The Gravity Equation in International Trade: Some Microeconomic Foundations and Empirical Evidence

Author(s): Jeffrey H. Bergstrand
Source: *The Review of Economics and Statistics*, Vol. 67, No. 3 (Aug., 1985), pp. 474-481
Published by: The MIT Press
Stable URL: https://www.jstor.org/stable/1925976
Accessed: 17-04-2020 23:09 UTC

THE GRAVITY EQUATION IN INTERNATIONAL TRADE: SOME MICROECONOMIC FOUNDATIONS AND EMPIRICAL EVIDENCE

Jeffrey H. Bergstrand*

Abstract—Despite the gravity equation's empirical success in "explaining" trade flows, the model's predictive potential has been inhibited by an absence of strong theoretical foundations. A general equilibrium world trade model is presented from which a gravity equation is derived by making certain assumptions, including perfect international product substitutability. If, however, trade flows are differentiated by origin as evidence suggests, the typical gravity equation is misspecified, omitting certain price variables. The last section presents empirical evidence supporting the notion that the gravity equation is a reduced form from a partial equilibrium subsystem of a general equilibrium model with nationally differentiated products.

THE "gravity equation" has been long recognized for its consistent empirical success in explaining many different types of flows, such as migration, commuting, tourism, and commodity shipping. Typically, the log-linear equation specifies that a flow from origin i to destination j can be explained by economic forces at the flow's origin, economic forces at the flow's destination, and economic forces either aiding or resisting the flow's movement from origin to destination.

In international trade, bilateral gross aggregate trade flows are explained commonly using the following specification:

$$PX_{ij} = \beta_0 (Y_i)^{\beta_1} (Y_j)^{\beta_2} (D_{ij})^{\beta_3} (A_{ij})^{\beta_4} u_{ij} \qquad (1)$$

where PX_{ij} is the U.S. dollar value of the flow from country i to country j, Y_i (Y_j) is the U.S. dollar value of nominal GDP in i (j), D_{ij} is the distance from the economic center of i to that of j, A_{ij} is any other factor(s) either aiding or resisting trade between i and j, and u_{ij} is a log-normally distributed error term with $E(\ln u_{ij}) = 0$. This specification was used in Tinbergen (1962), Poyhonen (1963a, 1963b), Pulliainen (1963), Geraci and Prewo (1977), Prewo (1978), and Abrams (1980).[1] Table 1 presents results from estimating a gravity equation similar to (1) for 15 OECD countries' trade flows.[2] Coefficient estimates are stable across years and are representative of trade gravity equations.

Despite the model's consistently high statistical explanatory power, its use for predictive purposes has been inhibited owing to an absence of strong theoretical foundations. The most common justification—used in Linnemann (1966), Aitken (1973), Geraci and Prewo (1977), Prewo (1978), Abrams (1980), and Sapir (1981)—was developed by Linnemann and asserts that the gravity model is a reduced form from a four-equation partial equilibrium model of export supply and import demand. Prices are always excluded since "they merely adjust to equate supply and demand."[3] However, critics have argued that this approach is "loose" and does not explain the multiplicative functional form.[4]

This study addresses these and other issues in developing further the microeconomic foundations of the gravity equation. The "looseness" critique is addressed by systematically describing assumptions necessary to generate a gravity equation similar to (1) from a general equilibrium framework. Specific, yet intuitively plausible, functions for utility and production generate the equation's multiplicative form. Section I presents a general equilibrium model of world trade derived from utility- and profit-maximizing agent behavior in N countries assuming a single factor of production in

Received for publication June 16, 1983. Revision accepted for publication December 12, 1984.

* Federal Reserve Bank of Boston.

The author is very grateful to J. David Richardson, Robert Baldwin, Rachel McCulloch, James Alm, Saul Schwartz and two anonymous referees for helpful comments on earlier drafts, and Doug Cleveland for research assistance. All errors remain the author's responsibility. The views expressed do not necessarily reflect the views of the Federal Reserve Bank of Boston or the Federal Reserve System.

[1] Linnemann (1966), Aitken (1973), Sattinger (1978) and Sapir (1981) used the same general specification, but also included exporter and importer populations. Microeconomic foundations of this alternative specification are discussed in Bergstrand (1984).

[2] The countries are Canada, United States, Japan, Belgium-Luxembourg, Denmark, France, West Germany, Italy, Netherlands, United Kingdom, Austria, Norway, Spain, Sweden, and Switzerland. The adjacency, EEC, and EFTA dummies are explained in the appendix.

[3] Linnemann (1966), p. 41; Leamer and Stern (1970), p. 146; Geraci and Prewo (1977), p. 68; Prewo (1978), p. 344; and Sapir (1981), p. 341.

[4] See, for example, Anderson (1979), p. 106 and Leamer and Stern (1970), p. 158.

TABLE 1.—TYPICAL GRAVITY EQUATION COEFFICIENT ESTIMATES FOR AGGREGATE TRADE FLOWS

Variables	1965	1966	1975	1976
Country i's Income	0.80[b]	0.80[b]	0.83[b]	0.84[b]
	(20.10)	(20.70)	(19.03)	(18.95)
Country j's Income	0.65[b]	0.66[b]	0.69[b]	0.69[b]
	(16.14)	(17.11)	(15.83)	(15.45)
Distance	−0.72[b]	−0.69[b]	−0.71[b]	−0.72[b]
	(12.15)	(12.11)	(10.35)	(10.21)
Adjacency Dummy	0.61[b]	0.63[b]	0.69[b]	0.74[b]
	(4.35)	(4.61)	(5.13)	(5.36)
EEC Dummy	0.35[a]	0.41[b]	0.24[a]	0.30[a]
	(2.02)	(2.46)	(1.80)	(2.23)
EFTA Dummy	0.69[b]	0.73[b]	0.66[b]	0.69[b]
	(4.94)	(5.40)	(3.35)	(3.46)
Constant	1.90[b]	1.54[b]	0.64	0.56
	(2.82)	(2.36)	(0.89)	(0.77)
Adjusted R^2	0.80	0.81	0.80	0.79
Root Mean Square Error	0.639	0.616	0.607	0.615
Number of Observations	210	210	210	210

Sources of data: See appendix.
Notes: All variables except dummies are expressed in natural logarithms; estimation is by ordinary least squares. t-statistics are in parentheses.
[a]Significant at the 5% level, one-tail test.
[b]Significant at the 1% level, one-tail test.

each. The reduced form from this system specifies the trade flow from i to j as a function of all countries' resource availabilities for a given year as well as trade barriers and transport-cost factors among all pairs of countries. However, this is not a "gravity equation." A bilateral trade flow equation must include exporter and importer incomes as exogenous variables to be a gravity model, by definition. Section II demonstrates that a gravity model similar to (1) can be explicitly derived from this system by making certain simplifying assumptions, including perfect substitutability of goods across countries. Yet if aggregate trade flows are differentiated by national origin, (1) misspecifies the gravity model by omitting certain price variables. In light of strong evidence implying the existence of nationally differentiated products, section III presents estimates of a gravity equation that includes price variables. The results support the notion that the gravity equation is a reduced form from a partial equilibrium subsystem of a general equilibrium trade model with nationally differentiated products.

I. A General Equilibrium Model of World Trade

Demand

In each country j in each year, consumers are assumed to share the constant-elasticity-of-substitution (CES) utility function:

$$U_j = \left\{ \left[\left(\sum_{\substack{k=1 \\ k \neq j}}^{N} X_{kj}^{\theta_j} \right)^{1/\theta_j} \right]^{\psi_j} + X_{jj}^{\psi_j} \right\}^{1/\psi_j}, \qquad j = 1, \ldots, N \quad (2)$$

where X_{kj} (X_{jj}) is the amount of k's aggregate good (j's domestically produced good) demanded by j's consumers, $\psi_j = (\mu_j - 1)/\mu_j$ where μ_j is the CES between domestic and importable goods in j ($0 \leqq \mu_j \leqq \infty$), and $\theta_j = (\sigma_j - 1)/\sigma_j$ where σ_j is the CES among importables in j ($0 \leqq \sigma_j \leqq \infty$). This specification allows the elasticity of substitution between domestic and importable goods and that among importables to differ.[5] Equation (2) simplifies to a standard CES function when μ_j and σ_j are constrained to be equal. Expenditures in j are constrained by income:

$$Y_j = \sum_{k=1}^{N} \bar{P}_{kj} X_{kj}, \qquad j = 1, \ldots, N \quad (3)$$

and $\bar{P}_{kj} = P_{kj} T_{kj} C_{kj} / E_{kj}$ where P_{kj} is the k-currency price of k's product sold in the j^{th} market,

[5]Some have argued that this "two-level" form suggests consumers first choose between domestic and importable goods according to relative aggregate (domestic/import) prices, and then choose among various foreign suppliers according to relative (bilateral) prices among importables. See Hickman and Lau (1973) and Geraci and Prewo (1982).

T_{kj} is one plus j's tariff rate on k's product ($T_{jj} = 1$), C_{kj} is the transport-cost (c.i.f./f.o.b.) factor to ship k's product to j ($C_{jj} = 1$), and E_{kj} is the spot value of j's currency in terms of k's currency ($E_{jj} = 1$). Henceforth, Σ'' will denote summation over $k = 1, \ldots, N$, $k \neq j$. Maximizing (2) subject to (3) generates $N(N+1)$ first-order conditions that are solvable for $N(N-1)$ bilateral aggregate import demand equations:

$$X_{ij}^{D} = Y_j \bar{P}_{ij}^{-\sigma_j} \left[\left(\Sigma'' \bar{P}_{kj}^{1-\sigma_j} \right)^{1/(1-\sigma_j)} \right]^{\sigma_j - \mu_j} \times \left\{ \left[\left(\Sigma'' \bar{P}_{kj}^{1-\sigma_j} \right)^{1/(1-\sigma_j)} \right]^{1-\mu_j} + P_{jj}^{1-\mu_j} \right\}^{-1} \quad i, j = 1, \ldots, N \ (i \neq j) \quad (4)$$

and N domestic demand equations:

$$X_{jj}^{D} = Y_j P_{jj}^{-\mu_j} \left\{ \left[\left(\Sigma'' \bar{P}_{kj}^{1-\sigma_j} \right)^{1/(1-\sigma_j)} \right]^{1-\mu_j} + P_{jj}^{1-\mu_j} \right\}^{-1}, \quad j = 1, \ldots, N. \quad (5)$$

Derivations, for above and below, are available from the author upon request.

Supply

In each country i in each year, firms maximize the profit function:

$$\Pi_i = \sum_{k=1}^{N} P_{ik} X_{ik} - W_i R_i, \quad i = 1, \ldots, N \quad (6)$$

where R_i is the amount available of the single, internationally immobile resource in a given year in i (e.g., labor hours) to produce the various outputs and W_i is the i-currency value of a unit of R_i. R in each country is allocated according to the constant-elasticity-of-transformation (CET) joint production surface:

$$R_i = \left\{ \left[\left(\sum_{\substack{k=1 \\ k \neq i}}^{N} X_{ik}^{\phi_i} \right)^{1/\phi_i} \right]^{\delta_i} + X_{ii}^{\delta_i} \right\}^{1/\delta_i}, \quad i = 1, \ldots, N \quad (7)$$

where $\delta_i = (1 + \eta_i)/\eta_i$ where η_i is i's CET between production for home and foreign markets ($0 \leqq \eta_i \leqq \infty$) and $\phi_i = (1 + \gamma_i)/\gamma_i$ where γ_i is i's CET for production among export markets ($0 \leqq \gamma_i \leqq \infty$). This specification allows the elasticity of transformation of supply between home and foreign markets and that among foreign markets to differ.[6] Equation (7) simplifies to a standard CET function when η_i and γ_i are constrained to be equal. Henceforth, Σ' will denote summation over $k = 1, \ldots, N$, $k \neq i$. Substituting (7) into (6) and maximizing the resulting equation yields N^2 first-order conditions that are solvable for $N(N-1)$ bilateral aggregate export supply equations:

$$X_{ij}^{S} = Y_i P_{ij}^{\gamma_i} \left[\left(\Sigma' P_{ik}^{1+\gamma_i} \right)^{1/(1+\gamma_i)} \right]^{-(\gamma_i - \eta_i)} \times \left\{ \left[\left(\Sigma' P_{ik}^{1+\gamma_i} \right)^{1/(1+\gamma_i)} \right]^{1+\eta_i} + P_{ii}^{1+\eta_i} \right\}^{-1} \quad i, j = 1, \ldots, N \ (i \neq j) \quad (8)$$

and N domestic supply equations:

$$X_{ii}^{S} = Y_i P_{ii}^{\eta_i} \left\{ \left[\left(\Sigma' P_{ik}^{1+\gamma_i} \right)^{1/(1+\gamma_i)} \right]^{1+\eta_i} + P_{ii}^{1+\eta_i} \right\}^{-1}, \quad i = 1, \ldots, N \quad (9)$$

where, with one factor of production, national income in i is constrained by

$$Y_i = W_i R_i, \quad i = 1, \ldots, N. \quad (10)$$

Equilibrium

Assume N^2 equilibrium conditions:

$$X_{ij} = X_{ij}^{D} = X_{ij}^{S}, \quad i, j = 1, \ldots, N \quad (11)$$

where X_{ij} is the actual trade flow volume from i to j. Equations (3)–(5) and (7)–(11) produce a general equilibrium model of world trade with $4N^2 + 3N$ equations and endogenous variables.

The reduced form for X_{ij} from this system would be a function of every R_i ($i = 1, \ldots, N$), T_{ij} and C_{ij} ($i, j = 1, \ldots, N$; $i \neq j$). Yet such a function is not a gravity equation, since this reduced form necessarily excludes endogenous exporter and importer incomes. The next section demonstrates that a gravity equation similar to (1), including incomes as exogenous variables, can nevertheless be derived from this system using certain additional assumptions.

II. Solving for the Gravity Equation: A Partial Equilibrium Approach

Assumption 1

The first assumption is that the market for the aggregate trade flow from i to j is small relative to

[6] Some have argued that this form suggests a "two-level" decision for producers analogous to that for consumers.

the other $N^2 - 1$ markets. This is analogous to the small open economy assumption frequently used in international finance studies, which implies that the foreign price level, the foreign interest rate, and foreign income can be treated as exogenous. The small market assumption implies that variations in X_{ij} and P_{ij} to equilibrate X_{ij}^D and X_{ij}^S have negligible impacts on Y_i, Y_j, P_{ii}, P_{jj}, $\Sigma' P_{ik}^{1+\gamma_i}$, and $\Sigma'' \overline{P}_{kj}^{1-\sigma_j}$. The general equilibrium system of $4N^2 + 3N$ equations can then be considered N^2 partial equilibrium subsystems of 4 equations each in 4 endogenous variables $(X_{ij}, X_{ij}^D, X_{ij}^S, P_{ij})$ and $3N$ constraints. Combining one each of (4) and (8) with one of (11) yields:

$$P_{ij} = \Bigg\{ Y_i^{-1} Y_j C_{ij}^{-\sigma_j} T_{ij}^{-\sigma_j} E_{ij}^{\sigma_j} \times \left(\sum{}' P_{ik}^{1+\gamma_i} \right)^{(\gamma_i - \eta_i)/(1+\gamma_i)} \times \left(\sum{}'' \overline{P}_{kj}^{1-\sigma_j} \right)^{(\sigma_j - \mu_j)/(1-\sigma_j)} \times \left[\left(\sum{}' P_{ik}^{1+\gamma_i} \right)^{(1+\eta_i)/(1+\gamma_i)} + P_{ii}^{1+\eta_i} \right] \times \left[\left(\sum{}'' \overline{P}_{kj}^{1-\sigma_j} \right)^{(1-\mu_j)/(1-\sigma_j)} + P_{jj}^{1-\mu_j} \right]^{-1} \Bigg\}^{1/(\gamma_i + \sigma_j)} \qquad (12)$$

and

$$X_{ij} = \Bigg\{ Y_i^{\sigma_j} Y_j^{\gamma_i} C_{ij}^{-\gamma_i \sigma_j} T_{ij}^{-\gamma_i \sigma_j} E_{ij}^{\gamma_i \sigma_j} \times \left(\sum{}' P_{ik}^{1+\gamma_i} \right)^{-\sigma_j(\gamma_i - \eta_i)/(1+\gamma_i)} \times \left(\sum{}'' \overline{P}_{kj}^{1-\sigma_j} \right)^{\gamma_i(\sigma_j - \mu_j)/(1-\sigma_j)} \times \left[\left(\sum{}' P_{ik}^{1+\gamma_i} \right)^{(1+\eta_i)/(1+\gamma_i)} + P_{ii}^{1+\eta_i} \right]^{-\sigma_j} \times \left[\left(\sum{}'' \overline{P}_{kj}^{1-\sigma_j} \right)^{(1-\mu_j)/(1-\sigma_j)} + P_{jj}^{1-\mu_j} \right]^{-\gamma_i} \Bigg\}^{1/(\gamma_i + \sigma_j)}$$
$$i, j = 1, \ldots, N \ (i \neq j). \qquad (13)$$

The small market assumption yields a reduced-form bilateral trade equation with Y_i and Y_j treated exogenously. A consequence of this assumption is that certain price terms are also treated exogenously.

Assumption 2

An assumption of identical utility and production functions across countries ensures that parameters in (12) and (13) are constant across all country pairings. This assumption is common to trade analyses, including the Heckscher-Ohlin-Samuelson model of interindustry trade and recent formal models of intraindustry trade, cf., Dixit and Norman (1980).[7] Combining (12), (13), and this assumption yields:

$$PX_{ij} = Y_i^{(\sigma-1)/(\gamma+\sigma)} Y_j^{(\gamma+1)/(\gamma+\sigma)} C_{ij}^{-\sigma(\gamma+1)/(\gamma+\sigma)} \times T_{ij}^{-\sigma(\gamma+1)/(\gamma+\sigma)} E_{ij}^{\sigma(\gamma+1)/(\gamma+\sigma)} \times \left(\sum{}' P_{ik}^{1+\gamma} \right)^{-(\sigma-1)(\gamma-\eta)/(1+\gamma)(\gamma+\sigma)} \times \left(\sum{}'' \overline{P}_{kj}^{1-\sigma} \right)^{(\gamma+1)(\sigma-\mu)/(1-\sigma)(\gamma+\sigma)} \times \left[\left(\sum{}' P_{ik}^{1+\gamma} \right)^{(1+\eta)/(1+\gamma)} + P_{ii}^{1+\eta} \right]^{-(\sigma-1)/(\gamma+\sigma)} \times \left[\left(\sum{}'' \overline{P}_{kj}^{1-\sigma} \right)^{(1-\mu)/(1-\sigma)} + P_{jj}^{1-\mu} \right]^{-(\gamma+1)/(\gamma+\sigma)} \qquad (14)$$

where PX_{ij} is the value of the trade flow from i to j $(PX_{ij} = P_{ij} X_{ij})$. Equation (14) is termed the "generalized" gravity equation. Given data limitations, (14) can be estimated by ordinary least squares (OLS) when a constant and log-normally distributed error term are appended. The specification is "general" because it treats exporter and importer incomes as *exogenous* yet imposes no restrictions on parameter values other than being identical across all country pairings.

Assumptions 3–6

A gravity model more similar to (1) that excludes all price terms can be obtained with four additional assumptions. Assuming perfect substitutability of goods internationally in production and consumption, perfect commodity arbitrage, zero tariffs, and zero transport costs (and normalizing all exchange rates to unity) implies $C_{ij} = T_{ij} = 1$ and $\overline{P}_{ij} = P$ for all $i, j = 1, \ldots, N$. Since $\sigma = \mu = \gamma = \eta = \infty$, (14) simplifies to

$$PX_{ij} = (1/2) Y_i^{1/2} Y_j^{1/2} \qquad (15)$$

which is similar to the gravity equation in (1).

[7]Likewise, Anderson (1979) assumed identical expenditure functions across countries in his theoretical foundation.

III. An Empirical Model of the Generalized Gravity Equation

While each of the previous six assumptions should be tested, this paper focuses on only the last four. Numerous studies over the past decade have revealed large and persistent deviations of national price levels from purchasing power parity (PPP). Isard (1977) found that for even the most disaggregated manufactured commodities for which U.S. and foreign prices could be matched, "relative price behavior... marks them as differentiated products, rather than near-perfect substitutes" (p. 942). Richardson (1978) found that commodity arbitrage did occur, but neither significantly for every commodity group nor at all for many groups. When commodity arbitrage did occur, it was imperfect. Kravis and Lipsey (1984) recently concluded, "we are pretty sure that equality of price levels among countries (PPP) will not turn out to be the norm, even in the long run" (p. 5). Thus, substantive deviations from PPP seem to persist even in the absence of tariffs and transport costs; the existence of these barriers only complicates problems.

This evidence suggests that assumptions 3–6 are restrictive and the generalized gravity equation would be more appropriate to estimate. This section presents an econometric version of (14) and discusses the results of its estimation.

Econometric Issues

The econometric analogue to (14) is distinguished from (1) predominantly by the former including price and exchange rate variables. The tariff variable in (14) can be proxied by dummy variables indicating the presence of preferential trading arrangements as in the basic gravity equation. The transport-cost factor can be proxied by the distance between economic centers of i and j and a dummy for adjacency.

Calculating the complex price terms in (14) is beyond this paper's scope; however, cross-country differences in aggregate price levels can be approximated by cross-country variation in aggregate price (or unit value) indexes. If (local-currency-denominated) export price indexes are calculated similarly for several countries using a common base period—the latter "well chosen" to avoid large divergences from PPP—then variation across countries in these indexes in a given year can approximate the cross-country variation of export price levels, that is, of $(\Sigma' P_{ik}^{1+\gamma})^{1/(1+\gamma)}$ across all i. Likewise, j's import price index can approximate $(\Sigma'' \bar{P}_{kj}^{1-\sigma})^{1/(1-\sigma)}$;[8] i's GDP deflator can approximate

$$\left[\left(\sum{}' P_{ik}^{1+\gamma}\right)^{(1+\eta)/(1+\gamma)} + P_{ii}^{1+\eta}\right];$$

and j's GDP deflator can approximate

$$\left[\left(\sum{}'' \bar{P}_{kj}^{1-\sigma}\right)^{(1-\mu)/(1-\sigma)} + P_{jj}^{1-\mu}\right].^{9}$$

The exchange rate index will indicate changes in the i-currency value of a unit of j's currency since the common base period. A rise in this index implies an appreciation (depreciation) of the importer's (exporter's) currency from the base.[10]

As before, the generalized gravity model is estimated for 1965, 1966, 1975 and 1976. This will help indicate the stability of parameter estimates from year to year, from one decade to another, and from "fixed" to "floating" exchange rates.

Previous partial-equilibrium time-series studies have suggested that price changes have multiyear effects on trade flows. Magee (1975) noted evidence of significant effects of price changes on the volume of traded goods five years after the price change. Base years 1960 for 1965/1966 estimates and 1970 for 1975/1976 estimates not only allow a generous lag length but also reflect years of "normal" economic activity—that is, neither years of recession troughs or expansion peaks nor years of exchange rate regime changes.[11]

[8] Export/import unit value indexes were used rather than export/import price indexes because the former were available for all 15 countries whereas the latter were available for only 4.

[9] Such considerations form the analytical basis for comparing internationally unit labor cost, unit value and aggregate price indexes in the IMF's *International Financial Statistics* (Cost and Price Comparisons). Critics may argue that construction and commodity composition of national price indexes varies widely across countries. Yet the aggregation/composition problem in cross-country index comparisons is no more severe than in time-series import and export demand studies. Country j's wholesale price index will also be used as a proxy for the weighted average of j's domestic and import prices.

[10] Local-currency-denominated import unit value indexes and importer GDP deflators implicitly reflect variations in exchange rates and tariff rates influencing $(\Sigma'' \bar{P}_{kj}^{1-\sigma})^{1/(1-\sigma)}$.

[11] Critics may argue that 1970 was not a year of "normal" economic activity. However, real GDP growth among industrial countries in 1970 was only 1 percentage point below the average for 1961–80. Consumer prices rose in 1970 only 0.4 percentage points below the average for the same period. 1970 avoided the 9-year global economic boom of the 1960s, yet preceded the 1971–73 transition to floating rates as well as the 1973–74 oil shock and its aftermath. Data are from the IMF's *International Financial Statistics Yearbook* (1983).

TABLE 2.—GENERALIZED GRAVITY EQUATION COEFFICIENT ESTIMATES FOR AGGREGATE TRADE FLOWS

Variables	1965	1966	1975	1976
Country i's Income	0.75[b]	0.76[b]	0.80[b]	0.84[b]
	(16.95)	(17.24)	(16.04)	(15.79)
Country j's Income	0.63[b]	0.66[b]	0.54[b]	0.56[b]
	(14.03)	(14.63)	(9.12)	(9.34)
Distance	−0.78[b]	−0.75[b]	−0.76[b]	−0.77[b]
	(12.70)	(12.47)	(11.22)	(10.92)
Adjacency Dummy	0.58[b]	0.59[b]	0.74[b]	0.76[b]
	(4.23)	(4.43)	(5.54)	(5.62)
EEC Dummy	0.32[a]	0.35[a]	0.18	0.18
	(1.82)	(2.07)	(1.37)	(1.35)
EFTA Dummy	0.67[b]	0.73[b]	0.62[b]	0.73[b]
	(4.92)	(5.45)	(3.20)	(3.67)
Exchange Rate (E_{ij})	0.58	0.30	0.74[a]	0.73
	(0.40)	(0.23)	(1.76)	(1.62)
i's Export Unit	−1.39[b]	−1.14[b]	−0.55	−0.96
Value Index	(3.03)	(2.83)	(0.90)	(1.55)
j's Import Unit	0.78	0.61	2.32[b]	1.85[b]
Value Index	(0.94)	(0.77)	(4.15)	(4.14)
i's GDP Deflator	−1.91[b]	−1.46[a]	−0.79	−0.05
	(2.37)	(2.00)	(1.17)	(0.07)
j's GDP Deflator	−1.28	−0.41	−1.13	−1.12[a]
	(1.43)	(0.50)	(1.55)	(1.67)
Constant	30.19[b]	19.62[a]	4.06	4.50
	(3.11)	(2.22)	(0.68)	(0.95)
Adjusted R^2	0.81	0.82	0.81	0.81
Root Mean Square Error	0.619	0.603	0.583	0.591
Number of Observations	210	210	210	210

Sources of data: See appendix.
Notes: See table 1.

Empirical Results

Some remarks are first in order regarding expected coefficient signs. Four variables have unambiguous expected impacts. A rise in j's income, an appreciation of j's currency, adjacency, and the presence of preferential trading arrangements should increase the trade flow from i to j; greater distance between these countries should reduce this flow. Remaining variables have ambiguous expected effects. If the elasticity of substitution among importables (σ) exceeds unity, i's income and GDP deflator will have positive and negative coefficients, respectively. If, additionally, the elasticity of transformation among exportables (γ) exceeds that between production for the domestic market and for abroad (η), i's export unit value index will have a negative coefficient. Country j's import unit value index will have a positive coefficient if the elasticity of substitution among importables exceeds that between domestic and imported products (μ). Finally, j's GDP deflator coefficient will be negative or positive depending upon whether μ is less than or greater than unity, respectively.

All coefficient estimate signs conform to those suggested above in all four years, as shown in table 2. Importer income, adjacency, and preferential trading arrangements have positive coefficient signs as in the basic gravity model; distance has a negative coefficient sign. An appreciation of the importer's currency increases the trade flow from i to j. A rise in exporter's income increases the trade flow, implying that σ exceeds unity. The negative coefficient estimate for i's GDP deflator supports this conclusion about σ. The negative coefficient estimate for i's export unit value index is consistent with σ greater than one and γ greater than η. The positive coefficient estimate for j's import unit value index is consistent with σ greater than μ. The negative coefficient estimate for j's GDP deflator suggests that μ is less than one. All these elasticity conclusions are intuitively plausible.

Most coefficient estimates for traditional gravity equation variables—incomes, distance, and dummies—are statistically significant in one-tail t-tests in all four years and are similar in value to estimates shown in table 1. Among price and exchange rate variables, 40% have statistically significant coefficient estimates in one-tail t-tests.

Interestingly, the exchange rate index coefficient estimate, which was insignificant under fixed exchange rates, became statistically significant in 1975 under flexible exchange rates, as this index became more volatile. The stability of coefficient estimates across years within decades suggests that the generalized gravity equation is rather robust.[12]

F-tests were conducted upon restrictions implied by assumptions 3–6, i.e., to test equation (15) versus (14). The restrictions imposed by these assumptions were overwhelmingly rejected.

Finally, what can be inferred about (1)? This equation cannot be explicitly derived from the theoretical model. Yet with the coefficients in (1) not constrained a priori, the specification implies that the elasticities of substitution and transformation are not expected to equal infinity. But if these elasticities do not equal infinity a priori, (14) is clearly more appropriate to estimate. Given the theoretical framework, (1) would not sensibly be estimated over (14), except in the absence of data for price and exchange rate variables. To be complete, *F*-tests rejected (1) relative to (14), i.e., that all price and exchange rate variables had zero coefficient estimates, at the 5% significance level in all four years and at the 1% level in three years.

IV. Conclusion

For twenty years, the gravity equation applied to international aggregate trade flows has been estimated in a specification represented by equation (1). The equation's empirical success induced curiosity about its underlying "behavior." Over the years, theories—with and without economic content—surfaced to explain this equation.

In this study, a general equilibrium model of world trade was introduced from which a gravity equation similar to (1) could be derived under certain assumptions. Many of these—such as perfect substitutability of goods internationally in consumption and production and perfect commodity arbitrage—have been refuted by recent empirical evidence, however. Because these assumptions were refutable, a "generalized" gravity equation could be derived. This methodology for understanding the trade gravity equation mirrors that used to augment understanding the gravity equation for migration flows. As Greenwood (1975) noted:

> Empirically based studies that have examined place-to-place migration within this framework have almost universally adopted for estimation purposes a modified gravity-type model of gross migration. The models are "gravity-type" in that migration is hypothesized to be directly related to size of the relevant origin and destination populations, and inversely related to distance. The models are "modified" in the sense that the variables of the basic gravity model are given behavioral content, and additional variables that are expected to importantly influence the decision to migrate are included in the estimated relationships. The additional variables are typically suggested as proxies for various arguments of individual utility functions. (p. 398)

Incomes make our generalized equation a "gravity-type" model. Yet price terms, derived from underlying utility and production functions, importantly influence trade flows and lend behavioral content to the gravity equation.

Empirically, the price and exchange rate variables have plausible and significant effects on aggregate trade flows. Coefficient estimates suggest that products are differentiated by national origin and commodity arbitrage is imperfect. Moreover, within the context of the theoretical model, these results imply that the elasticity of substitution among importables exceeds unity, the elasticity of substitution between domestic and imported products is below unity, and the elasticity of transformation among export markets exceeds that between production for domestic and foreign markets.

[12] The generalized gravity equation was also estimated for all four years substituting j's wholesale price index for j's GDP deflator. The results do not differ substantively from those in table 2. The small markets assumption enables the error term in the generalized gravity equation to be assumed uncorrelated with incomes, export and import price terms, and domestic price terms. If P_{ij} or X_{ij} significantly influences any of these variables, a simultaneous equations bias arises. The generalized gravity model was reestimated using (one-year) lagged values of incomes, unit value indexes, domestic price indexes, and the exchange rate index. The results do not differ substantively from those in table 2. However, this was not a powerful test since current and lagged values of these variables were highly correlated. Both sets of results are available from the author upon request.

APPENDIX

Bilateral trade flows are from OECD, *Statistics of Foreign Trade, Series C, Trade by Commodities*, various issues (c.i.f. import values; U.S. and Canadian f.o.b. values modified to conform). Incomes are GDPs in U.S. dollars from OECD *National Accounts*, various issues. For distance, sea distances are from U.S. Naval Oceanographic Office, *Distance Between*

Ports, H.O. Publication No. 151, U.S. Government Printing Office, 1965, and land distances are from *Rand McNally Road Atlas of Europe*, Rand McNally and Co., 1974. Land distances were multiplied by a factor of two following W. H. Gruber and R. Vernon, "The Technology Factor in a World Trade Matrix," in R. Vernon (ed.), *The Technology Factor in International Trade* (New York: National Bureau of Economic Research, 1970). Countries' economic centers are specified in Linnemann (1966). Exchange rates and export/import unit value indexes are from IMF *International Financial Statistics*, various issues. GDP deflators were calculated from nominal and real GDPs in OECD *National Accounts*. Wholesale price indexes are from UN *Statistical Yearbook*, 1968, 1977. The adjacency dummy equals 1 if both countries share a land border, 0 otherwise. The EEC (EFTA) dummy equals 1 if both countries are members of the European Economic Community (European Free Trade Association), 0 otherwise.

REFERENCES

Abrams, Richard K., "International Trade Flows under Flexible Exchange Rates," *Economic Review*, Federal Reserve Bank of Kansas City (Mar. 1980), 3–10.

Aitken, Norman D., "The Effect of EEC and EFTA on European Trade: A Temporal Cross-Section Analysis," *American Economic Review* 63 (Dec. 1973), 881–892.

Anderson, James E., "A Theoretical Foundation for the Gravity Equation," *American Economic Review* 69 (Mar. 1979), 106–116.

Bergstrand, Jeffrey H., "The Gravity Equation and the Factor-Proportions Theory of International Trade: A Theoretical and Empirical Synthesis," processed paper, Federal Reserve Bank of Boston, 1984.

Dixit, Avinash K., and Victor Norman, *Theory of International Trade* (London: Nisbet and Company, Ltd., 1980).

Geraci, Vincent J., and Wilfried Prewo, "Bilateral Trade Flows and Transport Costs," this REVIEW 59 (Feb. 1977), 67–74.

———, "An Empirical Demand and Supply Model of Multilateral Trade," this REVIEW 64 (Aug. 1982), 432–441.

Greenwood, Michael J., "Research on Internal Migration in the U.S.: A Survey," *Journal of Economic Literature* 13 (June 1975), 397–435.

Hickman, Bert G., and Lawrence J. Lau, "Elasticities of Substitution and Export Demands in a World Trade Model," *European Economic Review* 4 (1973), 347–380.

Isard, Peter, "How Far Can We Push the 'Law of One Price'?" *American Economic Review* 67 (Dec. 1977), 942–948.

Kravis, Irving B., and Robert E. Lipsey, "The Study of International Price Levels," research summary for the NBER Conference on Research on Recent and Prospective U.S. Trade Policy (Mar. 1984).

Leamer, Edward E., and Robert Stern, *Quantitative International Economics* (Chicago: Aldine Publishing Co., 1970).

Linnemann, Hans, *An Econometric Study of International Trade Flows* (Amsterdam: North-Holland Publishing Co., 1966).

Magee, Stephen P., "Prices, Incomes, and Foreign Trade," in P. B. Kenen (ed.), *International Trade and Finance* (Cambridge: Cambridge University Press, 1975).

Poyhonen, Pentti, "A Tentative Model for the Volume of Trade between Countries," *Weltwirtschaftliches Archiv*, Band 90, Heft 1 (1963a), 93–100.

———, "Toward a General Theory of International Trade," *Economiska Samfundets Tidskrift* 16 (1963b), 69–77.

Prewo, Wilfried, "Determinants of the Trade Pattern among OECD Countries from 1958 to 1974," *Jahrbucher fur Nationalekonomie und Statistik* 193 (Aug. 1978), 341–358.

Pulliainen, Kyosti, "A World Trade Study: An Econometric Model of the Pattern of the Commodity Flows of International Trade in 1948–60," *Economiska Samfundets Tidskrift* 16 (1963), 78–91.

Richardson, J. David, "Some Evidence on Commodity Arbitrage and the Law of One Price," *Journal of International Economics* 8 (May 1978), 341–352.

Sapir, Andre, "Trade Benefits under the EEC Generalized System of Preferences," *European Economic Review* 15 (1981), 339–355.

Sattinger, Michael, "Trade Flows and Differences between Countries," *Atlantic Economic Journal* 6 (July 1978), 22–29.

Tinbergen, Jan, *Shaping the World Economy: Suggestions for an International Economic Policy* (New York: The Twentieth Century Fund, 1962).