Journal of International Economics 53 (2001) 1–27
Journal of INTERNATIONAL ECONOMICS
www.elsevier.nl/locate/econbase

The growth of world trade: tariffs, transport costs, and income similarity

Scott L. Baier, Jeffrey H. Bergstrand*

Department of Finance and Business Economics, University of Notre Dame, Notre Dame, IN 46556-0399, USA

Received 6 October 1997; accepted 9 November 1999

Abstract

In the 25th anniversary issue of the *Brookings Papers on Economic Activity*, Paul Krugman [Krugman, P., 1995. Growing world trade: Causes and consequences. Brookings Papers on Economic Activity (1), 327–377] stated that the answer to the fundamental question ''Why has world trade grown?'' remains surprisingly disputed. He noted that journalistic discussion tends to view the growth of world trade as due to technology-led declines in transportation costs, while economists argue that policy-led multilateral and bilateral trade liberalization has spurred this growth. A third potential explanation raised by Elhanan Helpman [Helpman, E., 1987. Imperfect competition and international trade: Evidence from fourteen industrial countries. Journal of the Japanese and International Economies 1 (1) 62–81] and Hummels and Levinsohn (1995) [Hummels, D., Levinsohn, J., 1995. Monopolistic competition and international trade: Reconsidering the evidence. Quarterly Journal of Economics 110 (3) 799–836] is increased similarity of countries' incomes. The purpose of this study is to disentangle from one another (and from income growth) the relative effects of transport-cost reductions, tariff liberalization, and income convergence on the growth of world trade among several OECD countries between the late 1950s and the late 1980s. In the context of the model, the empirical results suggest that income growth explains about 67%, tariff-rate reductions about 25%, transport-cost declines about 8%, and income convergence virtually none of the average world trade growth of our post World War II sample.

Keywords: Trade; Tariffs; Transport Costs; Imperfect Competition; Gravity Equation

JEL classification: F12

*Corresponding author. Tel.: +1-219-631-6761; fax: +1-219-631-5255.
E-mail address: bergstrand.1@nd.edu (J.H. Bergstrand).

0022-1996/01/$ – see front matter
PII: S0022-1996(00)00060-X

1. Introduction

In the 25th anniversary issue of the *Brookings Papers on Economic Activity*, which focused on international economic issues, Krugman (1995) asked two very fundamental questions: Why has world trade grown, and what are the consequences of that growth? Both topics, he claimed, are surprisingly disputed. Regarding the first question, he noted that:

> Most journalistic discussion of the growth of world trade seems to view growing integration as driven by a technological imperative – to believe that improvements in transportation and communication technology constitute an irresistible force dissolving national boundaries. International economists, however, tend to view much, though not all, of the growth of trade as having essentially political causes, seeing its great expansion after World War II largely as a result of the removal of the protectionist measures that had constricted world markets since 1913 (p. 328).

With one of the leading international economists of our time raising this disputed issue to the fore, an empirical examination of the predominant sources of postwar growth of world trade seems warranted.

In the spirit of Krugman's article, Feenstra (1998) suggests four possible factors to explain the growth of world trade. Like Krugman, he notes the two sources that 'come to mind immediately' are trade liberalization and falling transportation costs. A third possible explanation is that trade has grown because economies have converged in economic size, as suggested in Helpman (1987) and Hummels and Levinsohn (1995). A fourth possibility is increased outsourcing; as the production process 'disintegrates' internationally and multinational firms become more vertically specialized, intermediate goods cross borders multiple times increasing world trade relative to output.

The primary purpose of this study is to disentangle from one another the relative empirical contributions of transport-cost reductions, trade liberalization, income convergence, and income growth to the expansion of world trade in the post WWII period.[1] We hope to provide a benchmark for the cross-sectional determinants of

[1]The possible role of increased vertical specialization is beyond the scope of this paper as the theoretical foundation for our empirical work is a standard trade model in *final* goods. See Hummels et al. (1998) and Feenstra (1998) on the role of increased vertical specialization.

trade growth.[2] The methodology employs the gravity equation, which Bayoumi and Eichengreen (1997) termed the 'workhorse for empirical studies of the pattern of trade' (p. 142) and Rauch (1999) noted is the 'standard empirical framework used to predict how countries match up in international trade' (p. 10).

In the context of Krugman's quote, the conclusion for the impatient reader is an interesting one: while neither side can take full credit, *economists have the edge!* In the context of our theoretical model, tariff-rate reductions have had roughly three times the impact upon the growth of world trade as transport-cost declines, other factors held constant. The remainder of this paper is as follows. Section 2 describes the empirical methodology used and the analytical justification for its use. Section 3 discusses econometric issues. Section 4 describes the data. Section 5 provides the empirical results on the relative economic impacts of transport-cost declines, tariff reductions, income convergence, and income growth on the enlargement of world trade among OECD countries based upon a reduced-form equation from a standard general equilibrium model of international trade in final goods and using bilateral trade flows. Section 6 concludes.

2. Methodological issues

As noted by Eichengreen and Irwin (1995), 'a standard framework for investigating the pattern of trade is the gravity model, which relates the value of bilateral flows to national income, population, distance, and contiguity' (p. 8). The empirical success of the gravity model for explaining and predicting cross-sectional international trade pattern levels is well documented and has a rich history beginning with Nobel laureate Jan Tinbergen (1962); see Baldwin (1994); Oguledo and MacPhee (1994); Frankel (1997, Ch. 4), and Deardorff (1998) for useful surveys.[3] The gravity equation is a log-linear cross-sectional specification, relating the nominal bilateral trade flow from exporter i to importer j in any year (PX_{ij}) to the exporting and importing countries' nominal gross domestic products (GDP_i and GDP_j, respectively), distance between their economic centers (D_{ij}), and

[2] This is not, of course, the first paper to examine empirically the sources of post-WWII trade growth. Rose (1991) examines numerous factors in a reduced-form regression to explain trade growth among 14 countries. For the small economies, he finds that changing industrial structure and tariffs, but not transport costs, have contributed to the growth of trade (relative to output). However, Rose uncovers no significant trade growth determinants for large economies. Rose's empirical findings are not addressed though in the context of an explicit general equilibrium model. Also, Bayoumi and Eichengreen (1997) examine the effects of the creation of preferential trade agreements on the growth in bilateral trade flows.

[3] Work by Tinbergen developed from early foundations established in Walter Isard (1954a,b).

typically an array of dummy variables reflecting the presence or absence of a preferential trading agreement (PTA_{ij}) or of a common land border (A_{ij}). The basic gravity equation has the econometric specification:

$$PX_{ij} = \beta_0 (GDP_i)^{\beta 1} (GDP_j)^{\beta 2} (D_{ij})^{\beta 3} e^{\beta 4(PTAij)} e^{\beta 5(Aij)} \varepsilon_{ij} \tag{1}$$

where e is the natural logarithm base and ε_{ij} is a log-normally distributed error term.

Empirical investigations in international trade using the gravity equation typically note that formal theoretical foundations for the model have been provided in Anderson (1979), Krugman (1979), Helpman and Krugman (1985), and Bergstrand (1985, 1989, 1990), and are now well established.[4] In these studies, the gravity equation is derived theoretically as a reduced form from a general equilibrium model of international trade in final goods. Exporter and importer GDPs can be interpreted in these models as the production and absorption capacities of the exporting and importing countries, respectively. Bilateral distance between the two countries is generally associated with transportation costs; more distance suggests greater transit costs.[5]

These papers are usually offered as theoretical substitutes; choose your preferred set of assumptions and model. We provide a brief discussion to show that these theoretical foundations are complementary, each a special case of a more general model. We use this framework to motivate a simple novel econometric specification to estimate the relative contributions of income growth, income convergence, trade liberalization, and transport-cost declines for explaining the growth of world trade.

2.1. Theories without tariffs, transportation costs, and distribution costs

Anderson (1979) provided a formal theoretical foundation for the gravity equation based upon the properties of expenditure systems. Assuming that each country specializes completely in the production of its own good, there is one good for each country and assume its price is normalized to unity. Assuming identical homothetic preferences, the volume of trade from country i to country j (X_{ij}) can be represented by:

$$X_{ij} = \theta_i Y_j \tag{2a}$$

---

[4] Baldwin (1994) noted that, ‘The gravity model used to have a poor reputation among reputable economists. Starting with Wang and Winters (1991), it has come back into fashion. One problem that lowered its respectability was its oft-asserted lack of theoretical foundations. In contrast to popular belief, it does have such foundations . . .’ (p. 82).

[5] As many authors have noted, the ‘costs’ of distance may extend well beyond freight charges, including cultural dissimilarities and other barriers measured with difficulty (cf., Anderson and Marcouiller, 1999). Thus, while distance has always been an important variable in gravity equations, authors have never been sure exactly what ‘costs’ distance represents.

or

$$\theta_i = X_{ij}/Y_j \tag{2b}$$

where θ_i denotes the fraction of income spent on country i's product (the fraction identical across importers) and Y_j denotes real GDP in importing country j. Since production of every country i must equal the volume of exports and domestic consumption of the good, then:

$$Y_i = \sum_{j=1}^{N} X_{ij} = \sum_{j=1}^{N} \theta_i Y_j = \theta_i \left(\sum_{j=1}^{N} Y_j \right) \tag{3a}$$

or

$$\theta_i = Y_i / \left(\sum_{j=1}^{N} Y_j \right) = Y_i / Y^W \tag{3b}$$

where $Y^W = \Sigma_{j=1}^{N} Y_j$ is world real GDP, which is constant across country pairs. Substituting Eq. (3b) into Eq. (2a) yields:

$$X_{ij} = Y_i Y_j / \left(\sum_{j=1}^{N} Y_j \right) = Y_i Y_j / Y^W. \tag{4}$$

This simple gravity equation relies only upon the (adding-up) constraints of an expenditure system combined with identical homothetic preferences and the specialization of each country in one good.

A limitation of this model is that product differentiation is constrained arbitrarily by the number of *countries*. The models of Krugman (1979, 1980) and Helpman and Krugman (1985) relax this strong restriction by offering instead a market structure. Using the Dixit and Stiglitz (1977) framework, they assume monopolistically competitive firms producing slightly differentiated final goods under increasing returns to scale in production. In the absence of transportation costs and tariff barriers, the Helpman-Krugman model leads to a simple gravity equation identical to Eq. (4), but where the number of goods produced differs across countries of different economic size and depends endogenously upon the level of fixed costs in production, the taste for variety, and factor endowments.[6]

[6] Monopolistic competition is not the only market structure compatible with a gravity model. For instance, Feenstra et al. (1998) derive a gravity equation from a reciprocal-dumping model of trade with homogeneous goods and Deardorff (1998) derives a gravity equation from a model with perfectly competitive markets (see footnote 8). However, Evenett and Keller (1998) show empirically that the monopolistic competition/increasing-returns-to-scale based theories of trade 'are an important reason why the gravity equation fits trade flows among industrialized countries well' (p. 2).

A limitation of both models, however, is the absence of natural (i.e., geographic) and artificial (i.e., policy-induced) impediments to trade, such as transportation costs and tariff barriers, respectively.

2.2. Theories with tariff barriers, transportation costs, and distribution costs

In reality, of course, economies are dispersed geographically in an asymmetric fashion, governments impose tariff and nontariff barriers asymmetrically, and firms face costs in distributing, marketing, and tailoring products to each country. Anderson (1979) and Bergstrand (1985) introduced bilateral trade barriers, such as tariffs and transportation costs, explicitly in their respective gravity models.[7] In both cases, bilateral trade flows are influenced by the absolute level of bilateral transaction costs *and* the level of bilateral transaction costs relative to an income-weighted average of the exporter's bilateral costs to all markets (including the home market), as discussed in Deardorff (1998) and Bergstrand (1998).[8]

Bergstrand (1985) differs from Anderson (1979) by also allowing potentially for the costs of distributing, marketing, and tailoring each country's product to each national market.[9] These potential distribution costs are captured formally by a constant-elasticity-of-transformation function that allows each country's producer to treat export supplies to each market as imperfect substitutes; Bergstrand finds empirical support for a finite elasticity of transformation of output among export markets. As in Anderson though, each country produces one (arbitrarily) differentiated good. Bergstrand (1989,1990) extends his earlier model to incorporate Dixit-Stiglitz preferences, monopolistically-competitive markets, and increasing returns to scale in production and nests this in a two-industry, two-factor, Heckscher-Ohlin context.

---

[7] Krugman (1980) and Helpman and Krugman (1985, Ch. 10) discuss transport costs using 'iceberg' technology, but do not solve for a gravity equation.

[8] Deardorff (1998) discusses a theoretical foundation for the gravity equation considering a similar decomposition: frictionless trade and impeded trade. With frictionless trade, the gravity model can be motivated even in the context of a Heckscher-Ohlin world with homogeneous goods and perfect competition. With impediments, his theory requires complete specialization (as in the other theories) and 'every good is produced by a different country'; hence, each good is identified with the country that produces it and then 'enter them into a utility function as imperfect substitutes' (pp. 17–18).

[9] One can interpret these as nation-by-nation 'specific factors.' Rauch (1999) and Rauch and Feenstra (1999) discuss such costs in the context of 'networks' in international trade. Engel and Rogers (1998) found recently that the degree of relative price dispersion across locations suggested that 'consumer markets are, to a great degree, national markets,' arguing that distribution efforts are 'organized nationally' (p. 18).

2.3. The theoretical framework

The gravity equation to be estimated is based upon a synthesis and generalization of these theories. Within this framework, the relative importance of expenditure constraints emphasized by Anderson, market structure emphasized by Helpman and Krugman, and distribution costs emphasized by Bergstrand becomes transparent.

2.3.1. Consumers and bilateral import demand

In each country, the representative consumer maximizes a constant-elasticity-of-substitution (CES) utility function subject to a budget constraint where prices of the imported products reflect 'iceberg' transportation costs and ad valorem tariffs. The constrained utility maximization yields the import demand function of country j for the product of the representative firm in country i (x_{ij}):

$$x_{ij} = (I_j/P_j^C)(\boldsymbol{p}_{ij}/P_j^C)^{-\sigma} \tag{5}$$

where I_j is nominal income in j, σ is the elasticity of substitution in consumption ($\sigma>1$), P_j^C is the standard Dixit-Stiglitz price index, $(\Sigma_{i=1}^{N} \Sigma_{k=1}^{ni} \boldsymbol{p}_{ijk}^{1-\sigma})^{1/(1-\sigma)}$, and $\boldsymbol{p}_{ijk}$ is the landed price in country j of the product of firm k in country i inclusive of tariffs. Assuming identical producers k in country i ($k = 1, \ldots, n_i$), $\boldsymbol{p}_{ij} = p_{ij}(1 + t_{ij})$ where p_{ij} is the c.i.f. price expressed in terms of the numeraire ($p_{jj}=1$) and t_{ij} is the ad valorem tariff rate.[10] Eq. (5) also represents the domestic demand function when $i=j$, for which $t_{ij}=0$.

2.3.2. Firms

The representative firm in country i maximizes profits subject to two technology constraints. First, the production of goods has fixed (α) and constant marginal (ϕ) costs given by the linear cost function:

$$l_i = \alpha + \phi y_i \tag{6}$$

where l_i denotes labor used by the representative firm in country i and y_i denotes output of the firm.

Second, the potential presence of costs in distributing the product to each market causes the representative firm to treat each potential market's supply as an

[10] Alternatively, the ad valorem tariff rate may be applied to the f.o.b. value of each good. Both methods have been used in the literature, cf., Frankel (1997) and Frankel et al. (1998). The approach used here follows the European Union approach, attaching tariff rates to c.i.f. values, while the United States uses f.o.b. values.

imperfect substitute, captured formally by the constant-elasticity-of-transformation (CET) function:

$$y_i = \left[\sum_{j=1}^{N} y_{ij}^{(1+\gamma)/\gamma} \right]^{\gamma/(1+\gamma)} \tag{7}$$

where y_{ij} is output supplied to country j by the representative firm in i and γ is the elasticity of transformation of production ($\gamma > 0$).[11] Assuming iceberg transport costs, a fraction δ_{ij} of the goods 'falls into the ocean' so that only $x_{ij} = (1 - \delta_{ij})y_{ij}$ arrives and is sold in country j (assume $\delta_{ii} = 0$). It will be convenient to assume that $a_{ij} \equiv \delta_{ij}/(1 - \delta_{ij})$, so that $(1 - \delta_{ij}) \equiv 1/\{1 + [\delta_{ij}/(1 - \delta_{ij})]\} \equiv 1/(1 + a_{ij})$.

While Eq. (6) is standard to this class of models, only a few studies have employed Eq. (7), in particular, Geraci and Prewo (1982); Bergstrand (1985, 1989); de Melo and Tarr (1992); Gould (1994), and Weyerbrock (1999). The motivation for this additional condition is simply that output of the representative firm in a differentiated-product industry is not likely be substituted *costlessly* between foreign markets, due to the costs of distributing, marketing, and tailoring a product to any foreign market. Rauch and Feenstra (1999) argue that differentiated-product industries tend to need networks to help match the 'multifarious characteristics of buyers and sellers' (p. 4). As a study by the European Commission (1989) noted, a survey of successful exporters found that half of them tailored their products to destination markets. Most trade models ignore these costs, assuming production is perfectly substitutable between home and export markets and among export markets (i.e., a linear transformation function as in Anderson and in Helpman and Krugman). At the other extreme, Deardorff and Stern (1986, 1990) in the Michigan World Trade Model assume that production for home and export markets is *completely separate*, resulting 'from locational requirements or from the need to tailor products to national markets'; they assume 'certain fixed factors of production that cannot easily be transferred between the sectors' (1990, p. 19).

The CET function provides an analytically and empirically tractable means of letting the data determine the degree of transformability, or substitutability, of production among markets. Estimates of γ can range theoretically from 0 to ∞. If γ equals infinity, output is perfectly substitutable across home and foreign markets as in most trade models; Eq. (7) reduces then to the simple expenditure constraint in Anderson (1979), as in Eq. (3a). Conversely, if γ equals 0, production is not substitutable across home and foreign markets, or among export markets, as in Deardorff and Stern (1986, 1990). In fact, our empirical evidence discussed later implies that γ is positive but finite, suggesting that exports are imperfectly substitutable across markets. By incorporating the CET function, our econometric

[11] See Powell and Gruen (1968) on the theoretical foundations for the CET function.

model can estimate how much world trade growth has been diminished by the resources absorbed in allocating production among various markets.[12]

2.3.3. Equilibrium, bilateral export supply, and full employment

Two conditions characterize equilibrium in this class of models. First, profit maximization ensures that prices are a markup over marginal costs:

$$P_i^F = [\sigma/(\sigma - 1)]\phi W_i \tag{8}$$

where ϕW_i is the marginal production cost of the representative firm, W_i is the wage rate, and P_i^F is a CET index of the firm's prices, i.e., $P_i^F = [\Sigma_{j=1}^N \, [p_{ij}/(1 + a_{ij})]^{1+\gamma}]^{1/(1+\gamma)}$. Second, under monopolistic competition firms earn zero profits which implies:

$$y_i = \left[\sum_{j=1}^{N} y_{ij}^{(1+\gamma)/\gamma} \right]^{\gamma/(1+\gamma)} = (\alpha/\varphi)(\sigma - 1) \equiv \psi \tag{9}$$

Hence, as is typical to these models, the firm's output is determined parametrically by the cost and utility functions.

Unlike other models in this class where exporters are assumed to face zero nationally-specific distribution costs, the presence of a potentially *finite* elasticity of transformation of output among destination markets allows this model to be solved for the bilateral export supply functions of the representative firm. Combining, from the firm's first-order conditions, $x_{ij} = (1 + a_{ij})^{-(\gamma+1)}(p_{ij}/p_{ii})^{\gamma} x_{ii}$ with $x_{ij} = y_{ij}/(1 + a_{ij})$, Eq. (9), and some algebra yields:

$$x_{ij} = \psi(p_{ij}/P_i^F)^{\gamma}(1 + a_{ij})^{-(\gamma+1)} \tag{10}$$

where the domestic supply function follows analogously for $j = i$ (assume $a_{ii} = 0$).

The assumption of full employment of labor in each country ensures that the size of the factor endowment (L_i) determines the number of varieties (n_i) produced, as is common to this class of models. Combining Eqs. (6) and (7) with $x_{ij} = (1 + a_{ij})^{-(\gamma+1)}(p_{ij}/p_{ii})^{\gamma} \, x_{ii}$ yields:

$$L_i = \sum_{k=1}^{n_i} l_{ik} = \alpha\sigma n_i \quad \text{or} \quad n_i = (\alpha\sigma)^{-1} L_i \tag{11}$$

---

[12] Some recent empirical studies in international trade have emphasized implicitly the costs of distribution to bring buyers and sellers of differentiated products together better. Gould (1994), Head and Ries (1998), and Dunlevy and Hutchinson (1999) provide evidence that stocks of immigrants enhance the export opportunities of the immigrants' home countries by providing exporters with knowledge about the host country. Rauch (1999) provides evidence that business networks enhance trade more in differentiated product industries than in homogeneous product industries.

2.3.4. The gravity equation

The solution for a gravity equation from this model is obtained by setting Eq. (5) equal to Eq. (10) for all pairs (i, j) including $i=j$ and noting that there are n_i producers in each country i (i.e., Eq. (11)). This yields the real bilateral trade flow relationship:

$$X_{ij} = n_i x_{ij} = \psi^{-\gamma/(\gamma+\sigma)} Y_i Y_j^{\gamma/(\gamma+\sigma)} (1+a_{ij})^{-\sigma(\gamma+1)/(\gamma+\sigma)} (1+t_{ij})^{-\sigma\gamma/(\gamma+\sigma)} \times \left[(P_i^F/P_j^C)^{-\sigma} (P_j^F/P_j^C) \right]^{\gamma/(\gamma+\sigma)} \quad (12)$$

where X_{ij} is the quantity of imports of country j from country i, Y_i is aggregate output of exporter i, and Y_j is aggregate output of importer j (where $Y_j = I_j/P_j^F = n_j y_j$). If distribution costs are zero as typically assumed, then $\gamma = \infty$ and the coefficient of Y_j above equals 1 as in Anderson (1979) and Helpman and Krugman (1985).[13]

Since country i's aggregate output is a CET function of its bilateral exports (including sales to itself), one can alternatively derive the gravity equation in the form:

$$X_{ij} = \frac{Y_i Y_j}{Y^W} \left[\frac{\theta_j^{-\sigma} (1+a_{ij})^{-\sigma(\gamma+1)/\gamma} (1+t_{ij})^{-\sigma} (P_i^F/P_j^C)^{-\sigma} (P_j^F/P_j^C)}{\left(\sum_{j=1}^{N} \left[\theta_j (1+a_{ij})^{1-\sigma} (1+t_{ij})^{-\sigma} (P_i^F/P_j^C)^{-\sigma} (P_j^F/P_j^C) \right]^{(\gamma+1)/(\gamma+\sigma)} \right)^{(\gamma+\sigma)/(\gamma+1)}} \right]^{\gamma/(\gamma+\sigma)} \quad (13)$$

which is the analogue to Eq. (4), where Y^W is a constant and $\theta_j = Y_j/Y^W$. In the context of this model, a particular exporter i that is either more (less) distant from importers or facing a higher (lower) tariff rate will have a lower (higher) P_i^F in general equilibrium. An exporter with a larger economic size will have a higher P_i^F in general equilibrium, as in Krugman (1980). Consequently, it can be shown that $(\Sigma_{j=1}^N [\theta_j (1+a_{ij})^{1-\sigma} (1+t_{ij})^{-\sigma} (P_i^F/P_j^C)^{-\sigma} (P_j^F/P_j^C)]^{(\gamma+1)/(\gamma+\sigma)})^{(\gamma+\sigma)/(\gamma+1)} = \psi/Y^W$, which is a constant in Eq. (13).

Eq. (13) is a generalized version of Eq. (4) that allows transport costs and tariff barriers to be non-zero, prices to be non-unity, and the elasticity of transformation to be non-infinity. In the special case when the elasticity of transformation (γ) is set equal to infinity and prices are set equal to unity, Eq. (13) reduces to Eqs. (16) and (18) in Anderson (1979) and Deardorff (1998), respectively. Moreover, when

[13] The complex bracketed relative price term has the following interpretation. The first part reflects terms of trade effects: for instance, P_i^F/P_j^C may be high for some country pairs due to a larger market in i, tending to reduce demand in j for i's products. The second part reflects an income effect: for instance, P_j^F/P_j^C may be high for country j due to lower tariffs in j, tending to raise real income and imports (as tariff revenue is not redistributed to consumers in our model).

$a_{ij} = t_{ij} = 0$ as well, Eq. (13) reduces further to Eq. (4), the frictionless gravity equation.

Eqs. (12) and (13) help to highlight the importance of output-expenditure constraints emphasized by Anderson, market structure emphasized by Helpman and Krugman, and distribution costs emphasized by Bergstrand. The model above incorporates the output-expenditure constraints emphasized in Anderson (1979), but allows potentially for costly transformation of output across markets, as suggested in Bergstrand (1985). We provide empirical evidence later that exports are not perfectly substitutable across markets. Furthermore, we allow for relative price levels to depart from unity, as documented by Summers and Heston (1991) and others. In the context of this class of models with economies of scale, monopolistic competition, asymmetric country sizes, and positive transport costs, relative price and wage levels will not likely be unity; consequently, the common assumption of setting all prices to unity is not innocuous. The model thus incorporates explicitly into the gravity equation the notion emphasized in Krugman (1980) that larger markets will tend to have relatively higher price and wage rate levels.

3. Econometric issues

The purpose of the econometric model is to evaluate empirically the absolute and relative roles of real income growth, real income convergence, tariff reductions, and falling transportation costs in explaining the growth of world trade between the late 1950s and the late 1980s. Gravity Eqs. (12) and (13) were derived to describe in the context of a general equilibrium model long-run determinants of bilateral trade flow *levels*. If one assumes that the elasticities of substitution in consumption (σ) and of transformation of production (γ) are stable over this period, then the growth of trade can be described by changes in the RHS variables in Eqs. (12) and (13).

We note two estimation issues. First, at the level of aggregation being investigated, the quantity of goods exported from i to j (X_{ij}) is unobservable. In fact, gravity equations are usually estimated across countries using nominal bilateral trade flow *values* (and nominal GDPs) for which data exist, because the gravity model has been used traditionally to explain the *level* of trade. Since we are interested in the growth of real trade flows, it is appropriate to deflate nominal trade flows by a price index. Since bilateral trade flow price deflators are unavailable, we employ nominal trade flows adjusted for changes in the firm's price index (P_i^F). As in Bayoumi and Eichengreen (1997), we use the exporter's GDP deflator; since the exporter's income variable is deflated by the GDP deflator, the model suggests this is the appropriate deflator for the trade flows. Second, the relative roles of real income growth versus real income convergence are not readily transparent from Eqs. (12) and (13).[14] The appendix details the algebra used to yield a form of Eq. (12) specified below that is more conducive to potential econometric evaluation of the rates of real income growth, real income convergence, and declining tariff rates and transport costs in explaining real trade flow growth:

$$X_{ij}^{cif} = \psi^{-(\gamma+1)/(\gamma+\sigma)}(Y_i + Y_j)^2(s_i s_j)(1 + a_{ij})^{(1-\sigma)(\gamma+1)/(\gamma+\sigma)} \cdot(1 + t_{ij})^{-\sigma(\gamma+1)/(\gamma+\sigma)} Y_j^{(1-\sigma)/(\gamma+\sigma)}\left[\left(P_i^F/P_j^C\right)\left(P_j^F/P_j^C\right)^{-1/\sigma}\right]^{-\sigma(\gamma+1)/(\gamma+\sigma)} \quad (14)$$

where X_{ij}^{cif} denotes the real trade flow (the nominal c.i.f. value of the trade flow divided by the exporter's deflator), $Y_i(Y_j)$ denotes real GDP of country $i(j)$, and $s_i(s_j)$ denotes i's(j's) share of the two countries real incomes (e.g., $s_i = Y_i/[Y_i + Y_j]$).

Similar to Bayoumi and Eichengreen (1997), we study the growth of world trade by examining the first-difference logarithmic form of Eq. (14):

$$\begin{aligned}\Delta \log X_{ij}^{cif} = \beta_0 &+ 2\Delta \log(Y_i + Y_j) + \Delta \log(s_i s_j) \\ &+[(1-\sigma)(\gamma+1)/(\gamma+\sigma)]\,\Delta \log(1 + a_{ij}) \\ &+[-\sigma(\gamma+1)/(\gamma+\sigma)]\,\Delta \log(1 + t_{ij}) \\ &+[(1-\sigma)/(\gamma+\sigma)]\,\Delta \log(Y_j) \\ &+[-\sigma(\gamma+1)/(\gamma+\sigma)]\,\Delta \log\left([P_i^F/P_j^C][P_j^F/P_j^C]^{-1/\sigma}\right) \end{aligned} \quad (15)$$

where log denotes the natural logarithm. The potential gains in estimating Eq. (15) are fivefold.

First, all variables are in real terms, which are the factors of interest for growth. Second, the effect of bilateral income growth is captured by variation in the term $(Y_i + Y_j)$; world income growth is captured in the constant.[15] Third, the effect of income convergence is captured by variation in $s_i s_j$. In the context of this model, the convergence of incomes of country pairs augments trade flow growth. Income convergence is monotonically positively related to $s_i s_j$, which can vary theoretically from 0 to 0.25. Fourth, the effects of transport-cost and tariff-rate changes are captured by the gross c.i.f.-f.o.b. factor $(1+a_{ij})$ and gross tariff rate $(1+t_{ij})$,

[14] Note that $Y_i Y_j = (Y_i + Y_j)^2(s_i s_j)$. In the context of this class of models, the trade flow is proportional to the product of the country incomes. Even though these terms are equivalent, we choose to include the latter because the coefficient estimates on the components of $(Y_i + Y_j)$ and $(s_i s_j)$ reflect *explicitly* the relative roles of income growth and income convergence, respectively.

[15] In the context of this model, $\beta_0 = -[(\gamma+1)/(\gamma+\sigma)][\Delta \log \psi] = -[(\gamma+1)/(\gamma+\sigma)][\Delta \log (\alpha/\phi)(\sigma-1)] = -[(\gamma+1)/(\gamma+\sigma)][\Delta \log (\alpha\sigma) + \Delta \log (Y^W/L^W)]$. Even though ψ, Y^W, and L^W are constant across country pairs within any year, these constants may be different *between* two periods. β_0 is likely to be negative, reflecting (although not equal to) the growth in world per capita real GDP due to technological change.

respectively. Fifth, the coefficient estimate of Y_j indicates whether or not the elasticity of transformation of output across markets is finite; if $\gamma = \infty$ as commonly assumed, Y_j's coefficient estimate will be 0.

Since some of the growth of trade may have resulted from the initial period (1958–60) not being one of 'general equilibrium,' we estimate the model including additionally the natural logarithm of the initial period's trade flow level, log $PX_{ij,1958-60}$.[16] Hence, the econometric model to be estimated is:

$$\begin{aligned}\Delta \log X_{ij}^{cif} = {} & \beta_0 + \beta_1 \Delta \log(Y_i + Y_j) + \beta_2 \Delta \log(s_i s_j) \\ & + \beta_3 \Delta \log(1 + a_{ij}) + \beta_4 \Delta \log(1 + t_{ij}) + \beta_5 \Delta \log(Y_j) \\ & + \beta_6 \Delta \log\left([P_i^F / P_j^C][P_j^F / P_j^C]^{-1/\sigma}\right) \\ & + \beta_7 \log(PX_{ij,1958-60}) + \varepsilon_{ij} \end{aligned} \tag{16}$$

where ε_{ij} is a normally distributed random error. Given the theoretical model, linear constraints can be evaluated for coefficient estimates of β_1 and β_2 and nonlinear constraints for coefficient estimates of β_3, β_4, β_5, and β_6.

As the next section of the paper will discuss, data for all variables except P_i^F / P_j^C and P_j^F / P_j^C are readily available. Since P_j^C is a Dixit-Stiglitz price index of landed prices in country j of products from all N markets (including j), the presence of P_j^C is problematic econometrically because the variable is a function of one of the model's parameters to be estimated (σ). Similarly, P_i^F and P_j^F are Dixit-Stiglitz indexes and are functions of another model parameter (γ). One possible solution is to estimate (16) using nonlinear least squares with values of the p_{ijk}s; however, cross-country data on the p_{ijk}s do not exist.

While we do not expect to capture the effects of these variables well, we attempt at least to capture some of the variation in the countries' relative price levels, P_i^F / P_j^C. Since the theoretical model separates nominal GDPs into real GDPs (Y_i,Y_j) and price levels, the natural choice for the proxies are the two countries' GDP deflators. We create a proxy for the relative price variable, P_i^F / P_j^C, employing the ratio of the countries' deflators (adjusted for the exchange rate), maintaining a low expectation that the coefficient estimates of β_6 will accord with the theory. There is no reasonable proxy for P_j^F / P_j^C; however, if tariff revenue is redistributed to households, the role of this factor diminishes. Moreover, changes in this ratio from the late 1950s to the late 1980s likely had little effect empirically on the growth of

[16] Since the initial period's trade flow enters as a log *level* cross-sectionally, it is meaningless to adjust the initial period's nominal trade flow levels by the exporter's deflator (an index). The model was also estimated without the initial period's log-level trade flow; the empirical results are qualitatively and quantitatively similar and are omitted here only due to space constraints of the journal.

country j's real income ($P_j^F Y_j / P_j^C$). Finally, the mis-measurement of $(P_i^F / P_j^C)(P_j^F / P_j^C)^{-1/\sigma}$ is likely to bias its coefficient estimate toward zero.

4. Data issues

Bayoumi and Eichengreen (1997) note that a common concern in some previous estimates of international trade gravity equations is the pooling of data for industrial and developing countries. The concern arises because the relationship 'between trade and economic characteristics may vary between the two groups of countries' (p. 143). For this reason and tariff data limitations (see below), our cross section includes bilateral trade flows and economic characteristics among 16 OECD countries (listed in Table 1). Systematically-measured bilateral trade flow data from the International Monetary Fund (IMF, 1958/62) begins in 1958 (see *Direction of Trade, Annual 1958–62*). Bilateral trade flow data from the OECD begins earlier, but excludes Japan, Australia and Finland (as the OEEC, the precursor to the OECD, was smaller in the early and mid 1950s). Consequently, we used the IMF's *Direction of Trade* bilateral trade flow import-measured data for the years 1958–1960, averaged over the three years. To avoid the consolidation of East and West Germany and the phased-in introduction of the Canada-U.S. Free Trade Agreement but to recognize fully-phased-in Tokyo Round tariff reductions, OECD (1992) bilateral trade data for the years 1986–1988, averaged over the

Table 1
Gross CIF-FOB factors for 16 OECD countries[a]

Country	1958–1960	1986–1988
Canada	1.0321	1.0250
United States	1.1148	1.0442
Japan	1.2005	1.0681
Belgium-Luxembourg	1.0700	1.0310
Denmark	1.0581	1.0464
France[b]	1.1461	1.0336
(W.) Germany	1.0702	1.0261
Italy	1.0993	1.0690
Netherlands	1.0600	1.0560
United Kingdom	1.1272	1.0438
Austria	1.0260	1.0470
Norway	1.0279	1.0270
Sweden	1.0710	1.0230
Switzerland	1.0140	1.0100
Australia	1.1258	1.0872
Finland	1.0702	1.0450

[a] Source: IMF International Financial Statistics (1995).
[b] For France, 1958–60 data was unavailable; 1960–62 data was used.

three years, were used.[17] OECD data for 1986–88 matched with corresponding IMF data, but the former were measured in thousands rather than millions of U.S. dollars.

In the context of Eq. (16), the effect of transportation-cost reductions on trade growth is reflected in the change in the gross cif-fob factor and the effect of policy-induced trade liberalization is reflected in the change in the gross tariff rate. Regarding c.i.f.-f.o.b. factors, the IMF's *Direction of Trade* statistics and the OECD's *Trade Series C-Foreign Trade by Commodities* both provide f.o.b.-valued export data and c.i.f.-valued import data on bilateral trade flows. In a perfectly measured world, all the f.o.b.-valued exports, say, from Canada to Belgium-Luxembourg would arrive in Belgium-Luxembourg so that the ratio of Belgium-Luxembourg's c.i.f.-valued imports from Canada to Canada's f.o.b.-valued exports to Belgium-Luxembourg would reveal the gross bilateral c.i.f.-f.o.b. transport-cost factor. In reality, not all of Canada's exports to Belgium-Luxembourg are imported by Belgium-Luxembourg. For instance, in 1986–88 the average annual f.o.b. value of Canada's exports to Belgium-Luxembourg was US$705.7 million while the average annual c.i.f. value of Belgium-Luxembourg's imports from Canada was US$470.2 million – only two-thirds of the value of the trade flow exported from Canada to Belgium-Luxembourg. This problem arose for several trade flows, suggesting that c.i.f.-f.o.b. factors for bilateral flows were not reliable estimates of bilateral transportation costs.

However, the IMF's *International Financial Statistics* (1995) provide estimates of countries' multilateral gross c.i.f.-f.o.b. factors (i.e., the ratio of c.i.f.-valued imports to f.o.b.-valued imports). The use of multilateral c.i.f.-f.o.b. factor changes assumes that declines over the (approximately) 30-year period in an importing country's transportation and insurance costs were proportionate among the suppliers.[18] Table 1 shows each country's gross (multilateral) c.i.f.-f.o.b. factor in 1958–60 and 1986–88. The average c.i.f.-f.o.b. factor was 8.21% in 1958–60 and declined 48% to 4.27% by 1986–88.

Some constraints were faced also estimating gross tariff-rate reductions. Ideally, we want to have bilateral measures of changes in ad valorem tariff rates (or their equivalents) as suggested by Eq. (16). The only source of such measures is data prepared for Prewo (1978). Prewo calculated annual bilateral average tariff rates for 18 OECD countries (the 16 countries listed in Table 1 and Portugal and Spain) for years 1958 through 1974, the last year being one in which Kennedy Round tariff reductions had been fully phased in but Tokyo Round tariff reductions had not yet been implemented. Deardorff and Stern (1986, 1990) provide measures of pre- and post-Tokyo Round average (multilateral) tariff rates for 18 OECD countries (the 16 listed in Table 1 and Ireland and New Zealand). Using the

[17] The data cutoff of 1988 also precludes the influence of the rapid decline in communication costs in the 1990s, for which measurement is difficult.

[18] Moreover, use of these data assumes the composition of imports changes little over time.

changes in average multilateral tariff rates from Deardorff and Stern (1986, 1990), we extended the Prewo (1978) average bilateral tariff rate data to 1987 (the year in which Tokyo Round tariff reductions had been fully phased in). This extension of bilateral tariff rates was not severely restricted by the use of the multilateral average tariff changes because, by 1987, 12 of the 16 countries in our sample had a free trade arrangement with each other (i.e., EC, EFTA, or the EC–EFTA pact).[19] Consequently, for 1986–1988 more than 132 of 240 bilateral trade relations had a zero tariff rate (or gross tariff rate of unity). The average bilateral tariff rate in the sample was 11.2% in 1958–1960 and declined 81% to 2.1% in 1986–1988; the low average tariff rate in the latter period, of course, reflects the large share of bilateral free trade arrangements.[20]

The remaining income and price variables needed to estimate Eq. (16) were obtained from the IMF *International Financial Statistics* (1995). Nominal and real GDP values and exchange rates for 1958–1960 and 1986–1988 were readily available. Bilateral exchange rates were measured using annual average values (*IFS* series rf) to express relative prices and real GDPs in terms of a common currency.

For later reference, Table 2 reports the mean, standard deviation, and coefficient of variation of the logarithmic difference (i.e., growth rate) of each of the variables and the log-level of the initial period's trade flow.

Table 2
Statistics for the growth rates and log-level of selected variables[a]

Variable	Mean (%)	Stand. Dev. (%)	Coeff. of variation
First-difference log of:			
Nominal Trade Flow (PX_{ij}^{cif})	327.1	86.7	0.27
Exporter's GDP Deflator (P_i^F)	179.5	30.5	0.17
Real Trade Flow (X_{ij}^{cif})	147.6	76.0	0.51
Average Real GDP ($Y_i + Y_j$)	105.0	24.3	0.23
Product of Real GDP Shares ($s_i s_j$)	−3.3	21.6	−6.55
Importer's Real GDP (Y_j)	103.3	23.9	0.23
Gross c.i.f./f.o.b. factor ($1 + a_{ij}$)	−3.6	3.7	−1.03
Gross Tariff Rate ($1 + t_{ij}$)	−8.5	4.1	−0.48
Relative Price Level (P_i^F / P_j^C)	0.0	44.6	na
Log-level of:			
Nominal Trade Flow ($PX_{ij,1958-60}$)	1108.3	159.5	0.14

[a] Sources: See text; 'na' denotes not applicable.

[19]We used the 1958–1960 average of the bilateral tariff rates in Prewo (1978). The Tokyo Round tariff reductions were phased in fully by 1987. The rates calculated for 1987 are used for the 1986–1988 variable.

[20]Regrettably, no such comparable measures exist of nontariff barriers, in order to consider their possible effect.

5. Empirical results

The empirical results are reported in four parts. In the first section, we report estimates of a simple regression of trade flow growth on the changes in the gross c.i.f.-f.o.b. factor and gross tariff rate – a specification suggested by intuition rather than an explicit general equilibrium model. Second, we estimate the first-difference logarithmic version of Eq. (4) to determine whether the basic 'frictionless' gravity equation holds. Third, we estimate Eq. (16) to evaluate empirically the absolute and relative effects of real income growth, real income convergence, falling transport costs, and declining tariffs on the growth of world trade. Fourth, we re-estimate Eq. (16) imposing restrictions implied by the theory that are not rejected statistically, use these coefficients to estimate the elasticities of substitution in consumption and of transformation of production among national markets, and then compare these elasticity estimates to others in the literature.

5.1. Preliminary results

Before reporting the results of estimating Eq. (16), we present some preliminary regression findings of a specification suggested by intuition discussed in the introduction. It is worth noting that an ordinary least squares (OLS) regression of changes in real bilateral trade flows from 1958–60 to 1986–88 on a constant and changes in the gross c.i.f.-f.o.b. factors and gross tariff rates over this period yields:

$$\begin{aligned} &\Delta \log X_{ij}^{cif} = \underset{(9.65)}{1.09} - \underset{(-3.38)}{4.41}\, \Delta \log(1 + a_{ij}) - \underset{(-2.29)}{2.71}\, \Delta \log(1 + t_{ij}) \\ &R^2 = 0.080,\ \text{Adjusted } R^2 = 0.072,\ \text{SEE} = 0.733,\ N = 240 \end{aligned} \tag{17}$$

where SEE is the standard error of the regression and *t*-statistics are in parentheses.

Three results emerge from this regression. First, the reduction over these 28 years in transportation costs and in tariff rates had the expected effects, both factors contributing to the growth of world trade (148 percentage points on average in this sample). However, these factors only explain 7% of the growth of trade (adjusted $R^2 = 0.07$), which is not surprising given the absence of income growth as an explanatory variable. Second, both factors had economically and statistically significant effects on world trade growth; also, since both measures are calculated comparably, a 1% reduction in tariff rates had a smaller impact on trade growth than did a 1% reduction in the transport-cost factor. Third, the average tariff reduction in our sample explains 23 percentage points of the 148 percentage point growth of world trade (approximately 16%) while the average transport-cost decline explains only 16 percentage points (approximately 11%). Although the coefficient estimate of tariffs is below that of transport costs, the average logarithmic change of gross tariffs (−8.5 percentage points for our sample) is almost $2\frac{1}{2}$ times higher than that of transport costs (−3.6 percentage points for our sample).[21]

5.2. Results from the 'frictionless' model

As Section 2 discusses, the frictionless Anderson and Helpman-Krugman models suggest Eq. (4) holds. We estimated the first-difference logarithmic version of Eq. (4):

$$\Delta \log X_{ij}^{cif} = -\Delta \log Y^{W} + \beta_1(\Delta \log Y_i + \Delta \log Y_j) + \varepsilon_{ij} \quad (18)$$

where, in the context of their models, $\beta_1 = 1$ and the constant should approximate the negative of the growth of world real GDP. Estimation of Eq. (18), without restricting β_1 to 1, yields:

$$\begin{aligned} &\Delta \log X_{ij}^{cif} = -\underset{(-4.54)}{1.19} + \underset{(10.29)}{1.29}(\Delta \log Y_i + \Delta \log Y_j) \\ &R^2 = 0.308, \text{ Adjusted } R^2 = 0.305, \text{ SEE} = 0.634, N = 240 \end{aligned} \quad (19)$$

This frictionless model explains 31% of the growth of world trade (adjusted $R^2 = 0.31$), more than the previous specification. The frictionless gravity model implies that the single coefficient estimate for both countries' income growth should not differ significantly from unity. This linear restriction cannot be rejected at the 1% significance level [$F(1{,}238) = 5.40$]. Moreover, the constant is negative and significant, consistent with theory; the intercept estimate of −1.19 suggests world output growth of 119%, close to the actual 103% world income growth of this sample.

We also estimated the frictionless model separating explicitly the effects of income growth and income convergence. The resulting regression was:

$$\begin{aligned} &\Delta \log X_{ij}^{cif} = -\underset{(-2.14)}{0.67} + \underset{(6.73)}{2.06}\,\Delta \log(Y_i + Y_j) + \underset{(1.03)}{0.35}\,\Delta \log(s_i s_j) \\ &R^2 = 0.332, \text{ Adjusted } R^2 = 0.326, \text{ SEE} = 0.624, N = 240 \end{aligned} \quad (20)$$

The income growth and income convergence variables' coefficient estimates have the expected signs. However, the joint hypothesis that the income growth

[21] Since any free trade agreement between a country pair would be captured by a gross bilateral tariff rate of unity, it seemed redundant to include a separate dummy variable to reflect the introduction of a preferential trading arrangement (PTA). However, one might argue that greater trade might be induced by the creation of a PTA *beyond* the effects of zero tariffs. To anticipate this concern, we added a dummy variable to the specification in (17) that had a value of 1 if a PTA was introduced between 1958 and 1988 (i.e., both countries became members of the EC or EFTA, or one EC and one EFTA), and zero otherwise. In this specification, the coefficient estimate of this dummy variable was negative, but trivially small (−0.18), and was statistically insignificant at the 1% level (*t*-statistic equal to 1.69). Thus, the trade-creating benefits were apparently captured by the bilateral tariff rate, as expected.

coefficient estimate is 2 and the income convergence coefficient estimate is 1 can be rejected at the 1% significance level [$F(2,237)=7.01$].

5.3. Results from the unrestricted model with tariffs, transport costs, and distribution costs

Estimation of Eq. (16) including the logarithm of the initial period's trade flow yields:

$$\begin{aligned} \Delta \log X_{ij}^{cif} = & \underset{(0.09)}{0.05} + \underset{(6.29)}{2.37} \Delta \log(Y_i + Y_j) + \underset{(1.74)}{0.60} \Delta \log(s_i s_j) \\ & - \underset{(-2.71)}{3.19} \Delta \log(1 + a_{ij}) - \underset{(-4.48)}{4.49} \Delta \log(1 + t_{ij}) - \underset{(-2.83)}{0.68} \Delta \log Y_j \\ & - \underset{(-2.69)}{0.25} \Delta \log(P_i^F / P_j^C) - \underset{(-2.62)}{0.08} \log PX_{ij,1958-60} \end{aligned}$$

$$R^2 = 0.400, \text{ Adjusted } R^2 = 0.388, \text{ SEE} = 0.584, N = 240 \qquad (21)$$

5.3.1. Summary of the regression results

Specification (21) has greater explanatory power (adjusted $R^2=0.39$) than either the simple frictionless trade model or the preliminary regression. All coefficient estimates have signs consistent with the theoretical model. The coefficient estimate for income growth has a value close to 2 and the coefficient estimate for income convergence has a value close to 1, as expected; results of statistical tests for these values are provided later. The coefficient estimates for transportation costs and tariff rates have negative signs and the estimate for the transport-cost factor is smaller (in absolute value) than that for tariffs, as expected given Eq. (15). The coefficient estimate for importer's real GDP is negative as expected and statistically significantly different from zero, indicating that the elasticity of transformation of output across national markets may be finite. The coefficient estimate for the growth rate of the relative price level is negative and statistically significant as expected. Not surprisingly, the coefficient estimate is close to zero, since the relative price level is likely mis-measured. Finally, the coefficient estimate for the initial trade flow has a significant negative effect with a plausible magnitude.

5.3.2. Explaining the mean growth of world trade

The results indicate that income growth, tariff rate reductions, and transport-cost declines all contributed nontrivially to the real growth of world trade. Using the results from specification (21), we estimate the contribution of each of these three factors for explaining the 148 percentage points mean growth of trade. First, income growth explains about 100 percentage points of this growth (or 67% of the total). This result is quite plausible since most estimates for OECD countries over the same period find that the share of merchandise trade in GDP increased about

2% annually.[22] Second, tariff-rate reductions explain 38 percentage points (or roughly 26%) of the growth of trade. This is obtained from the product of the mean logarithmic change of the tariff variable, −8.5 percentage points, and its coefficient estimate, −4.49. Third, transport-cost reductions explain 12 percentage points (or roughly 8%) of the growth. The mean logarithmic change of the gross c.i.f./f.o.b. factor was −3.6 percentage points and its coefficient estimate was −3.19.

However, income convergence explains virtually none of the mean growth of trade in our sample. Importantly, note that the *relationship* between trade and income convergence raised in Helpman (1987) does hold; that is, the coefficient estimate for $s_i s_j$ is not significantly different from unity, as expected. But the degree of income convergence measured is trivial in our sample. In fact, as Table 2 reveals the degree of income similarity in our sample of the richest industrialized countries fell by 3% over the 28-year period; in a broader sample of all OECD countries, we found an increase in income similarity of 4%. For our sample, the index of income convergence contributed a trivial −2 percentage points to world trade growth; this is the product of the mean growth rate of the index of similarity of real GDPs (−3.3 percentage points) and the coefficient of 0.60. Together, these four factors explain all 148 percentage points of the growth in world trade of this sample, since the mean logarithmic change in the relative price variable is zero.[23]

In the context of Krugman's quote earlier, the international economists seem to

---

[22]The estimate of 100 percentage points is determined by three factors. First, mean growth of the sum of the countries' real incomes, $\Delta\ log\ (Y_i + Y_j)$, was 1.05 (or 105 percentage points); multiplying this by its coefficient of 2.37 yields a contribution of 2.49. Second, if γ is finite, mean growth in importer income (1.03) will have a dampening effect on trade growth by a factor of −0.68, the importer's income coefficient. The product of 1.03 and −0.68 yields −0.70; subtracting 0.70 from 2.49 yields 1.79. Third, as noted in footnote 15, the constant is related to the negative of the logarithmic change in world per capita real GDP in the context of the model (excluding the lagged log-level of the trade flow). However, the constant contributes only 0.05, inconsistent with the growth of world per capita real GDP (0.80 in our sample). The reason is the presence of the lagged log-level trade flow. As Table 2 indicates, this variable had little variation compared with the growth rates; note the coefficient of variation of 0.14. Consequently, it is nearly perfectly collinear with the constant (a partial correlation coefficient of 0.99), which can bias the intercept's value. (In the comparable specification *without* the log-level trade flow, the constant was −1.04.) Combining the intercept estimate (0.05) with the effect from the lagged trade flow ($-0.84 = -0.08 \times 11.08$) yields −0.79; this suggests growth of world per capita real GDP growth of 0.79, close to the actual value for this sample of 0.80. Subtracting 0.79 from 1.79 yields 1.00, or 100 percentage points, as the estimate of the overall effect of income growth on trade growth.

[23]Since every pair of countries enters twice (each country as exporter and as importer), the mean logarithmic change in the relative price level is zero by construction. Using each pair of countries once, the mean growth rate of the relative price level provides an estimate of the average long-run departure from relative purchasing power parity. The absolute value of the mean logarithmic change of the relative price level using each pair once ($N = 120$) was a trivial 8.5 percentage points, consistent with other empirical evidence for industrialized countries that relative purchasing power parity holds on average between similar economies in the long run (cf., Frankel and Rose, 1996).

have been right! Using these estimates, trade liberalization appears to have contributed about 75% of the (approximately) 2% average annual growth of world merchandise trade as a share of income in the postwar period compared with transport-cost declines, which have contributed only 25% of the growth in trade relative to income.[24]

5.4. Estimating the values of the elasticities of substitution and transformation

Table 3 provides a summary of the F-statistics and results for the various linear and nonlinear restrictions imposed on Eq. (16) by theoretical Eq. (15). To summarize, the restrictions imposed by the theory – with the exception of one – could *not* be rejected. The restriction *systematically* rejected whenever included was that on the coefficient estimate for the relative price level $[\beta_6 = -\sigma(\gamma+1)/$

Table 3
Hypothesis test results for restrictions imposed by the theoretical model

Null hypothesis	F-statistic	F-critical	Accept or reject[a]
1. β_1	0.97	6.75	Accept
2. β_2	1.39	6.75	Accept
3. β_1, β_2	5.55	4.70	**Reject**
4. β_3, β_4, β_5	0.32	6.75	Accept
5. β_1, β_3, β_4, β_5	0.56	4.70	Accept
6. β_2, β_3, β_4, β_5	0.87	4.70	Accept
7. β_1, β_2, β_3, β_4, β_5	3.81	3.87	Accept
8. β_3, β_4, $\boldsymbol{\beta_6}$	30.63	6.75	**Reject**
9. β_1, β_3, β_4, $\boldsymbol{\beta_6}$	15.42	4.70	**Reject**
10. β_2, β_3, β_4, $\boldsymbol{\beta_6}$	16.36	4.70	**Reject**
11. β_1, β_2, β_3, β_4, $\boldsymbol{\beta_6}$	13.35	3.87	**Reject**
12. β_3, β_5, $\boldsymbol{\beta_6}$	9.74	6.75	**Reject**
13. β_1, β_3, β_5, $\boldsymbol{\beta_6}$	8.05	4.70	**Reject**
14. β_2, β_3, β_5, $\boldsymbol{\beta_6}$	4.70	4.70	**Reject**
15. β_1, β_2, β_3, β_5, $\boldsymbol{\beta_6}$	9.55	3.87	**Reject**
16. β_4, β_5, $\boldsymbol{\beta_6}$	22.71	6.75	**Reject**
17. β_1, β_4, β_5, $\boldsymbol{\beta_6}$	11.93	4.70	**Reject**
18. β_2, β_4, β_5, $\boldsymbol{\beta_6}$	10.03	4.70	**Reject**
19. β_1, β_2, β_4, β_5, $\boldsymbol{\beta_6}$	8.15	3.87	**Reject**
20. β_3, β_4, β_5, $\boldsymbol{\beta_6}$	19.16	4.70	**Reject**
21. β_1, β_3, β_4, β_5, $\boldsymbol{\beta_6}$	11.98	3.87	**Reject**
22. β_2, β_3, β_4, β_5, $\boldsymbol{\beta_6}$	14.01	3.87	**Reject**
23. β_1, β_2, β_3, β_4, β_5, $\boldsymbol{\beta_6}$	11.96	3.40	**Reject**

[a] 'Accept' denotes we could not reject the null hypothesis at the 1% significance level.

[24] One might argue that we have ignored important dynamic effects of tariff-rate and transport-cost declines on world trade growth. However, in an earlier version of this paper, we show that the dynamic effects of tariff-rate and transport-cost declines only contributed about 2 percentage points and 3 percentage points, respectively, to the growth of world trade.

$(\gamma + \sigma)$]; this restriction is boldfaced in Table 3. However, as previously discussed, the use of exporter and importer GDP deflators as proxies for the two theoretical Dixit-Stiglitz prices indexes and the likely associated mis-measurement could explain this result.

Given the results of the hypothesis tests, we re-estimated Eq. (16) imposing the 'accepted' linear and nonlinear constraints for coefficients β_1, β_2, β_3, β_4, and β_5. This yielded:

$$\begin{aligned}\Delta \log X_{ij}^{cif} = &\underset{(1.40)}{0.54} + 2\Delta \log(Y_i + Y_j) + 1\Delta \log(s_i s_j) \\ &- 3.46\Delta \log(1 + a_{ij}) - 4.10\Delta \log(1 + t_{ij}) - 0.36\Delta \log Y_j \\ &- \underset{(-2.29)}{0.21}\,\Delta \log\left(P_i^F / P_j^C\right) - \underset{(-4.26)}{0.11}\,\log PX_{ij,1958-60} \\ R^2 = 0.399,\ &\text{Adjusted } R^2 = 0.389,\ \text{SEE} = 0.594,\ N = 240 \end{aligned} \tag{22}$$

Restricted regression (22)'s coefficient estimates are similar to those for unrestricted regression (21) with a minor increase (in absolute value) in the coefficient estimate for the transport-cost factor relative to that for the tariff rate. Moreover, the adjusted R^2 of the restricted regression slightly exceeded that of the unrestricted regression. The decomposition of the growth of world trade for restricted regression (22) consequently is similar to that for unrestricted regression (21). Of the 148 percentage points mean growth of trade, 103 percentage points are accounted for by income growth (versus 100 points for the unrestricted regression), 35 percentage points by the tariff rate (vs. 38), 13 percentage points by the transport-cost factor (vs. 12), and −3 percentage points by income convergence (vs. −2). Tariff reductions still explain almost three times as much trade growth as transport-cost declines.

Unlike regression (21), restricted regression (22) allows the construction of point estimates and confidence intervals for the elasticities of substitution in consumption (σ) and of transformation of production among national markets (γ). Using regression (22), the point estimate of σ is 6.43 with a 90% confidence interval of 2.44 to 10.42. These estimates are well in line with other estimates from recent trade analyses of the elasticity of substitution among imports, cf., Harrigan (1993), Feenstra (1994), and Head and Ries (1999). These estimates are also in the range used in recent studies of the regionalization of trade policy using monopolistically-competitive market structures, cf., Krugman (1991), Frankel (1997), and Frankel et al. (1995, 1996, 1998); for instance, Krugman (1991) used a range of 2 to 10.

By contrast, many previous trade analyses typically assume that the elasticity of transformation in production among markets (γ) is either infinity (e.g., Helpman and Krugman, 1985) or zero (e.g., Deardorff and Stern, 1986, 1990). Using specification (22), the point estimate of γ is 8.56 with a 90% confidence interval of 1.37 to 15.75. These estimates suggest that exports are imperfectly substitutable across national markets, closer to the construct in Deardorff and Stern (1986, 1990). The implication that exports are not perfect substitutes is consistent with the conclusions of Engel and Rogers (1998), who noted that the degree of relative price dispersion observed suggested that consumer markets are national markets and that distribution efforts are 'organized nationally,' as well as empirical evidence of Gould (1994), Head and Ries (1998), and Rauch (1999). Without any benchmark for comparison, future research into estimating this transformation elasticity seems warranted.

6. Conclusions

In 'Growing World Trade,' Krugman (1995) noted that the answer to the question, 'Why has world trade grown?' remains 'surprisingly disputed.' Journalists have argued that technology-led declines in transportation costs have been the major source, while international economists tend to argue that policy-induced trade liberalization has been the critical factor. Feenstra (1998) notes that these two sources 'come to mind immediately,' and he argues that increased convergence in economic size and greater vertical specialization and outsourcing may have contributed as well.

This paper has attempted to provide an empirical benchmark for this issue. Using a standard theoretical general equilibrium model of international trade in final goods and the empirical workhorse for studying trade flow volumes, we estimated the relative contributions of income growth, income convergence, tariff reductions, and transport-cost declines in explaining the mean growth in real bilateral trade flows among a group of 16 OECD countries for which data was available. In this sample, the mean logarithmic growth of trade was 148 percentage points. We found that approximately 67–69% of this growth could be explained by real GDP growth, 23–26% by tariff-rate reductions and preferential trade agreements, 8–9% by transport-cost declines, and virtually none by real GDP convergence. Thus, the relative contribution of trade liberalization was three times that of transport costs, giving economists the edge in the debate articulated by Krugman.

Finally, the model explains approximately 40% of the variation in trade flow growth in the sample. Although income growth and convergence, tariff-rate decreases, and transport-cost declines are represented, increased vertical specialization and outsourcing of intermediate production was beyond the scope of this particular final-goods model. Future research might incorporate this aspect into the framework used here to try to explain some of the remaining variation in the sample left unexplained.

Acknowledgements

The authors thank Ralph Chami, Donald Davis, Simon Evenett, Robert Feenstra, David Hummels, Wolfgang Keller, Rafael Tenorio, Kei-Mu Yi, two anonymous referees, and participants at the Empirical Investigations in International Trade Conference III at Purdue University in 1996, American Economic Association in Chicago in 1998, CEPR conference on 'New Issues in Trade and Location' at Lund University in Sweden in 1998, and seminars at Indiana University at Bloomington, IU at Indianapolis, and Western Michigan University for helpful comments on earlier drafts. We are grateful to Gwen Bartscherer, Cynthia Cicon, Sean Cocchia, and Bethany Marquis for valuable research assistance and the Notre Dame Center for Research in Business for financial support.

Appendix A

This appendix details the solution for a gravity equation from this model for real bilateral trade flows, using nominal bilateral trade flows scaled by the exporter's price level. First, setting Eq. (5) equal to Eq. (10) for all pairs (i, j) including $i = j$ and noting that there are n_i producers in each country i (i.e., Eq. (11)) yields the bilateral trade flow relationship in nominal terms:

$$\begin{aligned} PX_{ij} = n_i p_{ij} x_{ij} = \psi^{-(\gamma+1)/(\gamma+\sigma)} Y_i Y_j^{(\gamma+1)/(\gamma+\sigma)} \\ \cdot (1 + a_{ij})^{(1-\sigma)(\gamma+1)/(\gamma+\sigma)} (1 + t_{ij})^{-\sigma(\gamma+1)/(\gamma+\sigma)} \\ \cdot (P_i^F)^{\gamma(1-\sigma)/(\gamma+\sigma)} (P_j^C)^{\sigma(\gamma+1)/(\gamma+\sigma)} \left[(P_j^F / P_j^C)\right]^{(\gamma+1)/(\gamma+\sigma)} \end{aligned} \tag{A.1}$$

where PX_{ij} is the value of imports of country j from country i.

Second, to convert the nominal trade flow into a real trade flow, divide each side by P_i^F:

$$\begin{aligned} X_{ij}^{cif} = PX_{ij} / P_i^F = \psi^{-(\gamma+1)/(\gamma+\sigma)} (Y_i Y_j) Y_j^{(1-\sigma)/(\gamma+\sigma)} \\ \cdot (1 + a_{ij})^{(1-\sigma)(\gamma+1)/(\gamma+\sigma)} (1 + t_{ij})^{-\sigma(\gamma+1)/(\gamma+\sigma)} \\ \cdot \left[(P_i^F / P_j^C)(P_j^F / P_j^C)^{-1/\sigma}\right]^{-\sigma(\gamma+1)/(\gamma+\sigma)} \end{aligned} \tag{A.2}$$

where X_i^{cif} is the real c.i.f. imports of country j from country i.

Finally, since $Y_i Y_j = (Y_i + Y_j)^2 s_i s_j$, where $s_i = Y_i / (Y_i + Y_j)$ and $s_j = 1 - s_i$, we substitute $(Y_i + Y_j)^2 \cdot (s_i \ s_j)$ for $Y_i \ Y_j$ in Eq. (A.2) above to yield Eq. (14) in the text.

References

Anderson, J.E., 1979. A theoretical foundation for the gravity equation. American Economic Review 69 (1), 106–116.

Anderson, J.E., Marcouiller, D., SJ, 1999. Trade, location and security: an empirical investigation. NBER Working Paper No. 7000.

Baldwin, R.E. 1994. Towards an Integrated Europe. Centre for Economic Policy Research, London.

Bayoumi, T., Eichengreen, B., 1997. Is regionalism simply a diversion? Evidence from the EU and EFTA. In: Ito, T., Kreuger, A. (Eds.), Regionalism versus Multilateral Trade Arrangements. The University of Chicago Press, Chicago.

Bergstrand, J.H., 1985. The gravity equation in international trade: Some microeconomic foundations and empirical evidence. Review of Economics and Statistics 67 (3), 474–481.

Bergstrand, J.H., 1989. The generalized gravity equation, monopolistic competition, and the factor-proportions theory in international trade. Review of Economics and Statistics 71 (1), 143–153.

Bergstrand, J.H., 1990. The Heckscher-Ohlin-Samuelson model, the Linder hypothesis, and the determinants of bilateral intra-industry trade. Economic Journal 100 (4), 1216–1229.

Bergstrand, J.H., 1998. Comments on Determinants of bilateral trade flows: Does gravity work in a neoclassical world. In: Frankel, J.A. (Ed.), The Regionalization of the World Economy. The University of Chicago Press, Chicago, pp. 23–28.

Deardorff, A.V., 1998. Determinants of bilateral trade flows: Does gravity work in a neoclassical world. In: Frankel, J.A. (Ed.), The Regionalization of the World Economy. The University of Chicago Press, Chicago, pp. 7–22.

Deardorff, A.V., Stern, R.M., 1986. The Michigan Model of World Production and Trade. MIT Press, Cambridge, MA.

Deardorff, A.V., Stern, R.M., 1990. Computational Analysis of Global Trading Arrangements. University of Michigan Press, Ann Arbor, MI.

de Melo, J., Tarr, D., 1992. A General Equilibrium Analysis of U.S. Foreign Trade Policy. MIT Press, Cambridge, MA.

Dixit, A., Stiglitz, J.E., 1977. Monopolistic competition and optimum product diversity. American Economic Review 67 (3), 297–308.

Dunlevy, J.A., Hutchinson, W.K., 1999. The impact of immigration on American import trade in the late nineteenth and early twentieth centuries. Journal of Economic History 59 (4), 1043–1062.

Eichengreen, B., Irwin, D., 1995. Trade blocs, currency blocs and the reorientation of world trade in the 1930s. Journal of International Economics 38 (1/2), 1–24.

Engel, C., Rogers, J.H. 1998. Relative price volatility: What role does the border play? International Finance Discussion Paper No. 623, Board of Governors of the Federal Reserve System.

European Commission, 1989. The Participation of Small- and Medium-Sized Enterprises in Exporting Outside the Community. Vol. 1, Main Report – Summary and Recommendations. Netherlands, January.

Evenett, S., Keller, W. 1998. On theories explaining the success of the gravity equation. Unpublished manuscript, May.

Feenstra, R.C., 1994. New product varieties and the measurement of international prices. American Economic Review 84 (1), 157–177.

Feenstra, R.C., 1998. Integration of trade and disintegration of production in the global economy. Journal of Economic Perspectives 12 (4), 31–50.

Feenstra, R.C., Markusen, J.A., Rose, A.K. 1998. Understanding the home market effect and the gravity equation: The role of differentiating goods. NBER Working Paper No. 6904.

Frankel, J.A., 1997. Regional Trading Blocs in the World Economic System. Institute for International Economics, Washington, DC.

Frankel, J.A., Stein, E., Wei, S.-J., 1995. Trading blocs and the Americas: The natural, the unnatural, and the super-natural. Journal of Development Economics 47 (1), 61–95.

Frankel, J.A., Stein, E., Wei, S.-J., 1996. Regional trading arrangements: Natural or supernatural? American Economic Review 86 (2), 52–56.

Frankel, J.A., Stein, E., Wei, S.-J., 1998. Continental trading blocs: Are they natural or supernatural. In: Frankel, J.A. (Ed.), The Regionalization of the World Economy. University of Chicago Press, Chicago.

Frankel, J.A., Rose, A.K., 1996. A panel project on purchasing power parity: Mean reversion within and between countries. Journal of International Economics 40 (CHR.4.17;), 209–224.

Geraci, V.J., Prewo, W., 1982. An empirical demand and supply model of multilateral trade. Review of Economics and Statistics 64 (3), 432–441.

Gould, D.M., 1994. Immigrant links to the home country: Empirical implications for US. bilateral trade flows. Review of Economics and Statistics 76, 302–316.

Harrigan, J., 1993. OECD imports and trade barriers in 1983. Journal of International Economics 35 (1), 91–111.

Head, K., Ries, J., 1998. Immigration and trade creation: Econometric evidence from Canada. Canadian Journal of Economics 31, 47–62.

Head, K., Ries, J., 1999. Armington vs. Krugman: A test of two trade models. Unpublished manuscript, November.

Helpman, E., 1987. Imperfect competition and international trade: Evidence from fourteen industrial countries. Journal of the Japanese and International Economies 1 (1), 62–81.

Helpman, E., Krugman, P., 1985. Market Structure and Foreign Trade. MIT Press, Cambridge, MA.

Hummels, D., Levinsohn, J., 1995. Monopolistic competition and international trade: Reconsidering the evidence. Quarterly Journal of Economics 110 (3), 799–836.

Hummels, D., Rapoport, D., Yi, K.-M., 1998. Vertical specialization and the changing nature of world trade. Federal Reserve Bank of New York Economic Policy Review 4 (2), 79–99.

International Monetary Fund, 1958/62. Direction of Trade, Annual 1958–62. International Monetary Fund, Washington, DC.

International Monetary Fund, 1995. International Financial Statistics, CD-ROM (June). International Monetary Fund, Washington, DC.

Isard, W., 1954a. Location theory and international and interregional trade. Quarterly Journal of Economics 68, 97–114.

Isard, W., 1954b. Location theory and trade theory: Short-run analysis. Quarterly Journal of Economics 68, 305–320.

Krugman, P., 1979. Increasing returns, monopolistic competition, and international trade. Journal of International Economics 9, 469–479.

Krugman, P., 1980. Scale economies, product differentiation, and the pattern of trade. American Economic Review 70 (5), 950–959.

Krugman, P., 1991. Is bilateralism bad. In: Helpman, E., Razin, A. (Eds.), International Trade and Trade Policy. MIT Press, Cambridge, MA.

Krugman, P. 1995. Growing world trade: Causes and consequences. Brookings Papers on Economic Activity (1), 327–377.

Oguledo, V.I., MacPhee, C.R., 1994. Gravity models: A reformulation and an application to discriminatory trade arrangements. Applied Economics 26, 107–120.

OECD, 1992. Trade Series C–Foreign Trade by Commodities, 1991. Organization for Economic Cooperation and Development, Paris.

Powell, A.A., Gruen, F.H.G., 1968. The constant elasticity of transformation production frontier and linear supply system. International Economic Review 9 (3), 315–328.

Prewo, W., 1978. Determinants of the trade pattern among OECD countries from 1958 to 1974. Jahrbucher fur Nationalekonomie und Statistick 193, 341–358.

Rauch, J.E., 1999. Networks versus markets in international trade. Journal of International Economics 48 (1), 7–35.

Rauch, J.E., Feenstra, R.C., 1999. Introduction to symposium on Business and Social Networks in International Trade. Journal of International Economics 48 (1), 3–6.

Rose, A.K., 1991. Why has world trade grown faster than income? Canadian Journal of Economics 24, 417–427.

Summers, R., Heston, A., 1991. The Penn world table (mark 5): An expanded set of international comparisons, 1950–1988. Quarterly Journal of Economics 106 (2), 327–368.

Tinbergen, J., 1962. Shaping the World Economy. Twentieth Century Fund, New York.

Wang, Z.K., Winters, L.A., 1991. The trading potential of eastern Europe. Centre for Economic Policy Research Discussion Paper No. 610, London.

Weyerbrock, S., 1999. East-West European integration: A general equilibrium analysis of alternative agricultural policies. Review of International Economics, forthcoming.