Journal of Agricultural and Resource Economics 47(3):598–615 ISSN: 1068-5502 (Print); 2327-8285 (Online)

doi: 10.22004/ag.econ.313317

Determinants of Global Agricultural Trade

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While comparative advantage factors expand agricultural trade, trade and domestic policies and gravity factors can either promote or hinder commodity trade. We use a theoretical multicountry trade model to analyze how various factors impact agricultural trade. Following previous literature, we model cross-country productivity differences using a probabilistic distribution. We then empirically implement the theoretical model to quantify the effects of various determinants of agricultural trade. Production-inhibiting policies and tariffs hinder bilateral trade, while domestic institutional quality, support programs, and land endowments expand bilateral trade.

Key words: factor endowment, gravity, Ricardian, subsidies, tariffs

Introduction

Global agricultural trade is impacted by several factors: comparative advantage, trade policies, domestic farm policies, and gravity factors (Anderson et al., 2008; Reimer and Li, 2010). Comparative advantage is a key determinant of agricultural trade and stems from Ricardian technological differences and Heckscher–Ohlin (H–O) factor endowment differences. Ricardian technological differences enable a country to produce commodities at a lower opportunity cost and to have an advantage in the world market by selling at lower prices relative to competitors. Several interrelated factors such as research and development (R&D) and effective institutions (government transparency, corruption-free and bribery-free economy, political stability, and a frictionless business climate; see Levchenko, 2007; Nunn, 2007) drive technological advancement and thus comparative advantage. Producers in countries with strong and effective institutions are generally more productive. Hence, such countries have a greater potential to trade because good governance (e.g., the effective enforcement of contracts) is a strong driver of frictionless bilateral trade transactions (Manova, 2012).

Factor endowments are other sources of comparative advantage. Countries with abundant factors generally have lower prices for these factors, leading to a lower cost of production for the goods that are intensive in their use, and thus enhancing the competitiveness of the exporting countries. This explains the H–O theorem that a country will export a commodity that uses its abundant factor intensively. Factors that enhance comparative advantage in agricultural commodity trade include fertile land, weather, fertilizers, machinery, and skilled farm managers.

Countries widely implement trade policies—including those that are import restricting (e.g., tariffs and quotas), import augmenting (import subsidies), export hindering (export taxes and

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The authors gratefully acknowledge the efficient review coordination of Jeff Reimer and the helpful comments received from two anonymous reviewers. This work was supported by the USDA National Institute of Food and Agriculture, Agricultural and Food Research Initiative Competitive Program, Agriculture Economics and Rural Communities, grant # 2020-67023-30962.

Review coordinated by Jeffrey J. Reimer.

quotas), and export expanding (export subsidies)—to distort agricultural trade (Schmitz, Haynes, and Schmitz, 2016). Import-restricting and export-expanding policies expand domestic production, while import-boosting and export-impeding policies curtail domestic production. Although these policies do not promote comparative advantage, they do impact competitive advantage and influence trade. For example, Reimer and Kang (2010) noted that countries erect trade barriers to mask comparative disadvantages in particular industries and in doing so gain a competitive advantage. Agricultural trade is also greatly hindered by the extensive use of nontariff barriers such as content regulations, packaging requirements, quality restrictions, and sanitary and phytosanitary conditions (Luckstead and Devadoss, 2016).

Countries extensively subsidize domestic production by providing income, output price, and input price supports. The degree of subsidization depends on the economic size of the country (Dewbre, Antón, and Thompson, 2001), with developed countries typically giving more in subsidies to their farmers than developing countries (Devadoss, 2006). Agricultural subsidies maintained by exporting countries promote production and augment exports (Tong, Pham, and Ulubaşoğlu, 2019), and domestic subsidies maintained by importing countries lower imports. Consequently, poor countries lose the most from the trade-distorting domestic policies of rich countries. With a high level of subsidy, a country that was initially an importer of a given agricultural commodity could become an exporter of that commodity. This trade reversal, accompanied by export subsidies, lowers the world market price and harms the original exporters (Houck, 1992). Consequently, these policies benefit the subsidized farmers in the newly exporting countries at the expense of farmers in the original exporting country.

Furthermore, agricultural policies cause misallocation of resources and create inefficiencies. Two common measures to quantify domestic subsidies include producer subsidy equivalents (PSEs) and nominal rate of assistance (NRA). PSEs measure the effects of a country's policies on total farm income, or the lump sum transfers that a country would have to provide farmers to maintain their income at a level if policies are terminated (Reed, 2006). The NRA is defined as the ratio of the net value of a unit of production (value at distorted price minus value at undistorted price) to the unit value of production at the undistorted price (Anderson et al., 2008). Thus, the NRA measures the degree of intervention in agriculture in all major developing and developed countries.

In addition to comparative advantage factors and policies, gravity forces are also significant determinants of trade. Major gravity forces capture both bilateral and multilateral barriers to trade as well as factors relating to market size. Countries with closer proximity to one another and contiguous borders tend to trade more because of lower transport costs. Market sizes are naturally major determinants of trade: Countries with larger markets (typically proxied for in the literature by variables such as gross domestic product [GDP]) generally maintain higher levels of productivity and possess greater potential to export commodities (Ahmad and Harnhirun, 1996; Zestos and Tao, 2002). The economic size of an importing country also plays an important role: A large country possesses a large market and thus imports more. Other bilateral factors, such as shared preferential trade agreement (PTA) membership and common language, augment trade among countries by reducing bilateral trade costs.

The objectives of this study are to (i) develop a theoretical model that extends the analytical frameworks of trade and comparative advantage from Eaton and Kortum (2002) and Chor (2010) to comprehensively capture the effects of Ricardian technological differences, institutional factors, H–O endowment differences, trade policies, domestic farm policies, and gravitational forces on agricultural trade; (ii) empirically quantify the effects of all these factors on agricultural trade; and (iii) draw policy implications to expand global trade in agricultural commodities. To our knowledge, this study is the first to comprehensively and simultaneously study the effects of each of these relevant factors in agricultural trade.

Model and Analysis

The theoretical model consists of a continuum of goods with numerous exporting and importing countries to account for extensive global trade in agricultural commodities.[1] We follow Eaton and Kortum (2002) and Chor (2010) to develop a model that incorporates the characteristics of the agricultural sector and accounts for government subsidies and trade barriers.

While our framework shares features of these two theoretical frameworks, we depart from them in several ways. Whereas these previous works focused on modeling production and trade in manufacturing, our framework is specific to the agricultural sector; thus, we address the need to incorporate production subsidies and agricultural trade policies (which are absent from Eaton and Kortum's and Chor's models) into the modeling environment given the salience of such policies in international agricultural production. Chor (2010) considers goods and varieties, but our focus is mainly on goods, not varieties, as in Eaton and Kortum (2002), due to the relative homogeneity of agricultural commodities in comparison to manufactured goods. We follow Chor in modeling productivity using the Gumbel distribution (in comparison to Eaton and Kortum, who employ the Fréchet distribution) because we want to capture how comparative advantage arises from the combination of country- and industry-specific factors, particularly country-level institutional environments and industry-level productivity.

Countries are indexed by i, $n = 1,2,\dots,N$ as we consider both exporting (i) and importing (n) countries. Below, we present the consumer's problem, producer's problem, and formulate a gravity equation for agricultural trade flows.

Consumer's Problem

Consider a representative consumer in country n with Cobb–Douglas preferences over a composite good (q_n^0) and a continuum of agricultural commodities q_n^k, $k \in [1,N]$, with share parameter $\gamma < 1$. Preferences over agricultural commodities are characterized by a constant elasticity of substitution (CES) subutility function, so that consumer preferences can be described by[2]

(1) $$\left(q_n^0\right)^{1-\gamma}\left(\int_1^N \left(q_n\left(k\right)\right)^{\frac{\sigma-1}{\sigma}} dk\right)^{\frac{\frac{\gamma}{\sigma}}{\sigma-1}},$$

where σ is the elasticity of substitution. Equation (1) is maximized subject to the budget constraint

(2) $$p_n^0\, q_n^0 + \int_1^N p_n\left(k\right) q_n\left(k\right) dk = Y_n,$$

where $p_n(k)$ is the price of agricultural commodity k in country n, and Y_n is the income of county n. This maximization yields the demand function

(3) $$q_n^k = \frac{\left(p_n^k\right)^{-\sigma}}{P^{1-\sigma}}\gamma\, Y_n \;\forall\, k,$$

where $P = [\int_1^N (p_n(k))^{1-\sigma} dk]^{\frac{1}{1-\sigma}}$ is the aggregate price index.[3]

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[1] The full derivation of the materials in the theoretical model is shown in the online supplement (see www.jareonline.org).

[2] To follow standard notation for integrals, we denote the commodity with index (k); however, we use superscript k in other equations to denote the commodity.

[3] Composite good demand is $q_n^0 = \frac{(1-\gamma)Y_n}{p_n^0}$. In the remainder of the paper, our focus will be on agricultural commodities.

Producers' Problem

Firms operate in a perfectly competitive market, and a representative firm in country i produces commodity y_i^k. The production function is

$$y_i^k = z_i^k l_i^k, \tag{4}$$

where z_i^k is the random productivity draw occurring in the production of good k in country i and l_i^k is the composite input used in the production of good k in country i. Because the production of y_i^k hinges on productivity draw z, profits also depend on z. The producer's problem is to maximize profit,

$$\pi_{in}^k = p_{in}^k S_i^k y_i^k - c_i^k l_i^k, \tag{5}$$

subject to the production constraint $y_i^k \tau_{in}^k = z_i^k l_i^k$, where p_{in}^k is the price at which country i sells commodity k to country n; $\tau_{in}^k = 1 + t_{in}$ is the (iceberg) trade cost with *ad valorem* rate t_{in} for exports from country i to country n, which covers transport and trade barriers;[4] S_i^k is the subsidy provided by the government in country i to the producers of commodity k; and c_i^k is the per unit cost of production of commodity k in country i. The subsidy $S_i^k = 1 + s_i^k$, where s_i^k is the subsidy rate, creates a wedge between the consumer price p_{in}^k and producer price $p_{in}^k S_i^k$. Profit maximization yields the pricing rule

$$p_{in}^k S_i^k = \frac{c_i^k \tau_{in}^k}{z_i^k}, \tag{6}$$

where c_i^k captures the prices of factors used in production and thus reflects the availability of endowments in country i. We employ a Cobb–Douglas production function, and the per unit cost function is thus given by $c_i^k = \prod_{h=0}^{H} (r_{ih})^{s_h^k}$ for commodity k, where r_{ih} is the price paid for factor h in country i, s_h^k is the share of payment to factor h, and $\sum_{h=0}^{H} s_h^k = 1$.[5]

Ricardian Productivity

The production of agricultural commodities is subject to random fluctuations across countries because of differences in climate, technological improvements, the prevalence of pests and disease, institutional factors, and idiosyncratic shocks. These random variations are captured by the productivity shock z:

$$\ln z_i^k = \boldsymbol{\psi} \boldsymbol{M}_i + \psi_0 \nu_i, \tag{7}$$

where $\boldsymbol{M}_i$ is the vector of systematic components (e.g., institutional factors) that influence the average productivity. The systematic components are not stochastic but differ across countries. In contrast, $\psi_0 \nu_i$ is stochastic, and ν_i captures the variations in productivity across countries, which we assume follow the Gumbel distribution; ψ_0 amplifies the variation of ν_i. Following Chor (2010), we model a stochastic productivity shock, ν_i, to follow a Gumbel distribution: $F(\nu) = \Pr(\nu_i \le \nu) = \exp[-\exp(-\nu)]$.

The pricing rule (6) and the productivity shock (7) can be combined to obtain

$$\ln p_{in}^k = \ln\left(c_i^k \tau_{in}^k\right) - \boldsymbol{\psi} \boldsymbol{M}_i - \psi_0 \nu_i - \ln S_i^k. \tag{8}$$

[4] To deliver one unit of a good in country n, country i has to produce τ_{in}^k units of the good. Thus, the production function in equation (4) is modified to introduce the trade cost τ_{in}^k.

[5] The land to labor and capital to labor ratios are utilized to represent the H–O relative factor endowments due to lack of appropriate cost data. The steps involved to obtain the input ratio as a proxy for costs are included in the online supplement.

Production and trade costs increase the price, higher productivity and subsidy lower the price, and institutional factors may increase or decrease the price depending on whether they expand or diminish productivity.

Price Determination

The volume of trade between countries depends on the prices offered by various exporters to the importers. Country n imports commodity k from the exporting country that offers the lowest price inclusive of all the trade costs:

$$(9) \qquad p_n^k(v) \equiv \min\left\{p_{1n}^k, p_{2n}^k, \ldots, p_{Nn}^k\right\} = \min\left\{\frac{c_1^k \tau_{1n}^k}{z_1^k S_1^k}, \frac{c_2^k \tau_{2n}^k}{z_2^k S_2^k}, \ldots, \frac{c_i^k \tau_{in}^k}{z_i^k S_i^k}, \ldots, \frac{c_N^k \tau_{Nn}^k}{z_N^k S_N^k}\right\}.$$

Since there are N possible offered prices, we need to determine the lowest price offered to n across exporters. We define $G_{in}^k(p)$ as the probability that a commodity from i can be sold in n at less than a given price p. Using the pricing rule from equation (6), this distribution can expressed as

$$(10) \qquad G_{in}^k(p) = \Pr\left(p_{in}^k \le p\right) = 1 - \left\{\exp\left[-\exp\left(-v_i^k\right)\right]\right\}.$$

From equation (8), we derive $v_i = \frac{1}{\psi_0}[\ln(c_i^k \tau_{ni}^k) - \boldsymbol{\psi M}_i - \ln p_{in}^k - \ln S_i^k]$ and define $\theta = \frac{1}{\psi_0}$ and $\Gamma_i^k = \exp\{\theta \boldsymbol{\psi M}_i\}$ to obtain $\exp(-v_i^k) = (c_i^k \tau_{in}^k)^{-\theta}(S_i^k p_{in}^k)^{\theta}\Gamma_i^k$. Thus, the price distribution is given by

$$(11) \qquad G_{in}^k(p) = 1 - \exp\left[-\left\{\left(c_i^k \tau_{in}^k\right)^{-\theta}\left(pS_i^k\right)^{\theta}\Gamma_i^k\right\}\right].$$

Note that higher Γ_i^k (e.g., effective institutions and greater technological capabilities) and subsidies S_i^k indicates that country i will offer to country n prices lower than p with higher probability. Similarly, a lower production cost c_i^k in country i and trade cost τ_{in}^k from country i to country n implies that country i will offer to country n prices less than p with higher probability. Furthermore, $1 - G_{in}^k(p)$ is the probability that n's own price is lower than the price offered by i, in which case n will not buy commodity k from i.

Because country n will buy from the lowest priced exporter, to ascertain the distribution of such prices, we define $G_n^k(p)$ as the probability that country n will buy at the lowest price by considering prices offered by every country, including its own price. Using the *i.i.d.* productivity (v) draw from the Gumbel distribution, we obtain

$$(12) \qquad G_n^k(p) = \Pr(p_n \le p) = 1 - \Pr(p \ge p_n) = 1 - \exp\left[-\left\{\sum_{i=1}^{N}\left(\frac{c_i^k \tau_{in}^k}{S_i^k}\right)^{-\theta}\Gamma_i^k\right\}p^{\theta}\right].$$

$G_n^k(p)$ depends on the technology Γ_i^k and θ, production cost c_i^k, subsidies S_i^k, and bilateral trade cost τ_{in}^k. These factors govern prices and thus shape the importing opportunities for a country. Thus, country n can import from countries that vary in their levels of productivity, (Γ_i^k); their factor costs, (c_i^k); their subsidy level, S_i^k; and their trading costs, (τ_{in}^k). Note that a larger value of θ indicates a lower variance in the distribution of productivities, which implies diminished scope for comparative advantage and smaller $G_n^k(p)$ (i.e., the probability that the importing country n will purchase at the lowest price given the prices in all the countries).

Next, we find the probability (ρ_{in}^k) that country i offers commodity k to country n at the lowest possible price:

$$(13) \qquad \rho_{in}^k = \Pr\left(p_{in}^k \le \min_{t \ne i} p_{tn}^k\right) = \int_0^{\infty} \prod_{t \ne i}\left[1 - G_{tn}^k(p)\right] dG_{in}^k(p),$$

where $1 - G_{tn}^k(p)$ is the probability that t offers a price greater than p to country n and $\prod_i [1 - G_{tn}^k(p)]$ is the probability that every country (other than i) prices its product greater than p to country n. We consider that countries trade a large number of agricultural commodities (i.e., there is a continuum of goods). Thus, by the law of large numbers, ρ_{in}^k is also the fraction of commodities that country i sells to n.

Trade Flows

Next, to determine the value of the bilateral trade between i and n, we need to know the price distribution conditional on exports from i to n. This distribution is the same as $G_n^k(p)$, which is identical to the price distribution of the goods that n buys from every other country. Therefore, the average price of exports from i to n is the same as the average price of exports from any country j to n. As a result, ρ_{in}^k also measures the value of bilateral trade from i to n. Then, substituting $G_{tn}^k(p) = 1 - \exp[-\{(c_t{}^k \tau_{tn}^k)^{-\theta} p^\theta (S_t{}^k)^\theta \Gamma_t{}^k\}]$ and $G_{in}^k(p) = 1 - \exp[-\{(c_i{}^k \tau_{in}^k)^{-\theta} p^\theta (S_i{}^k)^\theta \Gamma_i{}^k\}]$, and carrying out the integration in equation (13), we derive the bilateral trade equation

$$(14) \qquad \frac{X_{in}^k}{X_n^k} = \rho_{in}^k = \frac{\left(\frac{c_i{}^k \tau_{in}^k}{S_i{}^k}\right)^{-\theta} \Gamma_i{}^k}{\sum_{t=1} \left(\frac{c_t{}^k \tau_{tn}^k}{S_t{}^k}\right)^{-\theta} \Gamma_t{}^k},$$

where $X_n{}^k = \sum_{i=1}^N X_{in}^k$ is the total value of expenditures in country n for commodity k, and of which X_{in}^k is the value of imports of commodity k by n from i including transport costs; ρ_{in}^k represents the share of total expenditure (i.e., the amount of money spent on commodities imported from country i as a fraction of total expenditure in country n).

Equation (14) is similar to the standard gravity equation (which models bilateral trade as a function of the respective sizes of the trading partners and barriers to trade between the two countries) as bilateral trade X_{in}^k is related to total expenditure $X_n{}^k$, geographic barriers $\Gamma_i{}^k$, and trade barriers τ_{tn}^k. Equation (14) also shares natural similarities with the analogous expressions from the existing frameworks upon which our model is based (e.g., equation 11 in Chor); however, the novel inclusion of domestic production subsidies in the expression captures how such policies distort bilateral trading relationships. The denominator in the righthand side of the trade flow equation captures the multilateral trade resistance component of the gravity equation identified in Anderson and van Wincoop (2003); specifically, it reflects the barriers to trade between importer n and all of its potential import sources (i.e., inward multilateral resistance). θ controls the role of comparative advantage in dictating bilateral trade shares. As θ increases, bilateral trade between pairs of countries depends more on relative trade costs and less on comparative advantage. Thus, in the above gravity equation, country n compares country i's cost to all other countries' costs in making its import decisions. In summary, the trade flows between a pair of countries hinge upon all the key factors: technology, institutional factors, endowments, production subsidies, and trade costs.

Empirical Model

To formulate the empirical model, we first specify an exponential function of bilateral trade costs (τ_{in}^k) between countries i and n and gravity factors; because we will estimate the model in a panel data setting, we also introduce a time element (denoted by subscript t) for variables that change over time:

$$(15) \qquad \tau_{int}^k = \exp\left\{\alpha_1 \boldsymbol{E}_{int}^k + \gamma_{in}^k\right\},$$

where $\boldsymbol{E}_{int}^k$ is a vector of observable factors that determine trade costs (tariffs and joint PTA membership) and γ_{in}^k is a fixed effect that accounts for time-invariant factors such as geographical distance or two trading partners sharing a common language or contiguous border. As shown in Egger and Nigai (2015), γ_{in}^{k} more accurately measures long-run bilateral trade costs than traditionally used variables.

We substitute equation (15), $\Gamma_{it}^{k} = \exp\{\theta \boldsymbol{\psi} \boldsymbol{M}_{it}\}$, and $c_{it}^{k} = \prod_{h=0}^{H} (r_{iht})^{s_h^k}$ into equation (14), multiply both sides by X_{nt}^{k}, and introduce a random error term, ϵ_{int}^{k}, to obtain the empirical model:

$$(16) \quad X_{int}^{k} = \exp\left\{\boldsymbol{\beta}_1 \boldsymbol{E}_{int}^{k} + \beta_2 \ln S_{it}^{k} + \sum_h \beta_3^h \left(\frac{F_{iht}}{F_{i0t}}\right) + \beta_4 X_{nt}^{k} + \beta_5 X_{it}^{k} + \boldsymbol{\beta}_6 \boldsymbol{M}_{it} + \delta_{in}^{k} + \eta_t^{k}\right\} + \epsilon_{int}^{k}.$$

While equation (16) is similar to the analogous equation from Chor (2010) (equation 19), it differs in several ways—most obviously because of our inclusion commodity-level subsidies, the introduction of a time dimension, and the use of trade in levels compared to Chor's log-linearized version of gravity. The terms reflecting exporter and importer size effects ($\beta_4 X_{nt}^{k}$ and $\beta_5 X_{it}^{k}$) are also a point of departure and put our estimating equation more in line with canonical formulations of the gravity relationship.

The factor prices reflect the availability of factor endowments (i.e., the larger the endowment, the lower the factor prices). Since data on factor prices are not readily available, following Romalis (2004) we utilize endowments (i.e., H–O effects) to capture the impact of factor prices on bilateral trade. Thus, in the above equation, the relative factor abundance terms, $\frac{F_{iht}}{F_{i0t}}$, which include country i's cultivable land per worker and capital stock per worker, replace $c_{it}^{k} = \prod_{h=0}^{H} (r_{iht})^{s_h^k}$. The importing country's GDP serves as a proxy for total expenditure, X_{nt}^{k}. While the theoretical model did not imply a relationship between bilateral trade and the size of the exporter (which owes to the structure of the Eaton and Kortum and Chor frameworks), we augment the bilateral trade equation with the exporter's total production, X_{it}^{k}. We do this to follow standard gravity formulations and because the omission of such a term could induce omitted variable bias (e.g., because of the correlation between exporter size and unobserved productivity). An important element of equation (16), the country pair-commodity fixed effect δ_{in}^{k}, controls for all time-invariant, country pair-commodity specific factors (such as long-run determinants of bilateral trade costs, as mentioned previously) as well as all unobserved factors that reflect commodity-, exporter-, or importer-specific factors and any combinations thereof. The fact that this includes importer-commodity factors implies that this term also subsumes the time-invariant aspects (e.g., the average barriers to trade between importer n and its partners over the sample period) of the inward multilateral resistance term from above. We also introduce a commodity-year fixed effect, η_t^{k}, to account for commodity-time-specific shocks (e.g., the 2007–2008 world food price crisis) as well as global economic events that impacted international trade (e.g., the 2008 financial crisis).[6]

To test the robustness of our findings to alternative fixed effects specifications, we also estimate a version of equation (16) that incorporates exporter-commodity, importer-commodity, and commodity-year fixed effects in place of the country pair-commodity and year fixed effects in equation (16). The omission of the commodity-pair fixed effect obliges us to explicitly control for long-run bilateral determinants of trade costs such as geographical (distance, contiguous border) and cultural (common language) factors. Though the commodity-pair fixed effect approach controls for the same one-sided factors as the exporter-commodity and importer-commodity fixed effects, the latter approach allows us to test the sensitivity of our estimates and to include a much larger number of observations since fewer singleton observations are excluded in the estimation.[7]

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[6] Time-varying multilateral resistance could be accounted for with importer-commodity-year fixed effects; however, such an approach would preclude the identification of most of the effects of the variables of interest because of collinearity.

[7] Singleton observations are those that are perfectly predicted by the fixed effect; their inclusion in a regression can lead to incorrect inference see Correia, 2015 and are automatically excluded by most high-dimensional fixed effects estimation routines. With country pair-commodity fixed effects, trading pairs that never trade a particular commodity (i.e., for which trade is always zero) are excluded, which reduces the sample size significantly.

Table 1. Commodities in Empirical Analysis and 2010 Value of Total World Trade

Commodity	Total Trade ($ billions)	Commodity	Total Trade ($ billions)
Barley	5.0	Rice	20.7
Cocoa beans	9.7	Rubber	24.3
Coffee	24.1	Sorghum	1.3
Cotton	16.0	Soybeans	39.9
Grapes	8.2	Sugar	31.9
Maize	24.6	Tea	6.2
Oats	0.6	Tobacco	12.0
Pepper	2.4	Tomatoes	8.3
Potatoes	3.6	Wheat	37.0

Data Description

To estimate equation (16), we use a panel of bilateral trade data for 18 agricultural commodities that encompasses 161 exporting countries and 180 importing countries over the years 1996–2010, the years for which we have full coverage for all of the variables in the analysis. The dependent variable is the bilateral (unidirectional) trade flow, data for which is obtained from the BACI dataset developed by the Centre d'Études Prospectives et d'Informations Internationales (CEPII; Gaulier and Zignago, 2010). The commodities are defined at the level of 4-digit Harmonized System codes and are listed in Table 1. The commodities selected for this study—which generally include cereal crops, major fruits and vegetables, and several important nonfood commodities—have been chosen because they are each extensively traded by a large number of exporters and importers and, as seen in Table 1, they collectively account for hundreds of billions of dollars in annual trade.

We consider eight explanatory variables: two institutional factors (the rule of law and control of corruption), two H–O endowment variables (land and capital per worker in agriculture), trade and domestic policies, and gravity factors reflecting market size.

The institutional factor indices are collected from the World Bank's Worldwide Governance Indicators database developed by Kaufmann, Kraay, and Mastruzzi (2005), which estimates country-specific indicators on the effectiveness of governance, updated yearly. These indicators range in value from roughly −2.6 to 2.5, with higher values representing more favorable institutional quality. Among these factors, we utilize the rule of law and control of corruption, which capture the systematic institutions-based component of productivity and comparative advantage across countries. While the measures are not commodity-specific, the fact that systematic corruption and ineffective governance create universal frictions in commerce suggests that such institutional factors will present similar impediments to trade in all commodities. The H–O variables are constructed as the ratio of cultivable land to labor employed in agriculture and the ratio of the agricultural capital stock to agricultural employment, with land and capital data obtained from the Food and Agricultural Organization and labor data from the International Labour Organization.

For tariff data, we use the most favored nation (MFN) applied tariff on imports by country and commodity, which is obtained from the United Nations Conference on Trade and Development (UNCTAD) Trade Analysis Information System (TRAINS) database.[8] Since PSEs are available only for selected countries and commodities, we focus on NRA to measure the

[8] A significant portion of trade is conducted under preferential tariff relationships, implying that MFN tariffs are an imperfect measure of true applied tariff rates. However, it has long been noted that existing information on preferential tariff rates is incomplete and inaccurately reported (particularly for developing countries), even in standard sources such as the TRAINS database (Anderson and van Wincoop, 2004). We therefore focus on MFN tariffs because these data suffer from fewer missing and erroneous data issues. Nonetheless, the effects of preferential relationships on trade are to a large extent captured by our control for preferential trade agreement status.

Table 2. Summary Statistics

Variable	Min	Max	Mean	Std. Dev.
Trade flows	0.0	10,816.8	3.1	42.1
Rule of law	−2.6	2.0	0.1	1.0
Control of corruption	−1.9	2.5	0.1	1.0
Land abundance	0.3e−3	1.4	0.1	0.2
Capital abundance	0.4e−4	0.6	0.1	0.1
Tariff	0.0	3,000.0	20.7	79.6
PTA	0.0	1.0	0.3	0.5
Negative nominal rate of assistance	0.0	1.0	0.1	0.3
Positive nominal rate of assistance	0.0	1.0	0.3	0.4
Value of production	1.0e−6	77.7	2.2	7.2
GDP	0.1	14,992.1	953.8	2,304.6

Notes: Trade flows (which are measured by commodity) are expressed in million nominal USD, while GDP and value of production (also measured by commodity) are expressed in billion nominal USD. Land abundance is defined as hectares (in thousands) of arable land per worker employed in agriculture, and capital abundance is equal to the value of the net capital stock in agriculture (in million USD) per worker employed in agriculture.

presence of domestic support programs (either production-enhancing or production-inhibiting) by country and commodity. Further, the fact that NRA generally measures countries' coupled support programs—producer supports tied directly to the level of production—suggests that this measure more effectively captures distortions to production and trade than measures of uncoupled production subsidies. The NRA index is collected from Anderson, Valenzuela, and Nelgen (2013); to differentiate between production-enhancing support programs (i.e., subsidies) and taxes on agricultural production, we distinguish between the effects of positive rates of NRA (measured by an indicator variable, *Positive NRA*, which is equal to 1 if an exporter provides subsidies for the given commodity and 0 otherwise) and negative rates of NRA (measured by an indicator variable, *Negative NRA*, which is equal to 1 if an exporting country taxes a particular commodity and 0 otherwise). We define the NRA variables in this way because countries will often maintain different levels of support for different types of commodities (e.g., South Africa maintains negative rates of support for certain import-competing varieties of maize and positive rates of support for exported varieties). Value of production by commodity is obtained from FAO and importer GDPs are obtained from the World Bank database. Table 2 presents summary statistics for key variables.

Empirical Estimations

The empirical analysis involves an econometric estimation of the gravity equation given in equation (16). Tinbergen (1962) was the first to apply the gravity equation to international trade. Until the late 1980s, the gravity equation was not widely applied in trade analysis because of the notion that it lacked a theoretical economic foundation. However, once the theoretical underpinnings of microeconomics and trade theories were established, the gravity equation has evolved and has been widely applied to quantify the impacts of major determinants of bilateral trade flows (McCallum, 1995). Furthermore, the gravity equation has been extended to incorporate trade costs (McCallum, 1995), endowment differences (Bergstrand, 1989; Deardorff, 1998), Ricardian technological differences (Eaton and Kortum, 2002), and returns to scale (Feenstra, Markusen, and Rose, 2001; Bergstrand, 1989).

Starting in 1995, further advancements in the empirical estimation of the gravity equation led to a theoretically compatible econometric specifications (Head and Mayer, 2014). One of the earliest attempts to correct misspecification was to account for the multilateral trade resistance component of the structural model (Anderson and van Wincoop, 2003). Multilateral trade resistance is captured by employing theoretically consistent fixed effects to control for individual country's effects (Feenstra, 2004).[9]

Another empirical issue in estimating the gravity equation is missing values for bilateral trade flows that needs to be dealt with to avoid biased or inconsistent estimates that could render trade policy analysis invalid. The prevalence of missing trade flow data exacerbates the heteroskedasticity problem in the log-linear gravity equation, which needs to be corrected (Santos Silva and Tenreyro, 2006). In addressing these issues, the Poisson pseudo-maximum likelihood (PPML) has become the widely used method for gravity estimation. The major advantage of this approach is that estimates obtained by PPML are consistent in the presence of heteroskedasticity and, because the dependent variable is specified in levels, it tackles the zero-trade problem that hampers log-linear gravity estimators; hence, no information is lost by not omitting bilateral linkages with zero trade (Santos Silva and Tenreyro, 2006). It also yields asymptotically normal estimators (Gourieroux, Monfort, and Trognon, 1984).

Results and Discussions

Table 3 presents the estimates of equation (16); because the results in column 1 correspond to our preferred specification and the results in columns 1 and 2 are in general similar, we largely focus on these results. Only one of the two institutional variables (control of corruption) is estimated to be significant; however, the different institutional quality measures are highly correlated with one another. The positive relationship between exports and control of corruption illustrates that economic agents incur unnecessary additional costs on directly unproductive activities in production and transactions due to bribery and corruption. To give this estimate a more explicit economic meaning, we can consider the impact of a 1-standard-deviation increase in a country's control of corruption on average bilateral exports. Such an improvement in a country's institutions would (*ceteris paribus*) increase its exports by roughly 42% (= exp(0.130 – 1) × 100%), corresponding to a roughly \$1.4 billion increase in an average country's total annual exports of agricultural products. This large predicted increase from the improvement in a single institutional measure also likely reflects how control of corruption acts as a proxy for other institutional features, (e.g., efficacy of a country's governance and degree of frictions faced in a country's commerce). The directly unproductive activities hinder efficient production as farmers cannot use or obtain at exorbitant costs the needed inputs (e.g., agricultural credit, seed, fertilizers, and pesticides) and delay or impose additional costs in transporting commodities to ports. All these inefficient activities reduce a country's potential to be an exporter of agricultural commodities. Consequently, a country infested with bribery and corruption is less competitive and may lose its comparative advantage in the world market, where it competes with other efficient countries that do not incur additional costs on unproductive activities. Méon and Sekkat (2008) examined the roles of institutions as drivers or inhibitors of trade and found that defective institutions with a high prevalence of corruption inhibit exports in a nonmanufacturing sector such as agriculture, which our findings corroborate. In summary, the more pervasive a country's corruption, the lower the volume of its exports on average.

H–O factor endowments are sources of comparative advantage and play an important role in determining trade among countries. The H–O comparative advantage arises from the low prices of factors that are abundant and intensively used in the production of goods. Thus, the *a priori* expectation is that countries that are abundant in the factors used intensively in agriculture will positively influence trade. In this study, cultivable land availability per unit of labor is utilized to measure factor abundance in land because land is the most important input in agricultural production, and thus the major determinant of bilateral trade. Our results confirm a strongly positive relationship between a country's land abundance and the level of its exports. We can perform a similar exercise to

[9] In addition to controlling for bilateral factors, the commodity-specific bilateral-pair fixed effect δ_{in}^{k} subsumes separate commodity-exporter- and commodity-importer-specific fixed effects that reflect the multilateral resistance terms.

Table 3. Regression Estimates of Gravity Equation

	1	2
Institutional factors		
Rule of law	0.026	0.047
	(0.055)	(0.052)
Control of corruption	0.130***	0.120**
	(0.040)	(0.055)
Heckscher–Ohlin		
Land abundance	0.501***	0.399***
	(0.139)	(0.133)
Capital abundance	−1.042***	−1.164***
	(0.345)	(0.438)
Policy factors		
ln(1 + tariff)	−0.396***	−0.403***
	(0.094)	(0.113)
PTA	0.018	0.363***
	(0.037)	(0.037)
Negative nominal rate of assistance	−0.014	−0.024
	(0.035)	(0.042)
Positive nominal rate of assistance	0.022	0.016
	(0.033)	(0.042)
Gravity factors		
ln(exporter production)	0.694***	0.709***
	(0.042)	(0.043)
ln(GDP of importer)	0.560***	0.589***
	(0.058)	(0.079)
Bilateral trade cost factors		
ln(distance)		−1.483***
		(0.034)
Contiguous border		0.434***
		(0.053)
Common language		0.252***
		(0.035)
No. of obs.	552,622	2,920,827
Pseudo-R^2	0.935	0.871
Country pair-commodity fixed effects	Y	N
Commodity-year fixed effects	Y	Y
Exporter-commodity fixed effects	N	Y
Importer-commodity fixed effects	N	Y

Notes: Estimation method is Poisson pseudo-maximum likelihood. Values in parentheses are robust standard errors clustered by exporter-year and importer-year in parentheses. Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level, respectively.

analyze the economic magnitude of a hypothetical improvement in a country's abundance of arable land. For the average country, a 1-standard-deviation increase in its land abundance would (*ceteris paribus*) correspond to a roughly 41% increase in exports, or around $1.3 billion in total annual agricultural exports. Surprisingly, we estimate a strongly negative relationship between capital abundance (the dollar value of capital stock in agriculture per worker) and exports. A possible explanation for this finding is that a country's intensive use of capital might reflect its poorer natural endowments, which require significant amounts of capital and noncapital inputs to maintain production. Put another way, the negative association between capital abundance and exports might reflect agroecological factors not captured by the land abundance variable.

Countries use trade policies to impede free trade; these barriers to trade eventually distort production. The most commonly employed trade policy instruments are tariffs aimed to discourage imports. For example, the recent trade dispute between the United States and China has adversely impacted the trade between these two countries (Sabala and Devadoss, 2019). In contrast, declining tariffs lead to expansions in bilateral trade. According to the World Trade Organization (2015), global trade increased by 400% between 1996 and 2013 in response to a 15% decline in the average tariff. However, agricultural trade costs have remained high. For example, Reimer and Li (2010) analyzed the impacts of trade costs such as tariff, freight cost, and nontariff barriers on bilateral trade of grains and oilseeds and found that eliminating all trade costs would generate about a fifteenfold increase in global trade volume. Reimer and Kang (2010) estimated that the removal of all trade restrictions would increase farm sector's revenue by 21%. Our empirical results also indicate that tariffs negatively impact bilateral trade, consistent with our theoretical framework. Based on our estimate of the tariff elasticity, the average MFN tariff rate imposed on agricultural exports of roughly 21% decreases expected trade between two countries by around 8%, or around $250,000 for the average commodity-level *bilateral* trading relationship. (Though the fact that many countries maintain tariffs on agricultural products much higher than 21% suggests that there is large variation in these impacts.) Surprisingly, the effect of the PTA variable is estimated to be insignificant. We attribute this to the inclusion of the country pair-commodity fixed effect, which is highly correlated with the PTA measure.[10] This in turn inhibits identification of the PTA effect. That the PTA variable is positive and significant in column 2 of Table 3 supports this notion and accords with previous findings on the impacts of PTAs in the literature.

Domestic subsidies are policies implemented by a country to support agricultural production. These subsidies augment a country's competitiveness by boosting production which expands exports at the expense of other exporters. Lack of global agreements to control domestic subsidy distortions makes it convenient for countries to support their farmers, overproduce, and dispose of these commodities in the world market, which depresses international prices. Countries often do so without providing transparent information on the scope of their subsidy programs: For instance, the World Trade Organization (2018) reports indicate that many countries do not report the total extent of their agricultural subsidy programs to the WTO. The lack of notification of subsidy programs to WTO is not a one-time omission by members but rather a perpetual problem, which occurs because this is not a punishable offense. For example, Devadoss (2006) noted that the Doha agenda was to require countries to reduce trade-distorting domestic farm policies, but participating countries continue to heavily subsidize their agricultural sectors.

Subsidies are usually provided to farmers in various disguised forms to eschew WTO verification and oversight. Past studies have investigated these effects of domestic farm supports on international trade. For instance, Dewbre and Short (2002) and Dewbre, Antón, and Thompson (2001) evaluated the impacts of various domestic farm support instruments on farm income, international trade, and farmers' competitiveness. They found that these domestic farm policies enhance farm income but distort bilateral trade. Tong, Pham, and Ulubaşoğlu (2019) employed a gravity model to assess the role of US subsidies in promoting agricultural exports of US states. As expected, we find that

[10] To illustrate, the PTA variable for any two countries that were EU members for the duration of the sample is perfectly collinear with the specific bilateral country pair fixed effect for the pair.

negative rates of support are significant impediments to trade and that positive rates of support have trade-expanding effects (however, these estimates are found to be insignificant).

The market size factors (exporter's production and importer's GDP) demonstrate high levels of significance, indicating their relevance and importance in determining the bilateral agricultural trade. Exporters' production and importers' GDP show a positive relationship to exports. The result indicates that a 1% percent increase in the value of the exporter's production is correlated with around a 0.7% increase in the value of bilateral exports. Similarly, importers' GDP also influences the value of trade between partner countries. The larger the GDP of an importer, the higher the country's purchasing power, and hence, the more the country will purchase from abroad.

As the time-invariant gravity factors (distance, continuity, and common language) cannot be included in the baseline specification (owing to the inclusion of the country pair-commodity fixed effect), we can only estimate the effects of these variables in the specification shown in column 2 of Table 3. These estimates largely behave as predicted—greater distance impede trade, and geographical and cultural proximity encourage trade—and align with existing estimates on these variables from the gravity literature.

Alternative Specifications

To test the sensitivity of our baseline empirical results and explore potential sources of heterogeneity, we conduct two robustness exercises. First, we analyze whether alternative measures of institutional quality generate similar findings to our baseline specification. Second, we investigate whether developing and developed countries exhibit differences in factor-endowment effects, based on the logic that the relative importance of land or capital abundance in determining trade volumes might differ depending on a country's level of development.

Table 4 presents the results for the baseline specification (equation 16) using alternative measures of institutional quality based on the Economic Freedom of the World database from the Fraser Institute (Murphy and Lawson, 2018). The results are consistent with the baseline specification, in that stronger institutions, measured here by the efficacy of an exporter's legal enforcement of contracts and the integrity of its legal system, are conducive to higher levels of trade. Estimates of the other variables' effects are largely similar to those shown in column 1 of Table 3.

In Table 5, we explore whether our findings on the H–O exporter endowment effects give rise to heterogeneity with respect to countries' levels of development. We do this because there are substantial differences in relative land and capital abundances between developing versus developed countries; therefore, the way in which these factors drive the exports of countries in these respective groups likely differs. To assess this dimension of heterogeneity, we divide exporting countries based on their income group (low, low-middle, upper-middle, or high) from the World Bank's country income group classification. We define developing economies as those that fall in the low or low-middle brackets and developed economies as those in the upper-middle and high brackets. We fix the group assignment of each country by classifying countries based on their start-of-sample (1996) income classification to mitigate potential endogeneity between trade and level of development. We then modify the baseline specification by incorporating a dichotomous variable (equal to 1 if an exporting country is classified as developing and 0 otherwise) interacting with the land abundance and capital abundance variables to capture the structural break between developing versus advanced economy exporters.

Results for this analysis are shown in Table 5. Significant differences are evident in the estimates on the H–O variables: Land abundance has a positive effect on the agricultural exports of developing economies, but the effect is insignificant. On the other hand, capital abundance is found to have a large, positive relationship with the exports of developing economies and a negative one for advanced economies. The former result likely reflects the larger degree of variation (and thus scope for comparative advantage) in the capital endowments of developing countries, whereas advanced economies tend to be more similar in their capital abundances (with less scope for comparative

Table 4. Regression Estimates of Gravity Equation, Alternative Institutional Measures

	Estimate
Institutional factors	
Legal enforcement of contracts	0.063**
	(0.031)
Integrity of legal system	0.029**
	(0.012)
Heckscher–Ohlin	
Land abundance	0.475***
	(0.167)
Capital abundance	−1.087***
	(0.374)
Policy factors	
ln(1 + tariff)	−0.310***
	(0.095)
PTA	−0.011
	(0.038)
Negative nominal rate of assistance	0.020
	(0.039)
Positive nominal rate of assistance	0.021
	(0.036)
Gravity factors	
ln(exporter production)	0.619***
	(0.048)
ln(GDP of importer)	0.504***
	(0.058)
No. of obs.	447,410
Pseudo-R^2	0.944
Country pair-commodity fixed effects	Y
Commodity-year fixed effects	Y

Notes: Results are based on alternative institutional measures (from Fraser Institute). Estimation method is Poisson pseudo-maximum likelihood. Values in parentheses are robust standard errors clustered by exporter-year and importer-year. Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level, respectively

advantage across exporters). The strongly positive estimate on the impact of capital abundance for developing countries is also intuitive, as such countries often possess much larger agricultural labor forces and smaller capital stocks than their advanced counterparts; thus, improvements in the capital stock of such countries will lead to large improvements in the productivity of these countries, and consequently, improve their capacity to export.

Conclusions

The theoretical trade model analyzes the effects of Ricardian technological and Heckscher–Ohlin factor endowment comparative advantage, trade policies, domestic agricultural supports, and gravity factors. This model is empirically implemented to quantify the effects of these key factors on bilateral agricultural trade. The theoretical analysis captures the extensive influence of agricultural

Table 5. Regression Estimates of Gravity Equation, Heterogeneity of Heckscher–Ohlin Effects

	Estimate
Institutional factors	
Rule of law	0.012
	(0.055)
Control of corruption	0.119***
	(0.039)
Heckscher–Ohlin	
Land abundance	0.372***
	(0.138)
Land abundance × developing	14.040
	(15.042)
Capital abundance	−0.650*
	(0.344)
Capital abundance × developing	17.329***
	(5.775)
Policy factors	
ln(1 + tariff)	−0.403***
	(0.094)
PTA	0.010
	(0.037)
Negative nominal rate of assistance	−0.031
	(0.034)
Positive nominal rate of assistance	0.006
	(0.033)
Gravity factors	
ln(exporter production)	0.700***
	(0.042)
ln(GDP of importer)	0.554***
	(0.058)
No. of obs.	552,622
Pseudo-R^2	0.935
Country pair-commodity fixed effects	Y
Commodity-year fixed effects	Y

Notes: Estimation method is Poisson pseudo-maximum likelihood. Values in parentheses are robust standard errors clustered by exporter-year and importer-year. Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level, respectively

trade barriers and domestic farm policies as these policies augment and impede agricultural commodity trade, respectively.

Countries' institutional factors encourage technological advancement and serve as the backbone of smooth trade transactions. For instance, farmers need to sell their perishable agricultural commodities in a timely manner and binding legal transaction contracts are required so that wholesale buyers will not renege on their agreements. Therefore, legal institutions are imperative to enhance countries' comparative advantage. Our findings suggest that a 1-standard-deviation improvement in institutional factors would be conducive to the creation of over a billion dollars in an average country's total agricultural exports. H–O factor endowments such as cultivable land per worker also influence countries' comparative advantage and are major determinants of trade flows, as countries that possess abundant cultivable land significantly increase their exports. The results of the study indicate that both Ricardian and H–O comparative advantage factors are major drivers of agricultural bilateral trade.

Import trade restrictions curtail bilateral trade. The result indicates a strong negative relationship between import-restrictive policies and commodity trade. Contrary to agricultural trade barriers, domestic agricultural supports artificially enhance a country's degree of competitive advantage and expand exports of agricultural commodities. However, our findings show that subsidies have a statistically insignificant impact on the exports of the subsidizing countries.

Finally, the results corroborate theory by confirming that gravity factors (the exporter's level of production, the importer's GDP, geographical and cultural factors) are important in driving bilateral trade. GDP, a proxy for the size of a country, positively influences agricultural imports. The larger the economic size of a country, the larger are its purchases of foreign commodities.

We can derive several policy implications from this study. First, the results show that stronger institutions play a pertinent role in dictating bilateral trade. Institutions are particularly important in international trade when businesses from different countries engage in global trade because clear oversight is needed for smooth bilateral trade relations. Countries that want to promote trade should strengthen their legal institutions so that trade contracts can be strictly enforced to facilitate vibrant bilateral trade transactions. A country infested with pervasive bribery and corruption runs the risk of being relegated to the end in the international market arena even when businesses in these countries are willing to participate actively in the market. For instance, the volume of exports of agricultural commodities by developing countries is small compared to developed (developing) economies such as the United States (African countries); this is partly due to the prevalence of bribery and corruption in developing countries. For these countries to become effective players in the international market, they need to address bribery and corruption through appropriate policy measures.

Second, the result from the H–O factor endowment variable suggests that a country should continue to engage its abundant factor in production to enjoy a comparative advantage over its competitors. Governments can promote policies to increase the factors of production such as skilled labor through education, which will augment the comparative advantage in production and trade.

Third, trade policies play significant roles in dictating how countries trade bilaterally. Trade policies such as the imposition of import tariffs on trading partners curtail imports and encourage inefficient domestic production. A country whose objective is to increase production and export certain commodities will aggressively pursue policies that target heavy subsidization. Even though the import tariffs and domestic subsidies decrease the world economic welfare, countries continue to pursue these protective policies to safeguard domestic interests. The results of this study imply that a country can gain a competitive advantage through these protectionist trade policies.

[First submitted June 2021; accepted for publication August 2021.]

References

Ahmad, J., and S. Harnhirun. "Cointegration and Causality between Exports and Economic Growth: Evidence from the ASEAN Countries." *Canadian Journal of Economics* 29(1996): S413–S416. doi: 10.2307/136078.

Anderson, J. E., and E. van Wincoop. "Gravity with Gravitas: A Solution to the Border Puzzle." *American Economic Review* 93(2003):170–192. doi: 10.1257/000282803321455214.

———. "Trade Costs." *Journal of Economic Literature* 42(2004):691–751. doi: 10.3386/w10480.

Anderson, K., M. Kurzweil, W. Martin, D. Sandri, and E. Valenzuela. "Measuring Distortions to Agricultural Incentives, Revisited." *World Trade Review* 7(2008):675–704. doi: 10.1596/1813-9450-4612.

Anderson, K., E. Valenzuela, and S. Nelgen. "Estimates of Distortions to Agricultural Incentives, 1955–2011." World Bank Report WPS4612, World Bank, 2013.

Bergstrand, J. H. "The Generalized Gravity Equation, Monopolistic Competition, and the Factor-Proportions Theory in International Trade." *Review of Economics and Statistics* 71(1989): 143–153. doi: 10.2307/1928061.

Chor, D. "Unpacking Sources of Comparative Advantage: A Quantitative Approach." *Journal of International Economics* 82(2010):152–167. doi: 10.1016/j.jinteco.2010.07.004.

Correia, S. "Singletons, Cluster-Robust Standard Errors, and Fixed Effects: A Bad Mix." Working Paper, Duke University, 2015.

Deardorff, A. "Determinants of Bilateral Trade: Does Gravity Work in a Neoclassical World?" In J. A. Frankel, ed., *The Regionalization of the World Economy,* University of Chicago Press, 1998, 7–32. doi: 10.1142/9789814340373_0024.

Devadoss, S. "Why Do Developing Countries Resist Global Trade Agreements?" *Journal of International Trade & Economic Development* 15(2006):191–208. doi: 10.1080/09638190600 690895.

Dewbre, J., J. Antón, and W. Thompson. "The Transfer Efficiency and Trade Effects of Direct Payments." *American Journal of Agricultural Economics* 83(2001):1204–1214. doi: 10.1111/ 0002-9092.00268.

Dewbre, J., and C. Short. "Alternative Policy Instruments for Agriculture Support: Consequences for Trade, Farm Income and Competitiveness." *Canadian Journal of Agricultural Economics* 50(2002):443–464. doi: 10.1111/j.1744-7976.2002.tb00348.x.

Eaton, J., and S. Kortum. "Technology, Geography, and Trade." *Econometrica* 70(2002): 1741–1779. doi: 10.1111/1468-0262.00352.

Egger, P., and S. Nigai. "Structural Gravity with Dummies Only: Constrained ANOVA-Type Estimation of Gravity Models." *Journal of International Economics* 70(2015):1741–1779. doi: 10.1016/j.jinteco.2015.05.004.

Feenstra, R. C. *Advanced International Trade: Theory and Evidence*. Princeton, NJ: Princeton University Press, 2004.

Feenstra, R. C., J. R. Markusen, and A. K. Rose. "Using the Gravity Equation to Differentiate among Alternative Theories of Trade." *Canadian Journal of Economics* 34(2001):430–447. doi: 10.1111/0008-4085.00082.

Gaulier, G., and S. Zignago. "BACI: International Trade Database at the Product-Level." Working Paper 2010-23, CEPII, Paris, France, 2010.

Gourieroux, C., A. Monfort, and A. Trognon. "Pseudo Maximum Likelihood Methods: Theory." *Econometrica* 52(1984):681–700. doi: 10.2307/1913471.

Head, K., and T. Mayer. "Gravity Equations: Workhorse, Toolkit, and Cookbook." In G. Gopinath, E. Helpman, and K. Rogoff, eds., *Handbook of International Economics,* vol. 4. Elsevier, 2014, 131–195. doi: 10.1016/b978-0-444-54314-1.00003-3.

Houck, J. P. *Elements of Agricultural Trade Policies*. Waveland Press, 1992.

Kaufmann, D., A. Kraay, and M. Mastruzzi. "Governance Matters IV: Governance Indicators for 1996–2004." Policy Research Working Paper 3630, World Bank, Washington, DC, 2005. doi: 10.2139/ssrn.718081.

Levchenko, A. A. "Institutional Quality and International Trade." *Review of Economic Studies* 74(2007):791–819. doi: 10.1111/j.1467-937x.2007.00435.x.

Luckstead, J., and S. Devadoss. "Impacts of the Transatlantic Trade and Investment Partnership on Processed Food Trade under Monopolistic Competition and Firm Heterogeneity." *American Journal of Agricultural Economics* 98(2016):1389–1402. doi: 10.1093/ajae/aaw058.

Manova, K. "Credit Constraints, Heterogeneous Firms, and International Trade." *Review of Economic Studies* 80(2012):711–744. doi: 10.1093/restud/rds036.

McCallum, J. "National Borders Matter: Canada-US Regional Trade Patterns." *American Economic Review* 85(1995):615–623.

Méon, P.-G., and K. Sekkat. "Institutional Quality and Trade: Which Institutions? Which Trade?" *Economic Inquiry* 46(2008):227–240. doi: 10.1111/j.1465-7295.2007.00064.x.
Murphy, R. H., and R. A. Lawson. "Extending the Economic Freedom of the World Index to the Cold War Era." *Cato Journal* 38(2018):265.
Nunn, N. "Relationship-Specificity, Incomplete Contracts, and the Pattern of Trade." *Quarterly Journal of Economics* 46(2007):227–240. doi: 10.1162/qjec.122.2.569.
Reed, M. R. *International Trade in Agricultural Products*. Pearson, 2006.
Reimer, J. J., and S. M. Kang. "Estimation of Trade and Domestic Distortions: An Application to World Agriculture." *Journal of Productivity Analysis* 34(2010):257–265. doi: 10.1007/s11123-010-0172-4.
Reimer, J. J., and M. Li. "Trade Costs and the Gains from Trade in Crop Agriculture." *American Journal of Agricultural Economics* 92(2010):1024–1039. doi: 10.1093/ajae/aaq046.
Romalis, J. "Factor Proportions and the Structure of Commodity Trade." *American Economic Review* 94(2004):67–97. doi: 10.1257/000282804322970715.
Sabala, E., and S. Devadoss. "Impacts of Chinese Tariff on World Soybean Markets." *Journal of Agricultural and Resource Economics* 44(2019):291–310.
Santos Silva, J., and S. Tenreyro. "The Log of Gravity." *Review of Economics and Statistics* 88(2006):641–658. doi: 10.1162/rest.88.4.641.
Schmitz, A., D. Haynes, and T. G. Schmitz. "The Not-So-Simple Economics of Production Quota Buyouts." *Journal of Agricultural and Applied Economics* 48(2016):119–147. doi: 10.1017/aae.2016.5.
Tinbergen, J. *Shaping the World Economy*. New York: The Twentieth Century Fund, 1962. doi: 10.1002/tie.5060050113.
Tong, L. A., C. S. Pham, and M. A. Ulubaşoğlu. "The Effects of Farm Subsidies on Farm Exports in the United States." *American Journal of Agricultural Economics* 101(2019):1277–1304. doi: 10.1093/ajae/aay112.
World Trade Organization. *Trade and Tariffs*. Washington, DC: WTO, 2015. Available online at https://www.wto.org/english/thewto_e/20y_e/wto_20_brochure_e.pdf.
———. *Subsidies Committee Members Express Concerns on Lack of Notifications*. Washington, DC: WTO, 2018. Available online at https://www.wto.org/english/news_e/news18_e/scm_26oct18_e.htm.
Zestos, G. K., and X. Tao. "Trade and GDP Growth: Causal Relations in the United States and Canada." *Southern Economic Journal* 68(2002):859–874. doi: 10.2307/1061496.

Journal of Agricultural and Resource Economics 47(3):S1–S7 ISSN 1068-5502

doi: 10.22004/ag.econ.313317

Online Supplement: Determinants of Global Agricultural Trade

Stephen Devadoss, Blessing Ugwuanyi, and William Ridley

Derivation of Theoretical Model

Consumer Problem

The utility function

$$U_n = \left(q_n^0\right)^{1-\gamma} \left(\int_1^N \left(q_n\left(k\right)\right)^{\frac{\sigma-1}{\sigma}} dk\right)^{\frac{\gamma}{\frac{\sigma}{\sigma-1}}}$$

The budget constraint

$$p_n^0 q_n^0 + \int_1^N p_n\left(k\right)\left(q_n\left(k\right)\right) dk = Y_n$$

Since the utility function is a Cobb-Douglas function with non-tradable $\left(q_n^0\right)^{1-\gamma}$ and tradable $\left(\int_1^N \left(q_n\left(k\right)\right)^{\frac{\sigma-1}{\sigma}} dk\right)^{\frac{\gamma}{\frac{\sigma}{\sigma-1}}}$ portions, we can split the analysis.

Tradable Portion

The budget constraint

$$\int_1^N p_n^k \left(q_n\left(k\right)\right) dk = \gamma Y_n$$

Setting up the Lagrangian,

$$\mathcal{L} = \left(\int_1^N \left(q_n\left(k\right)\right)^{\frac{\sigma-1}{\sigma}} dk\right)^{\frac{\gamma}{\frac{\sigma}{\sigma-1}}} + \lambda\left(\gamma Y_n - \int_1^N p_n\left(k\right)\left(q_n\left(k\right)\right) dk\right),$$

with associated first order conditions

Industry 1, $k = 1$

$$\frac{dL}{dq_n^1} = \frac{\gamma}{\frac{\sigma}{\sigma-1}} \left(\int_1^N \left(q_n\left(k\right)\right)^{\frac{\sigma-1}{\sigma}} dk\right)^{\frac{\gamma}{\frac{\sigma}{\sigma-1}}-1} \frac{\sigma-1}{\sigma} \left(q_n^1\right)^{\frac{\sigma-1}{\sigma}-1} = \lambda p_n^1$$

Industry 2, $k = 2$

$$\frac{dL}{dq_n^2} = \frac{\gamma}{\frac{\sigma}{\sigma-1}} \left(\int_1^N \left(q_n\left(k\right)\right)^{\frac{\sigma-1}{\sigma}} dk\right)^{\frac{\gamma}{\frac{\sigma}{\sigma-1}}-1} \frac{\sigma-1}{\sigma} \left(q_n^2\right)^{\frac{\sigma-1}{\sigma}-1} = \lambda p_n^2$$

Taking the ratios of the FOCs

$$\frac{\frac{dL}{dq_n^1}}{\frac{dL}{dq_n^2}} = \frac{p_n^1}{p_n^2}$$

$$\frac{\left(q_n^1\right)^{\frac{\sigma-1}{\sigma}-1}}{\left(q_n^2\right)^{\frac{\sigma-1}{\sigma}-1}} = \frac{p_n^1}{p_n^2}$$

$$\left(q_n^1\right) = \left(\frac{p_n^2}{p_n^1}\right)^{\sigma} \left(q_n^2\right)$$

Similarly, for industry K

$$\left(q_n^K\right) = \left(\frac{p_n^2}{p_n^K}\right)^{\sigma} \left(q_n^2\right)$$

Substituting q_n^k for each $k = 1, \ldots, K$ into the budget constraint

$$\int_1^N p_n(k)\left(q_n(k)\right) dk = \gamma Y_n$$

Expanding the budget constraint,

$$p_n^1 \left(q_n^1\right) dk + p_n^2 \left(q_n^2\right) dk + \ldots + p_n^K \left(q_n^K\right) dk = \gamma Y_n$$

Substituting for $\left(q_n^1\right) = \left(\frac{p_n^k}{p_n^1}\right)^{\sigma} \left(q_n^k\right)$

$$q_n^2 \left(p_n^2\right)^{\sigma} \left(\left(p_n^1\right)^{1-\sigma} dk + \ldots + \left(p_n^K\right)^{1-\sigma} dk\right) = \gamma Y_n$$

Sum the prices over all K industries.

$$q_n^2 \left(p_n^2\right)^{\sigma} \int_1^N \left(p_n(k)\right)^{1-\sigma} dk = \gamma Y_n$$

$$q_n^2 = \frac{\gamma Y_n}{\left(p_n^2\right)^{\sigma} \int_1^N \left(p_n(k)\right)^{1-\sigma} dk}$$

$$q_n^2 = \frac{\left(P_n^2\right)^{-\sigma}}{\int_1^N \left(p_n(k)\right)^{1-\sigma} dk} \gamma Y_n$$

Similarly, the demand function for the kth industry is

$$q_n^k = \frac{\left(p_n^k\right)^{-\sigma}}{\int_1^N \left(p_n(k)\right)^{1-\sigma} dk} \gamma Y_n.$$

The demand function for the non-tradable utility can be easily derived using the share parameter γ of the Cobb Douglas utility function as $q_n^0 = \frac{(1-\gamma)Y_n}{p_n^0}$.

Producer Problem

The producer's problem is to maximize profit

$$\pi_i^k = p_{in}^k S_i^k y_i^k - c_i^k l_i^k,$$

subject to the production constraint $y_i^k \tau_{in}^k = z_i^k l_i^k$, where z_i^k is the random productivity shock to produce good k in country i, and l_i^k is the composite input used in the production of good k in country i. p_{in}^k is the price at which country i sells commodity k to country n, $\tau_{in}^k = 1 + t_{in}$ is the trade cost with ad valorem rate t_{in} for exports from country i to country n, covering transport and trade barriers, S_i^k is the subsidy provided by the government in country i to the producers of commodity k, and c_i^k is the per-unit cost of production of commodity k in country i. The subsidy $S_i^k = 1 + s_i^k$, where s_i^k is the subsidy rate, creates a wedge between consumer price p_{in}^k and producer price $p_{in}^k S_i^k$.

Optimizing the profit function with respect to y_i^k yields the pricing rule $p_{in}^k S_i^k = \frac{c_i^k \tau_{in}^k}{z_i^k}$.

Ricardian Productivity

Productivity is described by

$$\ln z_i^k = \boldsymbol{\psi M}_i + \psi_0 v_i,$$

where $\boldsymbol{M}_i$ is the vector of systematic components (e.g., institutional factors) that influence the average productivity. The systematic components are not stochastic, but differ across countries. In contrast, $\psi_0 v_i$ is stochastic, and v_i captures the variations in productivity across countries and follows the Gumbel distribution. ψ_0 amplifies this variation of v_i. The cumulative probability density of the Gumbel distribution $F(v) = \Pr(v_i \leq v) = \exp[-\exp(-v)]$. From the price linkage equation and the productivity equation above, Let v be any constant v_i^k.

$$F(v) = \Pr(v_i \leq v) = \exp[-\exp(-v)]$$

Recall,

$$z_i^k = \left(\frac{c_i^k \tau_{in}^k}{p_{in}^k S_i^k}\right)$$

Taking the log of both sides

$$\ln z_i^k + \ln S_i^k = \ln c_i^k \tau_{in}^k - \ln p_{in}^k$$

Substitute for $\ln z_i^k$

$$\ln c_i^k \tau_{in}^k - \ln p_{in}^k = \boldsymbol{\psi M}_i + \psi_0 v_i + \ln S_i^k$$

Define $\theta = \frac{1}{\psi_0}$

$$v_i^k = \theta\left[\ln c_i^k \tau_{in}^k - \ln p_{in}^k - \ln S_i^k\right] - \{\theta \boldsymbol{\psi M}_i\}$$

Recall,

$$F(v) = \exp[-\exp(-v)]$$

$$\exp\left(-v_i^k\right) = \exp\left(\theta\left[-\ln c_i^k \tau_{in}^k + \ln p_{in}^k + \ln S_i^k\right] + \theta \boldsymbol{\psi M}_i\right)$$

$$\exp\left(-v_i^k\right) = \exp \theta\left[-\ln c_i^k \tau_{in}^k + \ln p_{in}^k + \ln S_i^k\right] * \exp\{\theta \boldsymbol{\psi M}_i\}$$

Define $\Gamma_i^k = \exp\{\theta \boldsymbol{\psi M_i}\}$

Hence,

$$\exp\left(-v_i^k\right) = \left(c_i^k \tau_{in}^k\right)^{-\theta} \left(p_{in}^k\right)^{\theta} \left(S_i^k\right)^{\theta} \Gamma_i^k$$

From $\Pr\left[v_i^k \leq v\right] = F(v) = \{\exp\left[-\exp(-v)\right]\}$,

$$F\left(v_i^k\right) = \left\{\exp\left[-\exp\left(-v_i^k\right)\right]\right\} = \exp\left[-\left\{\left(c_i^k \tau_{in}^k\right)^{-\theta}\left(p_{in}^k\right)^{\theta}\left(S_i^k\right)^{\theta}\Gamma_i^k\right\}\right]$$

Let $G_{in}^k(p)$ be the probability that a good from i can be sold in country n at a price less than p. We derive $G_{in}^k(p)$ as follows:

$$G_{in}^k(p) = \Pr(p_{in} \leq p) = \Pr\left[\frac{c_i^k\tau_{in}^k}{z_i^k S_i^k} \leq p\right] = \Pr\left[\frac{c_i^k\tau_{in}^k}{pS_i^k} \leq z_i^k\right] = 1 - \Pr\left[\frac{c_i^k\tau_{in}^k}{pS_i^k} \geq z_i^k\right] = 1 - \Pr\left[z_i^k \leq \frac{c_i^k\tau_{in}^k}{pS_i^k}\right]$$

$$= 1 - F\left[\frac{c_i^k\tau_{in}^k}{pS_i^k}\right]$$

$$G_{in}^k(p) = 1 - F\left[\frac{c_i^k\tau_{in}^k}{pS_i^k}\right] = 1 - F(v).$$

If $F\left(v_i^k\right) = \left\{\exp\left[-\exp\left(-v_i^k\right)\right]\right\} = \exp\left[-\left\{\left(c_i^k \tau_{in}^k\right)^{-\theta}\left(p_{in}^k\right)^{\theta}\left(S_i^k\right)^{\theta}\Gamma_i^k\right\}\right]$, it follows that

$$F(v) = \{\exp\left[-\exp(-v)\right]\} = \exp\left[-\left\{\left(c_i^k \tau_{in}^k\right)^{-\theta} p^{\theta}\left(S_i^k\right)^{\theta}\Gamma_i^k\right\}\right]$$

and

$$G_{in}^k(p) = 1 - F\left(\frac{c_i^k\tau_{in}^k}{pS_i^k}\right) = 1 - F(v) = 1 - \exp\left[-\left\{\left(c_i^k \tau_{in}^k\right)^{-\theta} p^{\theta}\left(S_i^k\right)^{\theta}\Gamma_i^k\right\}\right].$$

$G_{in}^k(p)$ is the CDF of prices country i presents to country n. $1 - G_{in}^k(p)$ is the probability that n's own price is lower than the price offered by i.

Trade Flows

Countries will buy from a country offering the cheapest price. Assuming country n buys from country i who is the cheapest supplier of good k. Then, the probability that this happens is the distribution of actual price of all goods in country n. $G_n^k(p)$ is the actual price distribution in country n. This is the price distribution for the best price offered to n. Before n buys from any country, it looks at all possible available prices including its own price distribution $\left(G_{nn}^k(p)\right)$. $G_n^k(p)$ is the probability that country n will buy at the lowest price considering all prices offered by every country. It is derived as follows:

$$G_n^k(p) = \Pr\left(p_{in}^k \leq p\right)$$

where p_n^k is the actual price paid by n and it is less than any other given constant price p offered by any other country

$$G_n^k(p) = \Pr\left(p_{in}^k \leq p\right) = 1 - \Pr\left(p_{in}^k \geq p\right) = 1 - \prod_{i=1}^{N} \Pr\left(p_{in}^k \geq p\right)$$

Recall, $G_{in}^k(p) = \Pr\left(p_{in}^k \leq p\right)$, it follows that $1 - G_{in}^k(p) = \Pr\left(p_{in}^k \geq p\right)$

Thus,

$$G_n^k(p) = \Pr\left(p_{in}^k \leq p\right) = 1 - \prod_{i=1}^{N}\left[1 - G_{in}^k(p)\right]$$

Since $G_{in}^{k}(p) = 1 - \exp\left[-\left\{\left(c_i^k \tau_{in}^k\right)^{-\theta} p^{\theta} \left(S_i^k\right)^{\theta} \Gamma_i^k\right\}\right]$ which is the probability that i sells to n at a price less that p, it follows that $1 - G_{in}^{k}(p)$ is the probability that i sells to n at a price greater that p. Since the distribution is i.i.d. draws for all countries, it implies that $\prod_{i=1}^{N}\left[1 - G_{in}^{k}(p)\right]$ is the probability that every other country sells to n at a price greater than p.

$1-\prod_{i=1}^{N}\left[1 - G_{in}^{k}(p)\right]$ is the probability that at least one of the countries sells to n at a price less than p. It follows that

$$G_{n}^{k}(p) = 1-\prod_{i=1}^{N}\left[1 - G_{in}^{k}(p)\right] = 1-\prod_{i=1}^{N}\left[1 - 1 + \exp\left[-\left\{\left(c_i^k \tau_{in}^k\right)^{-\theta} p^{\theta} \left(S_i^k\right)^{\theta} \Gamma_i^k\right\}\right]\right]$$

$$G_{n}^{k}(p) = 1 - \exp\left[-\left\{\sum_{i=1}^{N}\left(c_i^k \tau_{in}^k\right)^{-\theta} \left(S_i^k\right)^{\theta} \Gamma_i^k\right\} p^{\theta}\right].$$

Gravity/Bilateral Trade Flows

Let the probability that country i is the least cost supplier of kth good be ρ_{in}^{k}. Since all goods receive *i.i.d.* draws and there is a continuum of goods, by the law of large numbers, this probability will be equal to the fraction of goods i sells to n.

Recall that $p_{in}^{k} = \min\{p_{1n}, p_{2n}, \ldots, p_{Nn}\}$ i.e., country n buys from the least cost supplier.

$$\rho_{in}^{k} = \Pr\left(p_{in}^{k} \leq \min_{t \neq i} p_{tn}\right) = \int_{0}^{\infty} \Pr\left\{\min_{t \neq i} p_{tn} \geq p\right\} dG_{in}^{k}(p) = \int_{0}^{\infty} \prod_{t \neq i}\left[1 - G_{tn}^{k}(p)\right] dG_{in}^{k}(p)$$

$1 - G_{tn}^{k}(p)$ is the probability that s offers a price greater than p to country n while $G_{in}^{k}(p)$ is the probability that i offers price p to country n. And $\prod_{t \neq i}\left[1 - G_{tn}^{k}(p)\right]$ is the probability that every other country offers a price greater than p to country n. Integrating over all possible prices, $p \in (0,\infty)$, $\rho_{in}^{k} = \int_{0}^{\infty} \prod_{t \neq i}\left[1 - G_{tn}^{k}(p)\right] dG_{in}^{k}(p)$

Substituting $G_{tn}^{k}(p) = 1 - \exp\left[-\left\{\left(c_t^k \tau_{tn}^k\right)^{-\theta} p^{\theta} \left(S_t^k\right)^{\theta} \Gamma_t^k\right\}\right]$ and

$$G_{in}^{k}(p) = 1 - \exp\left[-\left\{\left(c_i^k \tau_{in}^k\right)^{-\theta} p^{\theta} \left(S_i^k\right)^{\theta} \Gamma_i^k\right\}\right]$$

into ρ_{in}^{k},

$$\rho_{in}^{k} = \int_{0}^{\infty} \prod_{t \neq i}\left[\exp\left[-\left\{\left(c_t^k \tau_{tn}^k\right)^{-\theta} p^{\theta} \left(S_t^k\right)^{\theta} \Gamma_t^k\right\}\right]\right]\left[\frac{d}{dp}\left(1 - \exp\left[-\left\{\left(c_i^k \tau_{in}^k\right)^{-\theta} p^{\theta} \left(S_i^k\right)^{\theta} \Gamma_i^k\right\}\right]\right)\right] dp$$

$$\rho_{in}^{k} = \left(\theta\left(S_i^k\right)^{\theta}\left(c_i^k \tau_{in}^k\right)^{-\theta} \Gamma_i^k\right) \int_{0}^{\infty} \prod_{t \neq i}\left[\exp\left[-\left\{\left(c_t^k \tau_{tn}^k\right)^{-\theta} p^{\theta} \left(S_t^k\right)^{\theta} \Gamma_t^k\right\}\right]\right]$$
$$\left[\left(p^{\theta-1}\right)\left(\exp\left[-\left\{\left(c_i^k \tau_{in}^k\right)^{-\theta} p^{\theta} \left(S_i^k\right)^{\theta} \Gamma_i^k\right\}\right]\right)\right] dp$$

where

$$\prod_{t\neq i}\left[\exp\left[-\left\{\left(c_t^k\tau_{tn}^k\right)^{-\theta}p^{\theta}\left(S_t^k\right)^{\theta}\Gamma_t^k\right\}\right]\right]=\exp\left(\sum_{t\neq i}\left(-\left(c_t^k\tau_{tn}^k\right)^{-\theta}p^{\theta}\left(S_t^k\right)^{\theta}\right)\Gamma_t^k\right)$$

.

$$\rho_{in}^k=\left(\theta\left(S_i^k\right)^{\theta}\left(c_i^k\tau_{in}^k\right)^{-\theta}\Gamma_i^k\right)\int_0^{\infty}\exp\left(\sum_{t\neq i}\left(-\left(c_t^k\tau_{tn}^k\right)^{-\theta}p^{\theta}\left(S_t^k\right)^{\theta}\Gamma_t^k\right)\right)$$

$$\left[\left(p^{\theta-1}\right)\left(\exp\left[-\left\{\left(c_i^k\tau_{in}^k\right)^{-\theta}p^{\theta}\left(S_i^k\right)^{\theta}\Gamma_i^k\right\}\right]\right)\right]dp$$

define $\Phi_n=\sum_{t=1}\left(c_t^k\tau_{tn}^k\right)^{-\theta}\left(S_t^k\right)^{\theta}\Gamma_t^k$

$$\rho_{in}^k=\left(S_i^k\right)^{\theta}\Gamma_i^k\left(c_i^k\tau_{in}^k\right)^{-\theta}\frac{1}{\Phi_n}\int_0^{\infty}\theta\Phi_n\exp\left(-\Phi_n p^{\theta}\right)\left(p^{\theta-1}\right)dp$$

Since $\int_0^{\infty}\theta\Phi_n\exp\left(-\Phi_n p^{\theta}\right)\left(p^{\theta-1}\right)dp=1$,

$$\rho_{in}^k=\frac{\left(S_i^k\right)^{\theta}\left(c_i^k\tau_{in}^k\right)^{-\theta}\Gamma_i^k}{\Phi_n}\Rightarrow\frac{\left(S_i^k\right)^{\theta}\left(c_i^k\tau_{in}^k\right)^{-\theta}\Gamma_i^k}{\sum_{t=1}\left(c_t^k\tau_{tn}^k\right)^{-\theta}\left(S_t^k\right)^{\theta}\Gamma_t^k}$$

ρ_{in}^k is also the fraction of total expenditure spent on commodity k in country n, $\frac{X_{in}^k}{X_n^k}$. Thus,

$$\text{(S1)}\qquad \rho_{in}^k=\frac{X_{in}^k}{X_n^k}=\frac{\left(\frac{c_i^k\tau_{in}^k}{S_i^k}\right)^{-\theta}\Gamma_i^k}{\sum_{t=1}\left(\frac{c_t^k\tau_{tn}^k}{S_t^k}\right)^{-\theta}\Gamma_t^k}=\frac{\left(\frac{c_i^k\tau_{in}^k}{S_i^k}\right)^{-\theta}\Gamma_i^k}{\Phi_n}$$

where $X_n^k=\sum_{i=1}^{N}X_{in}^k$ is the total value of expenditure in country n for commodity k of which X_{in}^k is the value of imports of commodity k by n from i including transport costs.

Empirical Model

First log-linearize (S1), $X_{in}^k=\frac{\left(\frac{c_i^k\tau_{in}^k}{S_i^k}\right)^{-\theta}\Gamma_i^k}{\Phi_n}X_n^k$, to get

$$\text{(S2)}\qquad \ln X_{in}^k=\theta\ln S_i-\theta\ln c_i^k-\theta\ln\tau_{in}^k+\ln X_n^k+\ln\Gamma_i^k-\ln\Phi_n,$$

then substitute into (S2) to derive

$$\ln X_{in}^k=\theta\ln S_i-\theta\ln c_i^k-\theta\ln\tau_{in}^k+\ln X_n^k+\ln\Gamma_i^k-\ln\Phi_n.$$

Substitute for $\ln c_i$, we define $c_i^k=\prod_{h=0}^{H}\left(r_{ih}\right)^{s_h^k}$, a Cobb-Douglas cost function for all factors of production used in producing commodity k, where r_{ih} is the price paid for factor h in country i and s_h^k is the share of payment to factor all factors in producing commodity k.

$$\sum_{h=0}^{H}s_h^k=1$$

$s_0^k = 1 - \sum_{h=1}^{h} s_h^k$ is the share of factors used in a reference industry 0.

$$\ln X_{in}^k = \theta \ln S_i - \theta \ln c_i - \theta \ln \tau_{in}^k + \ln X_n^k + \ln \Gamma_i^k - \ln \Phi_n$$

Substituting for $c_i^k = \prod_{h=0}^{H} (r_{ih})^{s_h^k} = r_{i0}^{s_0^k} * r_{i1}^{s_1^k} * r_{i2}^{s_2^k} * \ldots * r_{iH}^{s_H^k}$

$$\ln c_i^k = \ln\left(\prod_{h=0}^{H} (r_{ih})^{s_h^k}\right) = s_0^k \ln r_{i0} + s_1^k \ln r_{i1} + s_2^k \ln r_{i2} + \ldots + s_H^k \ln r_{iH}$$

$$\ln X_{ni}^k = -\theta\left(s_0^k \ln r_{i0} + s_1^k \ln r_{i1} + s_2^k \ln r_{i2} + \ldots + s_H^k \ln r_{iH}\right) + \theta \ln S_i - \theta \ln \tau_{in}^k + \ln X_n^k + \ln \Gamma_i^k - \ln \Phi_n$$

Substituting for $1 - \sum_{h=1}^{H} s_h^k = s_0^k$,

$$\ln X_{in}^k = -\theta\left(\ln r_{i0} - \sum_{h=1}^{H} s_h^k \ln r_{i0} + s_1^k \ln r_{i1} + s_2^k \ln r_{i2} + \ldots + s_H^k \ln r_{iH}\right)$$
$$+\theta \ln S_i - \theta \ln \tau_{in}^k + \ln X_n^k + \ln \Gamma_i^k - \ln \Phi_n$$

Since $s_1^k \ln r_{i1} + s_2^k \ln r_{i2} + \ldots + s_H^k \ln r_{iH} = \sum_{h=1}^{H} s_h^k \ln r_{ih}$ Substituting for $\sum_{h=1}^{H} s_h^k \ln r_{ih}$

$$\ln X_{in}^k = \theta\left(\sum_{h=1}^{H}\left(\ln \frac{r_{ih}}{r_{i0}}\right) s_h^k\right) + \theta \ln S_i - \theta \ln \tau_{in}^k + \ln X_n^k + \ln \Gamma_i^k - \ln \Phi_n - \theta \ln r_{i0}$$

where $\left(\ln \frac{r_{ih}}{r_{i0}}\right)$ is the relative price of factors. Since it is difficult to obtain the prices, we proxy this with information on the relative abundance of each factor $\frac{F_{ih}}{F_{i0}}$.

Because we estimate the empirical model in a panel data setting, at this point we introduce a time element (denoted by subscript t) for variables that change over time. Specify trade costs τ_{int}^k as a function of observed and unobserved gravity factors:

$$\tau_{int}^k = \exp\left\{\boldsymbol{\alpha}_1 \boldsymbol{E}_{int}^k + \gamma_{in}^k\right\}, \tag{S3}$$

where τ_{int}^k is the trade costs between countries i and n in year t, $\boldsymbol{E}_{int}^k$ is a vector of observable trade cost variables including time-varying factors such as tariffs and trade agreements, and γ_{in}^k is a fixed effect reflecting unobserved country pair-commodity-specific trade costs that do not change over time, such as distance or contiguous border.

Substituting (S3) into the expression for $\ln X_{in}^k$ above, we obtain

$$\ln X_{int}^k = \theta\left(\sum_{h=1}^{H}\left(\frac{F_{iht}}{F_{i0t}}\right) s_h^k\right) + \theta \ln S_{it}^k - \theta \boldsymbol{\alpha}_1 \boldsymbol{E}_{int}^k - \theta \gamma_{in}^k + \ln X_{nt}^k + \ln \Gamma_{it}^k - \ln \Phi_n - \theta \ln r_{i0t}. \tag{S4}$$

Using $\Gamma_{it}^k = \exp\{\theta \boldsymbol{\psi} \boldsymbol{M}_{it}\}$, subsuming Φ_n (the multilateral resistance term) with a fixed effect, augmenting (S4) with the exporters' production, X_{it}^k, and assuming a stochastic component ϵ_{int}^k, we obtain the following equation:

$$X_{int}^k = \exp\left\{\boldsymbol{\beta}_1 \boldsymbol{E}_{int}^k + \beta_2 \ln S_{it}^k + \sum_h \beta_3^h \left(\frac{F_{iht}}{F_{i0t}}\right) + \beta_4 X_{nt}^k + \beta_5 X_{it}^k + \boldsymbol{\beta}_6 \boldsymbol{M}_{it} + \delta_{in}^k\right\} + \epsilon_{int}^k,$$

where β's are the parameter estimates for the associated variables with $\boldsymbol{\beta}_1 = -\theta \boldsymbol{\alpha}_1$, $\beta_2 = \theta$, $\beta_3 = \theta s_h^k$, $\beta_6 = \theta \boldsymbol{\psi}$, and $\delta_{in}^k = \theta \gamma_{in}^k$.