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THE GENERALIZED GRAVITY EQUATION, MONOPOLISTIC COMPETITION, AND THE FACTOR-PROPORTIONS THEORY IN INTERNATIONAL TRADE

Jeffrey H. Bergstrand*

Abstract—A general equilibrium model of world trade with two differentiated-product industries and two factors is developed to illustrate how the gravity equation, including exporter and importer populations as well as incomes, "fits in" with the Heckscher-Ohlin model of inter-industry trade and the Helpman-Krugman-Markusen models of intra-industry trade. The study extends the microeconomic foundations for a generalized gravity equation in Bergstrand (1985) to incorporate relative factor-endowment differences and non-homothetic tastes. Empirical estimates of this generalized gravity equation for single-digit SITC industry groups yield plausible inferences of their capital–labor intensities.

IN international trade gross bilateral trade flows across pairs of countries are explained commonly using the gravity equation:

$$PX_{ij} = \Psi_0 (Y_i)^{\Psi_1} (Y_i/L_i)^{\Psi_2} (Y_j)^{\Psi_3} \times (Y_j/L_j)^{\Psi_4} (D_{ij})^{\Psi_5} (A_{ij})^{\Psi_6} e_{ij} \qquad (1)$$

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 $i(j)$, $L_i(L_j)$ is the population 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 e_{ij} is a log-normally distributed error term. Estimates of Ψ_1, Ψ_2, Ψ_3 and Ψ_4 are typically positive; estimates of Ψ_5 are negative.[1] Formal theoretical foundations for the gravity equation have been provided in Anderson (1979), Bergstrand (1985), and Helpman and Krugman (1985, ch. 8). Although all three studies linked bilateral trade flows to exporter and importer incomes multiplicatively, exporter and importer per capita incomes (or populations) were ignored. Moreover, no one has attempted to fully integrate the gravity equation into the factor-proportions theory of trade.[2]

This study extends the microeconomic foundations for the gravity equation presented in Bergstrand (1985) to incorporate factor-endowment variables in the spirit of Heckscher-Ohlin (H-O) and taste variables in the spirit of Linder. The paper provides an explicit theoretical foundation for exporter and importer incomes and per capita incomes consistent with traditional (and newer) trade theories. Section I describes the taste assumptions. Section II describes the technology assumptions. Section III derives the "generalized" gravity equation. Section IV presents empirical

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[1] Bergstrand (1985) and Brada and Mendez (1985) cite previous empirical studies. An alternative specification to (1) uses L_i and L_j instead of Y_i/L_i and Y_j/L_j, respectively. Estimated coefficients of this alternative (denoted with asterisks) are related to (1)'s coefficients as $\Psi_2^* = -\Psi_2$, $\Psi_4^* = -\Psi_4$, $\Psi_1^* = \Psi_1 + \Psi_2$, and $\Psi_3^* = \Psi_3 + \Psi_4$.

[2] Linnemann (1966) and Leamer (1974) are the exceptions. Each *added* a variable(s) to reflect the commodity composition of the trade flow. In chapter 6, Linnemann added a variable representing the "goodness of fit" of i's exports to j's imports. Leamer estimated a modified gravity equation for various 2-digit SITC commodity classifications. While incorporating income and population variables, Leamer included *separate* measures of relative factor endowments as independent variables. Although income and population in Leamer's equations had no economic interpretation beyond being "stage-of-development" variables, income and population consistently outperformed the resistance variables (tariff, distance) and resource variables (per capita factor endowments). To capture the spirit of Linder (1961), two studies *added* the absolute difference between the two countries' per capita incomes as an explanatory variable to the basic gravity equation. Gruber and Vernon (1970) appended absolute per capita income differences to a specification like (1) as a "crude index of the difference in consumption patterns" (p. 256). Similarly, Thursby and Thursby (1987) added absolute per capita income differences to a generalized gravity equation without populations (see Bergstrand, 1985); Thursby and Thursby added this variable to "reflect differences in importer j's tastes" (p. 490). By contrast, this paper attempts to identify specifically the roles of income and population in a gravity equation like (1) for a particular commodity (group) using a Heckscher-Ohlin-Chamberlin-Linder framework *without* including additional measures of relative factor endowments (like Leamer) or taste differences (like Gruber and Vernon or Thursby and Thursby).

estimates for a two-factor, multi-industry, multi-country world. Section V concludes.

I. The Consumer

The representative consumer's behavior is modeled as a bilateral version of the one in Markusen (1986). The consumer is assumed to maximize a "nested" Cobb-Douglas–CES–Stone-Geary utility function subject to an income constraint; the resulting demand curves relate bilateral trade flows to national income, per capita income, and (c.i.f.) prices. Countries with similar per capita incomes will have similar demands, as suggested in Linder (1961, p. 94).

The utility function of consumer l in country j (U_{jl}) is

$$U_{jl} = \left[\left(\sum_{n=1}^{N}\sum_{h=1}^{H_{An}} X_{Ahnjl}^{\theta^A}\right)^{1/\theta^A}\right]^{\delta} \times \left[\left(\sum_{n=1}^{N}\sum_{h=1}^{H_{Bn}} X_{Bhnjl}^{\theta^B}\right)^{1/\theta^B} - \bar{X}_B\right]^{1-\delta}$$
$$-\infty < \theta^A, \theta^B < 1; 0 < \delta < 1 \quad (2)$$

where X_{Ahnjl} (X_{Bhnjl}) is the amount of the *manufactured* (*non-manufactured*) output of industry A's (B's) firm h in country n demanded by consumer-worker l in country j and $\bar{X}_B$ is the minimum consumption requirement of good B by any consumer (common to a Stone-Geary utility function). Expenditures are constrained by the consumer's nominal income measured on an aggregate expenditure basis (Y_{jl}):

$$Y_{jl} = \sum_{a=A,B}\sum_{n=1}^{N}\sum_{h=1}^{H_{an}}\left(P_{anj}T_{anj}/E_{nj}\right)X_{ahnjl} \quad (3)$$

where T_{anj} is one plus the exogenous tariff rate on industry a ($a = A, B$) exports from n to j, E_{nj} is the exogenous exchange rate between the two countries defined as n's currency per unit of j's currency, and P_{anj} is the f.o.b. price of firm h's output of industry a exported from country n to country j; for simplicity, assume that all firms in country n in an industry charge the same price in market j. Prices are denominated in j in a common monetary unit (the numeraire), the market for which is eliminated by Walras' Law (see Krugman, 1980). Henceforth Σ_n denotes the summation over $n = 1,\ldots, N$ and $\Sigma_h^A(\Sigma_h^B)$ denotes the summation over $h = 1,\ldots, H_{An}(H_{Bn})$.

Maximizing (2) subject to (3) yields a set of Armington-like bilateral import demand functions. Since consumers in country j are identical, we can aggregate demand curves across consumers and derive country j's (inverse) market demand curve for the output of A produced by firm g in country i:

$$P_{Aij} = \delta^{1/\sigma^A} X_{Agij}^{-1/\sigma^A}\left(Y_j\right)^{1/\sigma^A}\left(1 - y_j^{-1}\right)^{1/\sigma^A} T_{Aij}^{-1}E_{ij} \times \left[\sum_n \sum_h^A \left(P_{Ahjn}T_{Anj}/E_{nj}\right)^{1-\sigma^A}\right]^{-1/\sigma^A},$$
$$i = 1,\ldots, N \quad (4)$$

where $\sigma^A = 1/(1 - \theta^A)$, Y_j is j's nominal GDP and y_j is j's "per capita" GDP, where "capita" is expressed in terms of the minimum consumption requirement of B by the population. That is, $y_j = Y_j/(p_{Bj}\bar{X}_B)L_j$ where $p_{Bj} = [\Sigma_n\Sigma_h^B(P_{Bnj} \times T_{Bnj}/E_{nj})^{1-\sigma^B}]^{1/(1-\sigma^B)}$. Analogous demand curves for industry B's output exist with $(1 - y_j^{-1})$ replaced by $(1 + [\delta/(1 - \delta)]y_j^{-1})$. These functions imply that the national income elasticity of demand for $A(B)$ will be greater (less) than one if per capita income rises.

II. The Firm

The representative firm in country i is assumed to maximize profits in an environment similar to other recent models explaining the simultaneous existence of intra-industry and inter-industry trade. Each firm h in each of the two industries produces a uniquely differentiated product in a market that can be characterized as Chamberlinian monopolistic competition, using two factors of production, labor (L) and capital (K). The technology takes the linear form:

$$L_{agi} = \alpha_{La} + \beta_{La}X_{agi} \quad (5)$$

$$K_{agi} = \alpha_{Ka} + \beta_{Ka}X_{agi}$$
$$g = 1,\ldots, H_{ai};\ a = A, B;\ i = 1,\ldots, N \quad (6)$$

where $L_{agi}(K_{agi})$ is the labor (capital) required by firm g in industry a in country i to produce output X_{agi}, the α's are fixed setup costs, and the β's are the constant input requirements to produce a unit of output. All firms and countries share identical technology. The associated cost function for firm g in industry a:

$$S_{agi}(W_i, R_i, X_{agi}) = W_i L_{agi} + R_i K_{agi} = (W_i \alpha_{La} + R_i \alpha_{Ka}) + W_i \beta_{La} X_{agi} + R_i \beta_{Ka} X_{agi}$$

$$g = 1, \dots, H_{ai}; \quad a = A, B; \quad i = 1, \dots, N \quad (7)$$

where W_i and R_i are the given wage rate for labor and rental rate for capital, respectively (determined in competitive markets and denominated in i's currency), satisfies all the properties recommended in Helpman (1981). Assume labor and capital are in fixed supply in each country i:

$$L_i = \sum_h^A L_{Ahi} + \sum_h^B L_{Bhi} \quad (8a)$$

$$K_i = \sum_h^A K_{Ahi} + \sum_h^B K_{Bhi}. \quad (8b)$$

Following Geraci and Prewo (1982), each firm's output is assumed to be distributed among domestic and foreign markets according to the constant-elasticity-of-transformation (CET) function:

$$X_{agi} = \left[\sum_n (C_{ain} X_{agin})^{\phi^a} \right]^{1/\phi^a},$$

$$1 < \phi^a < \infty; \quad g = 1, \dots, H_{ai}; \quad a = A, B; \quad i = 1, \dots, N \quad (9)$$

where C_{ain} is the c.i.f./f.o.b. factor (> 1) to ship output in industry a from country i to country n; hence, only a portion of a shipment arrives at its destination with the part lost in transit representing the resources exhausted to ship the output, as in Krugman (1980). For $\phi^a > 1$, the transformation curve for output between domestic and foreign markets and among foreign markets is concave (like the typical production possibility frontier between two goods). Intuitively, each firm's behavior can be considered as a two-stage process. First, each firm *produces* a uniquely differentiated commodity under increasing returns to scale. In the second stage, each firm *distributes* its product to N markets (including the home market) under diminishing returns, similar to Krugman (1987).

Maximizing profit function:

$$\pi_{agi} = \sum_n P_{ain} X_{agin} - (W_i \alpha_{La} + R_i \alpha_{Ka}) - W_i \beta_{La} \left[\sum_n (C_{ain} X_{agin})^{\phi^a} \right]^{1/\phi^a} - R_i \beta_{Ka} \left[\sum_n (C_{ain} X_{agin})^{\phi^a} \right]^{1/\phi^a}$$

$$g = 1, \dots, H_{ai}; \quad a = A, B; \quad i = 1, \dots, N \quad (10)$$

for the representative firms in industries A and B yields equations for the marginal cost of exporting to any market j. For industry A:

$$X_{Agij} = H_{Ai}^{-1} (\beta_{KA}\beta_{LB} - \beta_{KB}\beta_{LA})^{-1} \times (\beta_{LB} K_i^* - \beta_{KB} L_i^*)(P_{Aij}/C_{Aij})^{\gamma^A} \times C_{Aij}^{-1} \left[\sum_n (P_{Ain}/C_{Ain})^{1+\gamma^A} \right]^{-\gamma^A/(1+\gamma^A)}$$

$$g = 1, \dots, H_{Ai}; \quad i = 1, \dots, N \quad (11)$$

where $\gamma^A = 1/(\phi^A - 1)$ and $K_i^*(L_i^*)$ is country i's capital (labor) stock net of resources consumed by set-up costs, e.g., $K_i^* = K_i - H_{Ai}\alpha_{KA} - H_{Bi}\alpha_{KB}$. Analogous marginal cost functions for industry B's firms exist with $(\beta_{LB} K_i^* - \beta_{KB} L_i^*)$ replaced by $(-\beta_{LA} K_i^* + \beta_{KA} L_i^*)$.

III. The Gravity Equation

Sections I and II provide an analytical framework for generating the gravity equation, as specified in (1). The "usual monopolistic competition assumption" that firms view the marginal utility of income as fixed is made; Y_j, y_j, and the bracketed price terms in (4) are treated as exogenous. The representative firm in A, for example, maximizes profits by supplying exports according to (11) given demand curve (4). Making the appropriate substitutions, solving for reduced forms, summing up across all firms in industry A in country i, and some mathematical manipulation yields the "generalized" gravity equation:

$$\begin{aligned} PX_{Aij} &= \delta^{(\gamma^A+1)/(\gamma^A+\sigma^A)}\left(Y_i^K\right)^{(\sigma^A-1)/(\gamma^A+\sigma^A)} \\ &\times(\beta_{KA}\beta_{LB}-\beta_{KB}\beta_{LA})^{-1} \\ &\times\left[\beta_{LB}-\beta_{KB}(K_i^*/L_i^*)^{-1}\right]^{(\sigma^A-1)/(\gamma^A+\sigma^A)} \\ &\times(Y_j)^{(\gamma^A+1)/(\gamma^A+\sigma^A)} \\ &\times\left(1-y_j^{-1}\right)^{(\gamma^A+1)/(\gamma^A+\sigma^A)} \\ &\times C_{Aij}^{-(\sigma^A-1)(1+\gamma^A)/(\gamma^A+\sigma^A)} \\ &\times T_{Aij}^{-\sigma^A(\gamma^A+1)/(\gamma^A+\sigma^A)} \\ &\times E_{ij}^{\sigma^A(\gamma^A+1)/(\gamma^A+\sigma^A)} \\ &\times\left\{\left[\sum_n(P_{Ain}/C_{Ain})^{1+\gamma^A}\right]^{1/(1+\gamma^A)}\right\}^{-\gamma^A(\sigma^A-1)/(\gamma^A+\sigma^A)} \\ &\times\left\{\left[\sum_n(P_{Anj}T_{Anj})/E_{nj}\right]^{1-\sigma^A}\right\}^{-(\gamma^A+1)/(\gamma^A+\sigma^A)} \end{aligned} \quad (12)$$

where PX_{Aij} is the value of the trade flow from i to j in industry A and Y_i^K is i's national output in terms of units of capital ($Y_i^K = K_i^* = \Sigma_h^A\beta_{KA}X_{Ahi} + \Sigma_h^B\beta_{KB}X_{Bhi}$).

Exporter i's national output and capital–labor ratio and importer j's income and per capita income enter explicitly with theoretically interpretable coefficients. In the typical gravity equation estimated, exporter GDP is a proxy of i's national output expressed in terms of units of capital. Exporter per capita GDP is a proxy of i's capital–labor endowment ratio. Importer GDP is j's national income. Importer per capita GDP is j's per capita income. Distance in the typical gravity equation is interpreted as the c.i.f./f.o.b. factor. Hence, A_{ij} should include measures of j's tariff rate on i's exports, the bilateral exchange rate, and the two complex price terms.

Typical gravity equations coefficient estimates for exporter and importer incomes and per capita incomes using specification (1) are all positive when aggregate trade flows are examined. If good A is the luxury in consumption, good A is capital intensive in production, and good A's elasticity of substitution exceeds unity, the theoretical coefficients for exporter and importer incomes and per capita incomes in equation (12) are all positively signed. Thus, typical gravity equation coefficient estimates for these variables in aggregate trade flow regressions suggest that the products exchanged tend to be capital intensive in production and luxuries in consumption; these are feasible inferences since estimation usually involves trade flows among major industrialized countries. Of course, expected coefficient signs would change as one or more of these assumptions change. Moreover, only in this special case of two industries and two factors can the capital or labor intensity of an industry be *inferred*.

IV. The Gravity Equation in a Multi-Industry World

Efforts to generalize the H-O model beyond two industries and two factors have usually failed. Moreover, empirical efforts to infer the relative factor abundance of a country given its technology matrix and its net exports have been shown recently to be flawed. Similarly, as Leamer and Bowen (1981, p. 1041) suggest, one cannot infer relative factor intensities of industries using the preceding gravity equation framework when there are more then two factors and two industries.

Yet Deardorff (1982) provided a "weak" generalization of the H-O theorem by proving that "countries tend to export those goods which use intensively their abundant factors" (p. 684). Analogously, the Rybczynski theorem can be generalized to show that in a multi-industry world an increase in a country's endowment of capital (labor) *tends* to increase the output of relatively capital-intensive (labor-intensive) industries; the proof is available upon request. Thus, the coefficient for exporter's per capita income (as a proxy for the exporter's K/L ratio) will have a certain *tendency* linked to whether the gravity equation is estimated for a capital- or labor-intensive industry. Consequently, a weak inference of the relative factor intensity of the industry can be made using exporter per capita income coefficient estimates from a gravity equation.

The empirical analysis of the generalized gravity equation here distinguishes industries by single-digit Standard Industrial Trade Classifications (SITCs) 0 through 8. The tariff variable is proxied by dummy variables indicating the presence of preferential trading arrangements, as is common. The transport-cost factor is proxied by the distance between economic centers of i and j and a dummy for adjacency.[3] The calculation of the complex price terms of (12) is beyond this paper's scope. However, as discussed in Bergstrand (1985) cross-country differences in such price levels can be approximated by cross-country variation in price indexes, if the latter are calculated similarly using a common base period "well chosen" to avoid large divergences from purchasing power parity. Aggregate wholesale price indexes (WPIs) are used.[4] 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. As in Bergstrand (1985), base years 1960 for 1965 and 1966 estimates and 1970 for 1975 and 1976 estimates were chosen. Estimation used the heteroskedasticity-consistent covariance-matrix estimator of White (1980), given cross-country data and the possibility of heteroskedastic error terms.

Some remarks are in order regarding expected coefficient signs. Four variables have unambiguous expected effects. A rise in j's income, an appreciation of j's currency, adjacency, and the presence of preferential trading arrangements should increase (the value of) the trade flow from i to j; greater distance between these countries should reduce this flow. If the elasticity of substitution in consumption for the industry (σ) exceeds unity, i's income, i's WPI, and j's WPI will have positive, negative, and positive coefficient estimates, respectively; conversely, if σ is less than one. If σ exceeds one, then a positive (negative) coefficient for exporter per capita income indicates a tendency for the industry to be capital (labor) intensive. Finally, a positive (negative) coefficient for importer per capita income indicates that the industry's output is a luxury (necessity) in consumption.

Tables 1–4 present coefficient estimates and t-statistics from the generalized gravity equations. Exporter and importer income coefficient estimates here conform to typical gravity equation results for aggregate trade flows in previous studies. Additionally, positive and statistically significant coefficient estimates for exporter income for each industry and year imply each industry's elasticity of substitution exceeds unity.

The coefficient estimate for exporter per capita income is positive and statistically significant for raw materials (SITC 2) in all four years, for chemicals (SITC 5) and machinery and transport equipment (SITC 7) in 1965, 1966, and 1975, for manufactures classified chiefly by material (SITC 6) in 1965 and 1966, and for food products (SITC 0) in 1975 and 1976, suggesting that these products *tend* to be capital intensive in production. This coefficient estimate is negative and statistically significant for beverages and tobacco (SITC 1) in all four years and miscellaneous manufactures (SITC 8) in 1975 and 1976, suggesting these products *tend* to be labor intensive. All of these results seem plausible.

The coefficient estimate for importer per capita income is positive and statistically significant for beverages and tobacco, manufactures classified chiefly by material, and miscellaneous manufactures in all four years, and for machinery and transport equipment in 1975 and 1976, suggesting that these products are luxuries. This coefficient estimate is negative and statistically significant for raw materials in 1975 and 1976, for fuel and fuel products (SITC 3) in 1965, and for chemicals in 1976, suggesting that these products are necessities. These results also seem plausible.

Traditional nonactivity variables, such as distance and dummies for adjacency, EC member-

[3] The countries are the United States, Canada, Japan, Austria, Belgium-Luxembourg, Denmark, France, Germany, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom. The sources for all data except populations are in Bergstrand (1985). Populations are from OECD *Annual Main Economic Indicators, 1955–71* for 1965 and 1966 and OECD *Monthly Main Economic Indicators*, January 1979 for 1975 and 1976. The adjacency dummy equals 1 if both countries share a common land border; 0 otherwise. The *EC* (*EFTA*) dummy assumes a value of 1 if both countries are members of the *EC* (*EFTA*); 0 otherwise. The *ECEFTA* dummy is for participation in the EC-EFTA free trade pact which applies to 1975 and 1976 trade flows; this dummy assumes a value of 1 if both countries are members of these trade groups and 0 otherwise.

[4] Aggregate wholesale price indexes are available for a wide range of countries whereas product price indexes by 1-digit SITC groups are not. OECD *Main Economic Indicators* (later monthly issues) publish producer price indexes by industry groups, and groups varying according to country. Nevertheless, cross-country variation in aggregate wholesale price indexes capture variation in these producer price indexes reasonably well, except for fuel. Cross-country correlation coefficients between 1976 wholesale price indexes and the respective 1976 industry-group producer price index (both based to 1970) when the latter had at least 7 observations are reported (the number of observations for each correlation is in parentheses): agriculture (7), 0.98; food products (11), 0.95; textiles (7), 0.93; metals (7), 0.89; chemicals (10), 0.87; fuel (13), 0.15. The poor correlation for fuel is not surprising since the OPEC shock of 1974 came between 1976 and the base year, 1970.

TABLE 1.—GENERALIZED GRAVITY EQUATION ESTIMATED FOR ONE-DIGIT SITC TRADE FLOWS, 1965

Right-Hand-Side Variables	SITC 0 Food & Live Animals	SITC 1 Beverages & Tobacco	SITC 2 Raw Materials	SITC 3 Fuels	SITC 4 Animal & Vegetable Oils & Fats	SITC 5 Chemicals	SITC 6 Manufactures Classified Chiefly by Material	SITC 7 Machinery & Transport Equipment	SITC 8 Miscellaneous Manufactures
Exporter Income	0.75[b]	1.67[b]	0.61[b]	1.87[b]	0.94[b]	0.92[b]	0.61[b]	0.95[b]	0.89[b]
	(8.80)	(13.81)	(8.83)	(11.81)	(7.46)	(14.49)	(10.76)	(15.31)	(14.65)
Exporter Per Capita	−0.12	−1.64[b]	0.73[b]	0.20	−0.25	0.41[b]	0.30[a]	1.40[b]	0.07
Income	(−0.68)	(−5.65)	(4.52)	(0.59)	(−0.90)	(2.68)	(2.34)	(8.61)	(0.47)
Importer Income	0.77[b]	0.76[b]	0.76[b]	0.68[b]	0.89[b]	0.67[b]	0.62[b]	0.54[b]	0.63[b]
	(8.45)	(6.00)	(10.87)	(4.42)	(6.60)	(10.69)	(10.59)	(7.51)	(9.63)
Importer Per Capita	0.32	1.13[b]	−0.08	−0.79[a]	−0.40	−0.22	0.48[b]	0.17	0.86[b]
Income	(1.46)	(3.94)	(−0.55)	(−2.34)	(−1.37)	(−1.53)	(3.89)	(1.17)	(6.03)
Distance	−0.84[b]	−1.77[b]	−0.70[b]	−2.80[b]	−1.10[b]	−0.93[b]	−0.86[b]	−0.70[b]	−0.67[b]
	(−6.24)	(−8.53)	(−7.15)	(−11.57)	(−5.62)	(−9.35)	(−9.89)	(−6.64)	(−6.72)
Adjacency Dummy	0.62[b]	−0.03	0.68[b]	0.99[a]	0.85[a]	0.60[b]	0.45[b]	0.75[b]	0.83[b]
	(2.80)	(−0.10)	(3.30)	(2.06)	(2.41)	(3.63)	(2.92)	(4.20)	(5.12)
EEC Dummy	0.43	−0.002	0.22	0.13	0.12	0.32[a]	0.57[b]	0.69[b]	0.62[a]
	(1.50)	(−0.005)	(0.98)	(0.25)	(0.37)	(1.97)	(3.39)	(3.12)	(2.52)
EFTA Dummy	0.33	0.96[b]	0.14	1.20[a]	0.56	0.73[b]	0.82[b]	0.42[a]	1.05[b]
	(1.28)	(2.64)	(0.59)	(2.50)	(1.37)	(4.08)	(5.20)	(2.33)	(6.50)
Appreciation of	7.83[b]	2.49	12.15[b]	−15.93[b]	−5.33	−5.62[a]	−1.36	−7.91[b]	−6.66[b]
Importer's Currency	(3.54)	(0.72)	(5.71)	(−3.35)	(−1.33)	(−2.52)	(−0.88)	(−4.19)	(−3.10)
Exporter WPI	0.62	0.12	−2.08	−6.05	−4.03	−2.41	−6.73[b]	0.88	−2.47
	(0.36)	(0.05)	(−1.59)	(−1.69)	(−1.64)	(−1.73)	(−5.61)	(0.53)	(−1.80)
Importer WPI	2.93	−4.62	0.07	−3.46	3.62	−0.17	0.65	0.95	−0.57
	(1.38)	(−1.61)	(0.04)	(−1.11)	(1.33)	(−0.13)	(0.56)	(0.74)	(−0.37)
Constant	−25.57	25.71	13.71	66.78	−2.37	17.19	45.96[b]	−14.07	18.80
	(−1.16)	(0.88)	(0.82)	(1.73)	(−0.09)	(1.08)	(3.45)	(−0.82)	(1.14)
Adjusted R^2	0.53	0.58	0.66	0.63	0.38	0.72	0.73	0.78	0.73
Root Mean Square Error	1.394	1.978	1.084	2.464	2.043	0.977	0.879	1.017	0.986
Number of Observations	240	240	240	240	240	240	240	240	240

Notes: All variables except dummies are expressed in natural logarithms. Estimation uses White's heteroskedasticity-consistent covariance matrix estimator. *t*-statistics are in parentheses.

[a] Significant in two-tail *t*-tests at the 5% level.

[b] Significant in two-tail *t*-tests at the 1% level.

TABLE 2.—GENERALIZED GRAVITY EQUATION ESTIMATED FOR ONE-DIGIT SITC TRADE FLOWS, 1966

	SITC 0	SITC 1	SITC 2	SITC 3	SITC 4	SITC 5	SITC 6	SITC 7	SITC 8
Right-Hand-Side Variables	Food & Live Animals	Beverages & Tobacco	Raw Materials	Fuels	Animal & Vegetable Oils & Fats	Chemicals	Manufactures Classified Chiefly by Material	Machinery & Transport Equipment	Miscellaneous Manufactures
Exporter Income	0.79[b]	1.68[b]	0.60[b]	1.93[b]	0.99[b]	0.89[b]	0.58[b]	0.93[b]	0.89[b]
	(9.58)	(13.98)	(9.14)	(12.71)	(7.44)	(13.89)	(10.65)	(14.16)	(14.64)
Exporter Per Capita	−0.01	−1.64[b]	0.84[b]	0.12	−0.09	0.46[b]	0.30[a]	1.28[b]	−0.06
Income	(−0.06)	(−5.47)	(5.29)	(0.33)	(−0.31)	(3.01)	(2.46)	(7.59)	(−0.35)
Importer Income	0.76[b]	0.82[b]	0.77[b]	0.74[b]	1.00[b]	0.69[b]	0.65[b]	0.60[b]	0.65[b]
	(8.90)	(6.72)	(11.08)	(4.86)	(6.92)	(10.92)	(11.83)	(8.23)	(10.45)
Importer Per Capita	0.33	1.06[b]	−0.12	−0.33	−0.28	−0.24	0.41[b]	0.07	0.79[b]
Income	(1.57)	(3.71)	(−0.82)	(−0.98)	(−0.92)	(−1.70)	(3.43)	(0.48)	(5.59)
Distance	−0.73[b]	−1.60[b]	−0.65[b]	−2.63[b]	−1.07[b]	−0.89[b]	−0.85[b]	−0.77[b]	−0.69[b]
	(−5.57)	(−7.74)	(−6.66)	(−10.83)	(−5.27)	(−9.20)	(−10.32)	(−7.16)	(−7.06)
Adjacency Dummy	0.65[b]	0.03	0.70[b]	0.88	0.69	0.61[b]	0.41[b]	0.71[b]	0.79[b]
	(3.26)	(0.09)	(3.38)	(1.82)	(1.81)	(3.56)	(2.72)	(4.12)	(4.56)
EEC Dummy	0.56[a]	0.28	0.30	0.20	0.65[a]	0.45[b]	0.69[b]	0.63[b]	0.72[b]
	(2.15)	(0.76)	(1.32)	(0.40)	(2.00)	(2.70)	(4.46)	(2.88)	(2.92)
EFTA Dummy	0.40	0.97[b]	0.03	0.97[a]	0.58	0.72[b]	0.88[b]	0.67[b]	1.17[b]
	(1.70)	(2.63)	(0.14)	(1.99)	(1.28)	(3.93)	(5.72)	(3.98)	(7.80)
Appreciation of	6.60[b]	2.72	10.16[b]	−10.57[a]	−7.23	−4.53[a]	−0.59	−7.69[b]	−5.55[b]
Importer's Currency	(3.58)	(0.93)	(5.69)	(−2.37)	(−1.84)	(−2.33)	(−0.47)	(−4.74)	(−2.94)
Exporter WPI	4.30[b]	4.08	−0.57	2.11	0.40	−3.94[b]	−7.47[b]	−2.61	−3.92[b]
	(2.88)	(1.57)	(−0.44)	(0.59)	(0.16)	(−2.85)	(−6.66)	(−1.56)	(−2.92)
Importer WPI	1.79	−2.90	1.36	−5.54	3.95	0.11	0.80	0.75	−0.31
	(0.91)	(−1.05)	(0.94)	(−1.80)	(1.32)	(0.09)	(0.72)	(0.58)	(−0.20)
Constant	−44.85[a]	−16.24	−6.50	21.62	−38.00	25.79	50.06[b]	11.85	27.24
	(−2.29)	(−0.56)	(−0.43)	(0.57)	(−1.32)	(1.69)	(3.89)	(1.68)	(1.66)
Adjusted R^2	0.56	0.58	0.68	0.62	0.40	0.72	0.74	0.77	0.73
Root Mean Square Error	1.309	1.946	1.046	2.444	2.146	0.974	0.834	1.030	0.974
Number of Observations	240	240	240	240	240	240	240	240	240

Notes: See table 1.

TABLE 3.—GENERALIZED GRAVITY EQUATION ESTIMATED FOR ONE-DIGIT SITC TRADE FLOWS, 1975

	SITC 0	SITC 1	SITC 2	SITC 3	SITC 4	SITC 5	SITC 6	SITC 7	SITC 8
Right-Hand-Side Variables	Food & Live Animals	Beverages & Tobacco	Raw Materials	Fuels	Animal & Vegetable Oils & Fats	Chemicals	Manufactures Classified Chiefly by Material	Machinery & Transport Equipment	Miscellaneous Manufactures
Exporter Income	0.63[b]	1.29[b]	0.60[b]	1.59[b]	1.10[b]	1.08[b]	0.92[b]	1.26[b]	1.15[b]
	(8.22)	(10.32)	(7.31)	(9.46)	(7.30)	(17.84)	(15.29)	(21.59)	(18.58)
Exporter Per Capita Income	0.47[a]	−1.54[b]	1.21[b]	0.58	0.34	0.33[a]	−0.10	0.32[a]	−0.85[b]
	(2.36)	(−4.68)	(5.81)	(1.27)	(0.87)	(2.20)	(−0.70)	(2.07)	(−5.03)
Importer Income	0.79[b]	0.92[b]	1.05[b]	1.04[b]	1.07[b]	0.84[b]	0.75[b]	0.67[b]	0.69[b]
	(9.40)	(5.71)	(11.57)	(5.23)	(7.13)	(13.21)	(13.36)	(10.88)	(11.34)
Importer Per Capita Income	0.001	1.71[b]	−0.54[b]	0.25	−0.45	−0.12	0.41[b]	0.32[a]	0.75[b]
	(0.01)	(5.20)	(−2.68)	(0.59)	(−1.15)	(−0.76)	(3.25)	(2.27)	(5.28)
Distance	−0.76[b]	−1.85[b]	−0.84[b]	−1.67[b]	−1.32[b]	−0.72[b]	−0.56[b]	−0.43[b]	−0.37[b]
	(−6.07)	(−6.65)	(−6.92)	(−5.87)	(−5.16)	(−7.19)	(−5.91)	(−4.22)	(−3.81)
Adjacency Dummy	0.83[b]	−0.02	0.66[b]	1.31[b]	0.78[a]	0.71[b]	0.71[b]	0.73[b]	0.93[b]
	(4.18)	(−0.06)	(3.16)	(2.77)	(2.05)	(3.53)	(4.68)	(4.52)	(5.30)
EEC Dummy	0.79[b]	−0.11	0.08	0.88	0.93[a]	0.90[b]	0.85[b]	1.11[b]	1.09[b]
	(2.90)	(−0.22)	(0.36)	(1.60)	(2.08)	(4.65)	(4.60)	(5.68)	(5.48)
EFTA Dummy	0.36	0.56	0.71[a]	0.12	0.30	1.04[b]	1.82[b]	1.69[b]	1.82[b]
	(1.22)	(1.17)	(2.08)	(0.15)	(0.43)	(3.79)	(9.83)	(6.86)	(7.47)
ECEFTA Dummy	−0.21	−0.80	0.56[a]	1.38[b]	0.72	0.92[b]	1.18[b]	1.25[b]	1.08[b]
	(−0.96)	(−1.88)	(2.38)	(2.70)	(1.74)	(4.97)	(7.86)	(7.58)	(5.87)
Appreciation of Importer's Currency	1.44	−1.99	5.07[b]	6.39[b]	0.51	0.76	−0.30	−1.83[b]	−2.65[b]
	(1.86)	(−1.52)	(6.20)	(3.31)	(0.36)	(1.24)	(−0.54)	(−3.26)	(−4.87)
Exporter WPI	0.67	5.07[b]	−1.62	−3.71	−0.17	−3.04[b]	−0.66	1.26	0.96
	(0.54)	(2.63)	(−1.29)	(−1.24)	(−0.08)	(−3.35)	(−0.78)	(1.59)	(1.19)
Importer WPI	2.58[a]	0.91	5.66[b]	11.19[b]	−0.61	1.19	0.94	−0.87	−2.78[b]
	(2.29)	(0.44)	(4.50)	(3.88)	(−0.27)	(1.26)	(1.09)	(−1.07)	(−3.14)
Constant	−25.40[b]	−48.39[b]	−33.95[b]	−66.88[b]	−3.33	6.17	−7.04	−12.21[a]	4.88
	(−3.31)	(−3.69)	(−4.11)	(−3.57)	(−0.21)	(0.86)	(−1.22)	(−2.22)	(0.80)
Adjusted R^2	0.65	0.61	0.63	0.55	0.49	0.78	0.76	0.81	0.77
Root Mean Square Error	1.064	1.809	1.132	2.482	2.009	0.848	0.734	0.760	0.803
Number of Observations	240	240	240	240	240	240	240	240	240

Notes: See table 1.

TABLE 4.—GENERALIZED GRAVITY EQUATION ESTIMATED FOR ONE-DIGIT SITC TRADE FLOWS, 1976

	SITC 0	SITC 1	SITC 2	SITC 3	SITC 4	SITC 5	SITC 6	SITC 7	SITC 8
Right-Hand-Side Variables	Food & Live Animals	Beverages & Tobacco	Raw Materials	Fuels	Animal & Vegetable Oils & Fats	Chemicals	Manufactures Classified Chiefly by Material	Machinery & Transport Equipment	Miscellaneous Manufactures
Exporter Income	0.70[b]	1.22[b]	0.72[b]	1.54[b]	1.32[b]	1.05[b]	0.94[b]	1.35[b]	1.16[b]
	(8.77)	(8.63)	(9.13)	(8.88)	(8.17)	(16.81)	(14.89)	(20.29)	(16.91)
Exporter Per Capita Income	0.62[b]	−1.39[b]	1.36[b]	1.57[b]	0.49	0.26	−0.21	0.21	−0.95[b]
	(3.03)	(−3.91)	(6.14)	(2.93)	(1.20)	(1.57)	(−1.38)	(1.15)	(−4.93)
Importer Income	0.72[b]	1.20[b]	0.91[b]	1.21[b]	0.93[b]	0.96[b]	0.79[b]	0.69[b]	0.72[b]
	(8.04)	(7.16)	(10.23)	(6.12)	(5.70)	(15.04)	(13.25)	(9.74)	(10.57)
Importer Per Capita	0.12	1.68[b]	−0.56[b]	0.50	−0.53	−0.36[a]	0.37[b]	0.45[b]	0.82[b]
	(0.62)	(4.76)	(−2.74)	(1.08)	(−1.33)	(−2.07)	(2.74)	(2.70)	(4.67)
Distance	−0.79[b]	−1.85[b]	−0.88[b]	−2.07[b]	−1.42[b]	−0.77[b]	−0.57[b]	−0.44[b]	−0.36[b]
	(−6.01)	(−6.93)	(−7.94)	(−7.74)	(−5.27)	(−7.95)	(−6.07)	(−3.94)	(−3.58)
Adjacency Dummy	0.83[b]	−0.09	0.64[b]	1.36[b]	0.77[a]	0.62[b]	0.70[b]	0.78[b]	0.97[b]
	(4.20)	(−0.25)	(3.40)	(3.01)	(2.04)	(3.16)	(4.66)	(4.61)	(5.36)
EEC Dummy	0.73[b]	0.09	0.002	1.01	0.97[a]	1.04[b]	1.05[b]	1.32[b]	1.23[b]
	(2.69)	(0.19)	(0.01)	(1.84)	(2.00)	(5.31)	(5.61)	(6.26)	(5.87)
EFTA Dummy	0.26	0.85	0.80[b]	0.59	0.53	1.25[b]	1.93[b]	1.90[b]	1.81[b]
	(0.86)	(1.62)	(2.67)	(0.78)	(0.79)	(4.57)	(10.40)	(7.11)	(6.61)
ECEFTA Dummy	−0.26	−0.56	0.52[a]	1.54[b]	0.76	1.09[b]	1.34[b]	1.44[b]	1.20[b]
	(−1.17)	(−1.27)	(2.46)	(2.96)	(1.74)	(5.93)	(8.68)	(7.80)	(6.03)
Appreciation of Importer's Currency	0.37	1.77	1.74[a]	7.14[b]	−2.42	2.14[b]	−0.41	−1.86[b]	−2.04[b]
	(0.40)	(1.10)	(2.05)	(3.46)	(−1.55)	(3.31)	(−0.64)	(−2.78)	(−3.28)
Exporter WPI	1.36	−0.19	1.19	−4.28	4.92[a]	−4.00[b]	−0.22	1.77[a]	0.88
	(1.03)	(−0.08)	(0.92)	(−1.41)	(2.20)	(−4.38)	(−0.24)	(1.97)	(0.96)
Importer WPI	1.25	4.32[a]	2.30[a]	11.72[b]	−4.16	2.66[b]	0.43	−1.05	−2.05[a]
	(1.06)	(2.00)	(2.02)	(4.12)	(−1.92)	(2.85)	(0.49)	(−1.14)	(−2.29)
Constant	−21.19[b]	−37.98	−29.92[b]	−68.39[b]	−15.26	2.36	−7.08	−16.13[b]	−0.34
	(−3.32)	(−3.26)	(−4.67)	(−4.68)	(−1.27)	(0.41)	(−1.55)	(−3.25)	(−0.06)
Adjusted R^2	0.66	0.62	0.63	0.60	0.52	0.79	0.77	0.79	0.75
Root Mean Square Error	1.043	1.824	1.058	2.471	1.990	0.840	0.736	0.827	0.857
Number of Observations	240	240	240	240	240	240	240	240	240

Notes: See table 1.

ship, EFTA membership, and the EC-EFTA trade pact, generally have the expected coefficient signs and are often significant. Distance's coefficient estimate sign is negative and statistically significant in all 36 regressions. Adjacency's coefficient estimate is positive in all industries but beverages and tobacco, and is positive and statistically significant in all but beverages and tobacco, fuels, and animal and vegetable oil and fats (some years). The dummies for trade-preference membership are positive in 84 and 90 cases and are statistically significant in 56 cases.

Nontraditional nonactivity variables—exporter and importer WPI's and the exchange rate—do not fare as well; coefficient estimates have mixed signs and are usually statistically insignificant. Aggregate WPIs— being crude proxies for industry-specific producer price indexes—may explain these poor results. Finally, the coefficient estimate for the appreciation of the importer's currency—anticipated to be positive—is positive and statistically significant in 9 (of 36) cases, but is negative and statistically significant in 12 cases. Although the latter results can be discounted for 1965 and 1966 because of little variation in this variable during the pre-1973 regime of "fixed" exchange rates, the remaining negative and statistically significant exchange rate coefficient estimates in 1975 and 1976 for two industries, machinery and transport equipment and miscellaneous manufactures, cannot be so readily explained.

V. Conclusion

The purpose of this study was to offer an analytical framework for understanding the gravity equation that is consistent with modern theories of inter-industry and intra-industry trade. Using a two-factor, two-industry, N-country Heckscher-Ohlin-Chamberlin-Linder model, exporter income and per capita income could be interpreted as national output in terms of units of capital and the country's capital–labor endowment ratio, respectively. Changes in importer income and per capita income could be interpreted as alterations of expenditure capabilities and taste preferences á la Linder, respectively.

The generalized gravity equation explains empirically between 40% and 80% of the variation across countries in one-digit SITC trade flows. Exporter and importer income coefficients match those from typical and generalized gravity equations estimated for aggregate trade flows. Exporter per capita income coefficient estimates suggest that raw materials, chemicals, machinery and transport equipment, manufactures classified chiefly by material, and food products tend to be capital intensive in production and that beverages and tobacco and miscellaneous manufactures tend to be labor intensive in production. Importer per capita income coefficient estimates suggest that manufactures tend to be luxuries and that raw materials, fuels, and chemicals tend to be necessities in consumption. Since price and exchange rate coefficients have mixed signs probably owing to the crudeness of the proxies, future research should refine the proxies for the complex theoretical price terms, perhaps along the line suggested in Kravis, Heston and Summers (1982); moreover, such research should extend the level of disaggregation.

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