the dependent variable excludes zero-trade flows, creating another source of potential bias. Consequently, Santos Silva and Tenreyro (2006) propose estimating equation (34) using Poisson pseudo-maximum likelihood (PPML) estimation, which has become standard in estimating the gravity equation.

Once the gravity equation is estimated, it can be used for policy analyses such as tariff reductions (Ridley, Luckstead, and Devadoss, 2022) and the impact of NTMs (Ridley, Luckstead, and Devadoss, 2024). These policy analyses are conducted using baseline estimation of status quo policies and a counterfactual estimation of policy changes, and comparing the results of the

counterfactuals to the baseline. For more details on the theoretical background of these policy analyses, see Yotov et al. (2016), and for applications in agricultural trade see Dhoubhadel, Ridley, and Devadoss (2023), Ridley, Akhundjanov, and Devadoss (2023), Luckstead, Devadoss, and Zhao (2024), Choi et al. (2025), and Devadoss and Luckstead (2025).

Computable General Equilibrium (CGE) Models

To my knowledge, three different types of general equilibrium models are used for global trade analysis: the CGE model developed by Lofgren, Harris, and Robinson (2002),[2] the MPSGE (Mathematical Programming System for General Equilibrium Analysis) model developed by Rutherford (1998), and the GTAP (Global Trade Analysis Project) model developed by Hertel (1997). These general equilibrium models are solved numerically, rather than algebraically, and that is why they are called computable general equilibrium models. These models optimize the behavior of agents (i.e., consumers' utility maximization and producers' profit maximization or cost minimization) in the economy. Consumers own the factors that are utilized by firms in the production, and the firms make factor payments to the households. All production factors are assumed to be fully employed. Factors such as capital and labor are perfectly mobile across sectors within a region, which implies returns to each of these factors will be equalized across all sectors. Fixed inputs such as land and natural resources are imperfectly mobile, and returns to these factors differ across sectors. Consumers' expenditures on goods are received as payments by firms. Most CGE models do not incorporate government; consequently, households receive the tariff and tax revenues and incur public expenditures. Tax flows are reflected in the interaction between the regional household expenditures and producers. Welfare indicators are computed from the regional household's utility function.

The GTAP model accounts for the consumption and production of all commodities in each national economy included in the model (Hertel, 1997; Corong et al., 2017). This model utilizes the GTAP Database, a comprehensive database containing extensive information on bilateral trade, production, consumption, and policies (bilateral applied tariffs, agricultural export subsidies, and domestic support). The most recent GTAP Database distinguishes 141 countries and 19 aggregate regions (Aguiar et al., 2019). For each country, 65 commodities/sectors are covered (12 agricultural, 8 food, 25 manufacturing, and 20 service sectors). The GTAP model includes eight factors with five labor categories, capital, land, and natural resources.

The advantages of these CGE models over the partial equilibrium models are that they analyze the impacts of domestic economic and trade policies on the various sectors of the economy, rather than on a particular sector or sectors, by capturing the interactions among many sectors and with their factor markets. The effects of these policies can have ripple effects throughout the global economy. Therefore, these models are very useful for analyzing policies such as mass deportations (Aguiar and Devadoss, 2025; Thierfelder, Robinson, and Hinojosa, 2025), disease outbreaks (Devadoss et al., 2006), large-scale trade wars (Li, Balistreri, and Zhang, 2020), agricultural domestic and trade policies (Holtman, Aguiar, and Devadoss, 2022), shocks to oil markets (Beckman, Hertel, and Tyner, 2011), and biofuel production (Devadoss and Bayham, 2010) that generate economy-wide impacts.

In all the above models, trade occurs based on the underlying principles of various trade theories that countries with low autarky prices export and countries with high autarky prices import.

Armington (1969) proposed that commodities be differentiated depending on the country of origin, and this product differentiation is incorporated in various trade models, including spatial equilibrium, gravity, and computable general equilibrium. Thus, the Armington model is not a trade model *per se*, but its basic elements are widely embedded in various trade models.

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[2] See Hosoe, Gasawa, and Hashimoto (2010) for similar CGE model structure

Trade Negotiations and Disputes

Agriculture trade has always faced numerous policy interventions by many countries. Since the first seven rounds of trade agreements under the General Agreement on the Tariffs and Trade (GATT) mainly focused on liberalizing trade in manufacturing goods but not in agricultural and food products, agrifood trade barriers were not governed by the GATT. The Uruguay Round, which is the eighth round of GATT and took effect in 1995, brought, after prolonged and contentious negotiations, agriculture into multilateral trade agreements with the goal of moving towards liberalizing agricultural trade restrictions and domestic supports. Under this agreement, agricultural tariffs were cut by a minimum of 10% over a 6-year period for developed countries and over a 10-year period for developing countries and by an average of 36% for all commodities for developed countries and 24% for developing countries. This agreement required countries not to provide new export subsidies and also to reduce the quantity of products with export subsidies by 21% and the total value of export subsidies by 36%. This agreement also reduced the aggregate measurement of support by 20% over a 6-year period for developed countries and 13% over a 10-year period for developing countries. The implementation phase of the Uruguay Round ended by 2005.

With the completion of the Uruguay Round, the World Trade Organization (WTO) was established on January 1, 1995, as a successor to the General Agreements on Tariffs and Trade (GATT). Under the auspices of the WTO, the next round of multilateral negotiation began in 1999 in Seattle; however, the start of the negotiations was scuttled because of developing countries' strong view that trade negotiations tend to favor developed countries (Devadoss, 2006). Despite the negotiations being a nonstarter in Seattle, the next round was launched in Doha, Qatar, in November 2001. Further multilateral negotiations under the Doha Round did not produce any successful agreements, as stalemates among member countries persisted, with no clear path forward. In view of this gridlock, many countries negotiated preferential trade agreements; as of May 2025, 375 regional trade agreements are in effect (WTO, 2025b).

Some of the major trade disputes in which the United States was involved and that were litigated by the WTO were EU sanitary and phytosanitary (SPS) and technical barriers to trade (TBT) restrictions against US Meat products treated with hormones; European Union's importation, distribution, and sale of bananas; Japanese sanitary and phytosanitary (SPS) measures against imports of US apples; United States subsidies on upland cotton; Mexico–US sugar disputes; US–Canadian lumber disputes; and collateral damages of Airbus–Boeing trade battle on agricultural products. For the details of these and other disputes, see Devadoss (2022) and Schmitz and Sheldon (2018).

With the implementation of the Uruguay Round, numerous domestic and trade interventions undertaken by WTO member countries were brought to the WTO Dispute Settlement Body for litigation. These litigations covered four areas of agricultural disputes: (i) the Agreement on Agriculture, (ii) WTO members' adherence to meet commitments on domestic support, market access, and export subsidies, (iii) sanitary and phytosanitary (SPS) measures, and (iv) issues related to least-developed and net food-importing developing countries (WTO, 2025a). As of June 2025, the WTO Settlement Body had dealt with 639 disputes, of which about 350 rulings had been issued. These dispute cases come under the categories of antidumping, subsidies and countervailing duties, agriculture, safeguards, sanitary and phytosanitary standards, import licensing, technical barriers, etc.

However, the dispute settlement process experienced a significant interruption as the first and, more importantly, second Trump adminsitrations caused disarray in world trade order (more about this in the next section). The WTO dispute settlement process has not been functioning efficiently because the United States has blocked appointments to the appellate body (Hult, 2025). Arguably, the large-scale trade-disruptive forces that occurred under the first Trump administration are the US–China Trade War that began in 2018 (see Ridley and Devadoss, 2023, for a summary of this

dispute).[3] In July 2018, the Trump administration imposed a 25% tariff on 818 Chinese goods; in a tit-for-tat trade war, China retaliated with a 25% tariff on 545 major US products, including numerous agricultural products (e.g., soybeans, pork, fruits and nuts, and cereal crops). This set of tariffs by both countries is generally known as the List 1 tariffs. Following this first set of tariff retaliations, several rounds of tit-for-tat tariff shots were fired by both countries, with List 2 tariffs following in August 2018 and List 3 tariffs in September 2018. These tariffs further expanded the coverage of commodities with additional US tariffs on several hundred Chinese goods and retaliation by China with duties of 5%–25% on numerous US goods. In early 2020, to halt the escalating trade war, the United States and China signed the Phase One agreement. Under this agreement, China was to purchase $200 billion worth of US exports, including $36.6 billion worth of US agricultural commodities. However, Chinese purchases fell short of the agreement, and many of the tariffs imposed under the first Trump administration remained in place under the Biden administration (Ridley and Devadoss, 2025). The second Trump administration further intensified a tariff war with numerous countries as it imposed or threatened to impose large tariffs, some exceeding prohibitive tariffs. Given the lack of progress in Doha Round negotiations and Trump's unilateral pursuit of tariff policies, the role of the WTO and its dispute settlement body is unclear (Hult, 2025).

Major Forces Impacting Trade

Several factors can influence trade, including domestic policies, trade policies, economic reforms, economic growth, and climate change. In the interest of space, here we focus on two key factors: trade policies and climate change.

Trade Wars

As indicated previously, the agricultural sector was not a part of free trade agreements until the Uruguay Round. Even in the Uruguay Round, agricultural trade liberalization was very minimal. Furthermore, agricultural trade was beset with numerous trade disputes, and the WTO Dispute Settlement Body has been preoccupied with resolving these cases since 1995 (WTO, 2025b). However, the US–China Trade War under the first Trump administration disrupted the dispute settlement body's process. Further, the proposed tariff escalation with nearly all countries across the globe by Trump's April 2, 2025, "Liberation Day" tariff further intensified world trade disruptions.

These tariffs violate the Most Favored Nation principle, which calls for all WTO member countries to give the same preferences. One of the justifications for these tariff threats is that the United States faced a high trade deficit with most trade partners. The Trump administration had hoped that these tariff declarations would lead to favorable trade negotiations. Since the announcement of the Liberation Day tariffs, several tariff changes and pauses have been issued, causing more uncertainty for businesses. (Bown, 2025, chronologically documents in a lengthy table of tariff announcements, pauses, rollbacks, backtracking, restructuring, reimpositions, and agreements.). However, the largest retaliatory tariff proposals were against China. Specifically, the United States threatened to impose a 145% tariff on Chinese goods, and China retaliated with a proposal of a 125% tariff (The Week, 2025). Later, both countries agreed to a mutual 115% reduction in tariffs, resulting in a US tariff of 30% on Chinese goods and a Chinese tariff of 10% on US goods. As of August 1, 2025, the United States had agreed to trade deals with eight countries (the European Union, Indonesia, Japan, Pakistan, the Philippines, South Korea, the United Kingdom, and Vietnam), and negotiations—particularly with other major trading partners such as China, Canada, Mexico, and India—are on-going.

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[3] Marchant and Wang (2018) spearheaded a series of articles in *Choices Magazine* examining the US–China Trade War. Several studies examine the impacts of tariff retaliations of this trade war on specific commodities, including soybean (Sabala and Devadoss, 2019), soybean complex (Baryshpolets, Devadoss, and Sabala, 2022), cotton (Sabala and Devadoss, 2021b), and sorghum (Sabala and Devadoss, 2021a).

The key distinguishing feature of the Trump administration's tariff policy is that, being unilateral, it deviates from the multilateral negotiations usually carried out by the WTO. If such unilateral policies and potential trade agreements enable greater trade between the United States and member countries, it does have implications for other bilateral trade links. Some countries have to alter their trade pattern, (i.e., they may import more products at higher cost from the United States instead of importing products at lower cost from other countries, creating inefficiencies). Such trade reallocations and disruptions are the results of current Trump policies. Furthermore, these tariff wars can move countries toward greater protectionism.

Climate Change

Climate change has been a major force in determining trade by altering comparative advantage across countries, and changes in trade patterns seem to mitigate the adverse effects of climate change. Reilly and Hohmann (1993) is one of the earliest studies to examine the impacts of climate change on agricultural trade. Their key conclusions are that interregional adjustments in production and consumption will help to lessen the adverse effects of climate change, and developing countries may experience a greater disadvantage. Jones and Olken (2010) observed that high temperatures reduce the exports of poor countries between 2% and 5.7% but have no impact on rich countries' exports. Moreover, the agricultural and light manufacturing sectors' exports are more susceptible to high temperatures (also see Osberghaus, 2019). Oh and Reuveny (2010) concluded that political risk intensifies the adverse effect of climate change on trade. Gassebner, Keck, and Teh (2010) estimated that natural disasters (e.g., hurricanes, floods, droughts) reduce exports and imports, but less democratic and smaller countries incur greater losses. Huang, von Lampe, and van Tongeren (2011) concluded that climate change will bring considerable uncertainty in agricultural production, particularly in areas prone to extreme weather, but a well-functioning trading system can buffer the adverse climate shocks (also see Dall'Erba, Chen, and Nava, 2021). Li, Xiang, and Gu (2015) found that climate variability in China curtailed exports but had no significant impact on imports. Gouel and Laborde (2018) found that climate change lowers yield in most parts of the world, except in a few higher-latitude countries, which alters the trade pattern and helps mitigate the adverse effects of climate change. Barua and Valenzuela (2018) utilized data on temperature and precipitation, national income, comparative advantage in land, technology and productivity, climatic zone differences, estimates of agricultural nominal rates of assistance, and trade membership for 67 countries from 1962 to 2014 to study the effects of climate change on agricultural trade. They found that higher temperatures lower exports from tropical and developing regions (Asia and Africa) but augment exports from temperate regions (Australia and New Zealand). Exports of commodities such as grains, oil seeds, and livestock and dairy products are more prone to temperature shocks (also see Dallmann, 2019). Magalhães Vital et al. (2022) conducted a meta-analysis of studies in this area and found that high temperatures in exporting countries negatively affect agricultural trade, and the effects of precipitation on agricultural trade vary greatly.

Conclusions

This special issue article on agricultural trade presents an overview of key trade theories that are widely used in trade textbooks, empirical trade models that are frequently employed for policy analysis, the current status of multilateral trade negotiations, major agricultural trade disputes, Trump's trade policies, and important forces that will shape the future global agricultural trade. Given the space limitation, this article summarizes these key areas and directs interested readers to specific studies for more in-depth literature.

International trade is entering a new era where global trade agreements seem to be impossible to achieve, given the failure of the Doha Negotiations and many countries' pursuit of regional trade agreements. Further, Trump's unilateral approach to setting tariffs and bilateral agreements

between the United States and various countries establishes a wrong precedent for future global trade negotiations. Finally, constant changes in these policies cause discord in the world trade order by creating unpredictability and uncertainty, which disrupts investment, production, purchase, and sales decisions by businesses. Such disruptions could lead to economic inefficiencies and slower growth in many parts of the world.

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