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International Trade Efficiency, the Gravity Equation, and the Stochastic Frontier

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Abstract

In the gravity equation of international trade, bilateral trade flows are regressed on trading partners' income and the distance that separates them along with other variables. This widely used equation is traditionally estimated by the ordinary least squares method. We employ an alternative technique of stochastic frontier estimation to assess the potential bilateral trade flows from the same gravity equation. Countries are shown to have low efficiencies in their international trade as the predicted trade from frontier estimation is generally far greater than actual trade. Trade efficiencies are computed and ranked for individual countries, ten geographical regions, and eleven regional trade agreements.

Key Words: Efficiency coefficients; OLS residuals; trade gravity; trade potentials.

JEL Classification: F10, F14, C13

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I. Introduction

The gravity equation (GE) is widely used in explaining bilateral trade flows. The GE has been derived from diverse international trade models, ranging from models of complete specialization and identical consumers' preferences (Anderson 1979; Bergstrand 1985; Deardorff 1998) to models of product differentiation in a regime of monopolistic competition (Helpman 1987) to hybrid models of different factor proportions and product differentiation (Bergstrand 1989) and to models of incomplete specialization and trade costs (Haveman and Hummels 2004). Under complete specialization in production, identical consumers' preferences and zero barriers to trade, country i imports from all other countries and its import from country j is equal to Y_iY_j/Y_w, where Y is income and the subscripts refer to country i, country j, and the world, respectively (see, for example, Deardorff 1998, eq. (2)).

Typically, the ordinary least squares (OLS) estimation of the gravity equation shows the value of R-squared of about 0.65. The actual trade often deviates considerably from the predicted values from the model. Furthermore, the prediction that each country imports from all other countries does not hold in reality. Haveman and Hummels (2004, p. 211) show that four-fifths of importers at the four and five-digit SITC (Standard International Trade Classification) level buy from fewer than 10 per cent of available suppliers. One way to cope with this fact is to introduce trade frictions and let importers purchase from the cheapest exporters. By denoting with t_{ij} the ratio of prices paid by country i to prices charged by country j, the amount of imports of i from j becomes equal to $Y_iY_j/ t_{ij}Y_w$ (Deardorff 1998, eq. (11)). Trade frictions are unobservable, but are empirically related to distance and national borders. The relationship between trading costs and distance is assumed to be continuous, whereas the relationship between trading costs and national borders is discontinuous: a sort of jump due, among other things, to differences in legal systems and practices, languages, networks, competitive policies, monetary regimes, tariffs and other restrictions that discriminate against foreign producers.

In addition to income, distance, and borders, the explanatory variables of the GE include a host of other factors that influence bilateral trade. The GE has been very successful in explaining actual trade patterns; in fact, it is considered to be state of the art for the determination of bilateral trade (Leamer and Levinsohn 1995, p. 1384; Feenstra et al. 2001, p. 431). Traditionally, the GE has been estimated by OLS under the assumption that the differences between the actual values and the predicted values, between country i and country j at time t, are purely random; that is,

(1) $y_{ij,t} = f(X_{ij,t}) + \varepsilon_{ij,t}$,

where $\varepsilon_{ij,t}$ is the disturbance term, assumed to be independently and identically distributed (iid). In (1), $y_{ij,t}$ is the actual value of bilateral trade, $X_{ij,t}$ is the vector of explanatory variables mentioned above, and $f(X_{ij,t})$ the value of predicted bilateral trade. With OLS, we assume that actual values of trade deviate from their predicted values by a random value. Luck or measurement errors may constitute the disturbance term of $\varepsilon_{ij,t}$. Therefore, this disturbance is sometimes positive and sometimes negative, but, by construction, its average value is zero.

The fundamental question we try to answer in this paper is: what would bilateral trade flows be if countries operated at the frontier of the GE model? It is not obvious that all optimizing agents, countries in our case, can operate at the frontier. To begin with, critical inputs may be missing from the empirical specification of the model: two obvious examples, in this regard, are the managerial input and the country's infrastructure. Second, utilization rates of specified inputs may differ across countries because of differences in the quality of institutions. Countries with good institutions have higher marginal input productivities than countries with poor institutions. Finally, trading costs reflect, to some extent, the rent that domestic producers can extract by erecting barriers to trade. Rent extraction will differ across countries and will depend on a host of factors.

Missing inputs, differences in input utilization rates, and differences in rent extraction are for the econometrician a source of misspecification that is hard to correct because it is driven by difficult-to-measure variables. Only by comparing, ex post, the performance of the best against the performance of a particular trading partner can one infer a degree of efficiency of the particular performer with respect to the best possible performer. To be sure, both the representative and the potentially best-performing trading partner are optimizing, but the former faces tighter constraints than the latter.

Newton's gravity equation shows the maximum force between two masses which are spatially separated. Trade gravity equation in (1) can be interpreted the same way. Two countries try to maximize their trade given the distance, their economy sizes, and other factors in the equation. Equation (1) can be viewed as a production function of bilateral trade between the two countries. Alternatively, (1) can be viewed as an outcome of cost minimization in which two trading partners try to minimize transaction or transportation costs in international trade. In fact, under the title of "a spatial theory of trade," Rossi-Hansberg (2005) shows in the development of his general trade theory; how countries make their optimum decisions on mutual trade and argues that "[his} model is consistent with estimations of the gravity equation both within and across countries (p. 1485)." When the trade gravity equation is viewed as the outcome of cost minimization, the use of stochastic frontier estimation is justified.

In sum, to answer our question we need to apply a methodology that is able to differentiate the performance of a given particular trading partner from that of the potentially best, and measure the gap between the two, which we call efficiency. This is the role of stochastic frontier estimation. For example, Aigner et al. (1977), Charnes et al. (1978), and Schmidt (1985) use stochastic frontier estimation to calculate efficiency scores obtained from the deviation of actual production or cost values from frontier estimates. Zak et al. (1979) apply the same methodology in evaluating efficiency to professional basketball, Porter and Scully (1982) to professional baseball, Huang and Bagi (1984) to farms in Northwest India, Cummins and Weiss (1993) to the U.S. insurance industry, Zuckerman et al. (1994) to hospitals, Kaparakis et al. (1994) and Berger and Humphrey (1997) to commercial banks, Hay and Liu (1997) to the UK manufacturing sector, and Worthington (1998) to non-bank financial institutions. Lovell (1993) reviews the methods used in other industries. Some researchers have applied stochastic frontier estimation to compare efficiencies and performances across countries. Allen and Rai (1996) have done it for banks across 15 countries, Beccalli (2004) for investment firms in the United Kingdom and Italy, and Weill (2004) for European corporations.

Under stochastic frontier estimation, $\varepsilon_{ij,t}$ is decomposed into two parts, $v_{ij,t}$ and $u_{ij,t}$:

(2) $y_{ij,t} = f(X_{ij,t}) + \varepsilon_{ij,t} = f(X_{ij,t}) + v_{ij,t} - u_{ij,t}$,

where $v_{ij,t}$ is assumed to have an iid normal distribution and $u_{ij,t}$ to have an iid nonnegative half normal distribution. That is,

(3) $v_{ij,t} \sim \text{iid } N(0, \sigma_v^2)$ and

(4) $u_{ij,t} \sim \text{iid } N^+(0, \sigma_u^2)$,

closely following Kumbhakar and Knox Lovell (2000, pp. 74-78). We further assume, following the literature, that $u_{ij,t}$ and $v_{ij,t}$ are distributed independently of each other and of the regressors of $X_{ij,t}$ in (2).

The two-sided error term, $v_{ij,t}$, is the normal statistical noise due to luck or measurement errors, whereas the one-sided error term, $u_{ij,t}$, represents the measure of performance or, in case of production functions, the degree to which actual output falls short of potential output given by the stochastic frontier equation (2). The nonnegative $u_{ij,t}$ in (2) represents "efficiency" of a country in its foreign trade arising from its lack of proper infrastructure or managerial expertise. According to Jondrow et al. (1982), technical efficiency for each observation is $E[u_{ij,t} \mid \varepsilon_{ij,t}]$, given the estimate of the residuals in (2) for $\varepsilon_{ij,t}$ from the stochastic frontier method. In particular, from the stochastic frontier estimation of (2), we have the estimates of σ_v^2, σ_u^2, and $\varepsilon_{ij,t}$. The estimate of the error term, $\varepsilon_{ij,t}$, is the residual. From the estimation, the following quantities can be computed: $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\lambda = \sigma_u / \sigma_v$.

From these estimates, technical efficiency, TE, of each observation is computed by

(5) $TE_{ij,t} = \exp\{-(\sigma_u^2\, \sigma_v^2 / \sigma^2)\, [\varphi(\eta_{ij,t}) / \{1 - \Phi(\eta_{ij,t})\} - \eta_{ij,t}]\}$,

where $\eta_{ij,t} = \varepsilon_{ij,t} \lambda / \sigma$, φ is the standard normal density function, and Φ is the cumulative standard normal distribution function. Once efficiency is computed for each observation, then average technical efficiency can be calculated for any country or for any group of countries.

Several papers have employed the Jondrow et al.(1882)'s or Kumbhakar and Knox Lovell (2000)'s approach. For instance, Hunt-McCool et al. (1996) calculate the maximum stock price for initial public offerings and compare the OLS and stochastic frontier estimates to see if the offerings have been systematically underpriced. Kaparakis et al. (1994) compare cost efficiencies in commercial banks in different U.S. states and calculate technical inefficiencies of each individual bank. Huang and Bagi (1984) compute the level of inefficiency for 151 individual farms in Northwest India and find that it ranges from 4.0 to 22.38 per cent. In all these papers, the dependent variables are expressed in logarithmic terms.

In this paper, we have adopted the normal-half normal distribution of $v_{ij,t}$ and $u_{ij,t}$. Other distributional assumptions can be made. Instead of the half normal distribution, Kumbhakar and Knox Lovell (2000, pp. 80-89) suggest exponential, truncated normal, or gamma distributions and show that the numerical values of the technical efficiency are sensitive to the choice of the particular distributions. Yet, relative efficiency measures across observations are shown not to be critically dependent on the particular distribution: see Kumbhakar and Knox Lovell (2000, p. 90). Use of the normal-half normal in this paper will provide useful relative efficiencies of a given country or of a given group of countries.

II. The Trade Gravity Equation

We estimate the following GE:

(6) $\ln T_{ij,t} = \beta_0 + \beta_1 \ln Y_{i,t}Y_{j,t} + \beta_2 (Y_{i,t}Y_{j,t} / N_{i,t}N_{j,t}) + \beta_3 D_{ij} + \beta_4 F_{ij,t} + \varepsilon_{ij,t}$,

where $T_{ij,t}$ is the value of bilateral trade between country i and country j in year t measured in constant U.S. dollars, $Y_{i,t}$ is real gross domestic product (GDP) of country i in year t also measured in U.S. dollars, $N_{i,t}$ is population of country i in year t, D_{ij} is distance between i and j, $F_{ij,t}$ is a vector of other factors, and $\varepsilon_{ij,t}$ is a disturbance term. Equation (6) is the same as the GE derived by Bergstrand (1989, equation 1), except for the fact that Bergstrand's is expressed in nominal rather than in real terms. Equation (6) is also the same equation used by, among others, Rose (2000, 2002, and 2003).

Vector F includes a fairly comprehensive list of variables that affect bilateral trade, such as dummy variables if the two countries belong to the same regional trade agreement (RTA), and if they share a common currency, common border, common language, common colonizer in the past, or if one country colonized the other. The RTA dummy proxies for a tariff variable indicating preferential trading. Its coefficient should be positive if countries belonging to RTAs trade more than countries that do not belong to an RTA. We also add an "interregional" dummy variable which is equal to one if the two countries belong to two separate RTAs. The coefficient is negative if there is trade diversion. Common currency, common border, common language, and common colonizer are all trade enhancing. Finally, we add year dummies to control for certain idiosyncratic differences in different calendar years.

III. Frontier Estimates

Rose (2002) uses the residuals from the gravity equation to estimate the trade friction of six different regions of the world. He obtains the residuals from the OLS estimates of the GE with fixed time effects. Positive residuals indicate that the predicted trade from the GE falls short of actual trade. Negative residuals show that the predicted trade is greater than actual trade. Rose interprets negative residuals as a measure of protectionism, because protectionism is not explicitly included in the GE. Residuals are then averaged for different regions, with larger averages implying more liberal trade policies than lower averages. In fact, residuals are interpreted in broader terms as residual friction, given that RTA and interregional dummies already capture preferential trade arrangements.[1]

Unlike Rose, we use stochastic frontier estimation to quantify trade efficiency as the distance between actual trade flows and the maximum possible trade flows predicted by (6). Stochastic frontier estimation technique, as opposed to OLS method, has been used, as mentioned above, for production functions and cost functions. Since we view the GE as the outcome of the minimization of transaction or transportation costs in international trade, the stochastic frontier estimation is relevant and adequate for the GE.

Frontier estimation has been performed by using LIMDEP, Version 8, assuming that the efficiency component is half-normally distributed. In addition to stochastic frontier estimation, we also estimate (6) by OLS. Results are given in Table 1.

[Insert Table 1 about here]

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[1] Some authors have dealt with trade potentials. According to Sohn and Yoon (2001, p. 29), positive residuals mean that those countries are trading more than the model predicts to indicate "that other factors not considered by gravity model may be facilitating" the trade, whereas negative residuals indicate that "there exist other important trade impeding factors leading to a considerable level of 'missing trade,' which cannot be explained in our gravity model."

The first column in Table 1 shows the right-hand side variables of (6). Data are mostly from Rose (2003) and consist of 43,746 observations for the years 1975, 1980, 1985, 1990, 1995, and 1999; for more details, see notes to Table 1. Though year dummy variables have been included in the equation for the time fixed effects, their estimated coefficients are not reported in the table for brevity. The estimated results from OLS are shown in the second column. Except for the common country dummy, whose coefficient is statistically significant at the 10% level, all the estimated coefficients are significant at the 1% level. They all have the expected signs and in fact the results are very similar to those in the literature. The results from the frontier estimation are given in the last column. The statistical significance and numerical magnitude of the estimated coefficients do not appear to be very different from those of OLS.

Though a formal test cannot be conducted to investigate the differences or similarities between the two sets of results, the standard errors given in parentheses can be used to shed some light on the comparisons. For example, the coefficient of the distance is −1.17 from the OLS and −1.03 from the frontier estimation. Using two standard errors to cover the 95% confidence interval, the two estimates do not overlap each other implying that those two estimates are significantly different. The same is true for the coefficients of the log of real GDP: the 95% confidence interval for the OLS estimate of 0.88 is from 0.872 to 0.888, while that for the frontier estimate of 0.80 is from 0.792 to 0.808. Hence, the two elasticities are statistically different from each other. Similarly, the coefficients for the real per capita GDP appear to be statistically different, although those two estimates are fairly close to each other with their estimates of 0.42 and 0.38. That is, the OLS and frontier estimates are numerically but not statistically similar. The value of R^2 is 0.64 from the OLS and that of the likelihood function is −91,897 from the frontier estimation.

Unlike in Table 1, where regional trade agreements are only collectively included under regional and interregional dummy variables, Table 2 identifies eleven separate RTAs. The differences and similarities between OLS and frontier estimates in Table 2 are about the same as those in Table 1. Again, the results in Table 2 from OLS are broadly similar to those reported in the literature. The purpose of presenting both OLS and frontier estimates in two different specifications, with and without individual RTAs, is to show the similarities and differences of the two estimation techniques.

[Insert Table 2 about here]

IV. Trade Efficiency Measures

Once we have estimated the trade GE by the stochastic frontier technique, we compute the efficiency measures for each observation using (5). In Table 3, the efficiency measures are the averages for each of 177 countries, over its effective number of observations, in the dataset. For comparison, we also show "efficiency" measures from the OLS estimation. Efficiency measures from the frontier method fall in the range from 0 to 1: a value of one indicates 100% efficiency or 0% inefficiency and a value of zero suggests 0% efficiency or 100% inefficiency. The values of the OLS residuals, however, are either positive or negative. Positive values indicate that the actual trade flows, on average, are larger than the predicted values indicating that the country is "efficient" in trade. Negative values, on the other hand, indicate that the country is "inefficient" in trade. The correlation coefficient between these two efficiency measures is, as shown at the bottom of the table, 0.96.

[Insert Table 3 about here]

The last two columns of Table 3 rank countries in terms of their trade efficiency measures. For both measures, Singapore has the highest rank, followed by Vietnam. The third highest rank goes to Hong Kong when the frontier estimation is used and to Kiribati when the OLS residuals are used. The United States is ranked 34th according to the frontier method and 40th according to the OLS method. The correlation between the two rankings is 0.95, again showing a high relationship. We have to be careful in interpreting some of the efficiency measures, whether they are from stochastic frontier or OLS estimation. For some countries, but especially for small ones, the number of observations tends to be small, because they do not often trade with all the countries in the rest of the world.[2] In addition, many of them do not have any trade data, especially for those years at the beginning of the data period. The number of observations for each country is also given in Table 3.

We investigate the efficiency measures for selected groups of countries in our sample; see Table 4.[3] Out of ten groups, which are neither mutually exclusive nor exhaustive, high income economies have the highest average efficiencies according to both measures. On the other hand, South Asian countries have the lowest efficiencies. According to frontier estimations, the efficiency of the EU is about the same as that of the OECD, but according to OLS estimations, the EU is more efficient than the OECD. The

[2] For the statistical relevance of zero values for bilateral trade, see Haveman and Hummels (2004, pp. 210-213).

[3] Rose (2000) reports similar efficiency measures for certain groups of countries by taking averages of his OLS residuals.

correlation between the two measures is 0.90. We have also investigated the efficiency measures for those eleven RTAs; see Table 5. The ANDEAN has the lowest efficiency according to the frontier method, but the NAFTA has the lowest one according to the OLS method. On the other hand, the ASEAN has the highest efficiency from the frontier method, but the ANZCERTA has the largest OLS residual. The correlation coefficient between the two residuals is 0.74, which is considerably lower than those in the earlier groupings.

[Insert Tables 4 and 5 about here]

In spite of the fact that efficiency rankings are about the same from both methods, there are some fundamental reasons why efficiency measures from the stochastic frontier technique should be preferred to those from OLS. First, OLS residuals are not designed to measure efficiency. By construction, some OLS residuals are positive and some are negative, but are on average zero. Strictly speaking, negative residuals indicate that actual trade flows happen to be lower than what the model predicts, and the reverse is true for positive residuals. Logically, OLS residuals cannot therefore be used to measure trade efficiencies or the extent of trade barriers, because positive residuals would indicate the presence of some trade enhancements.

Second, the stochastic frontier method is designed to measure efficiency in production or cost functions. In production, we explicitly recognize that some firms are more efficient than others. The most efficient firms are at the frontier of the production function and produce the maximum possible output for given technology and inputs. The most efficient firm, or the firm with best practices, will have zero inefficiency in the "deterministic" frontier estimation technique. In our "stochastic" frontier estimation technique, however, we allow that even the most efficient firm may not be on the production frontier by introducing an additional stochastic error term, $v_{ij,t}$ in (2), in the function.

Third, the efficiency measures from the stochastic frontier estimation therefore compute "realistic" departures from the production or cost frontier. The most efficient production firm or the most cost effective firm may still have some room for further improvement to reduce the random disturbance component. As such, the stochastic frontier estimation technique has been used to investigate the efficiency of different commercial banks, production facilities, and cost effectiveness of different firms.

Notwithstanding our preferences for frontier methodology over OLS, we have to be careful in interpreting efficiency measures and rankings. These measures are model specific. In our case, we take the GE as the best or "true" model of international trade. The "true" model is different from the perfect model, which would perfectly explain the dependent variable by the right-hand side variables without any disturbance terms. The true model, although it has all relevant variables, explains the dependent variable with errors. As such our efficiency from the gravity equation should alternatively be termed as "GE-efficiency."

We have argued that the GE is regarded as the best equation of bilateral trade flows. As long as the equation is considered to be the best one, the efficiency measures that it generates can also be regarded as the best ones. It is possible, and in fact it is common practice, to improve upon our Equation (6) by including other relevant factors. With improvements in specification, subsequent efficiency measures will also improve.

Thus, the efficiency measures in this paper are the most accurate ones given the equation and the data we currently have.

Our efficiency measures are generally low, suggesting large deviations of actual observed trade flows from potential trade flows predicted by the GE. The implication is that frictions are still very large for virtually all countries. At the same time, the wide dispersion in efficiency measures suggests that for those countries with relative low trade efficiency levels, there is ample room to raise trade flows by converging to countries with relative high efficiency levels.

V. Concluding Remarks

This paper has investigated the fundamental issue of what bilateral trade flows would be if countries operated at the frontier of the trade gravity equation model. The literature has relied on OLS residuals to measure the gap between potential and actual trade flows. Instead, we have adopted a new approach, the stochastic frontier estimation technique, to deal with the same issue. This technique, so far, has been employed to measure efficiency in production functions as well as firm performance, but not bilateral trade flow efficiency. We have argued that efficiency measures obtained from stochastic frontier residuals are preferable to those obtained from the traditional OLS residuals.

Our computed trade efficiencies, generated from the GE, are relatively small. Singapore, the most efficient country in our sample, has a score of 0.338 out of a maximum of one, suggesting that the frontier is very distant. The ASEAN is the most efficient RTA, whereas the ANDEAN is the least efficient. As Kumbhakar and Knox Lovell (2000, p. 90) show, the absolute values of the efficiency measures are sensitive to the adoption of particular distributions in stochastic frontier estimation. We have used a half normal distribution. Yet, as Kumbhakar and Knox Lovell (2000, p. 90) also show, the relative values of the efficiency measures across observations, in this case across trading partners, are not very sensitive to the particular distributional assumptions. The efficiency measures of different countries or of different groups of countries in this paper will be very useful for comparison purposes. Finally, the wide dispersion in computed efficiencies suggests that significant increases in global trade flows can be achieved by relative low-efficiency countries converging to the performance of high-efficiency countries.

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Table 1: Estimates from the gravity equation

Variables	OLS Estimate	Frontier Estimate
Intercept	-29.28*** (0.214)	-24.00*** (0.190)
Log of real GDP	0.88*** (0.004)	0.80*** (0.004)
Log of real GDP per capita	0.42*** (0.007)	0.38*** (0.006)
Log of distance	-1.17*** (0.014)	-1.03*** (0.014)
Regional dummy	1.16*** (0.074)	1.20*** (0.076)
Interregional dummy	0.35*** (0.036)	0.17*** (0.038)
Common currency dummy	0.80*** (0.085)	0.70*** (0.075)
Common land border dummy	0.43*** (0.066)	0.54*** (0.063)
Common colonizer before 1945 dummy	0.62*** (0.038)	0.68*** (0.029)
Common country dummy	1.18* (0.662)	1.07* (0.877)
Colonial relationship dummy	1.58*** (0.077)	1.52*** (0.097)
Common language dummy	0.35*** (0.027)	0.30*** (0.024)
1975, 1980, 1985, 1990, 1995, and 1999 year dummies	Estimated but not reported here	Estimated but not reported here
Number of observations	43,746	43,746
R^2	0.64	
MLE		-91,897

Note: The dependent variable is the log of the average of four-way flows between country i and j divided by the U.S. price deflator. Numbers in parentheses are standard errors: * indicates statistical significance at the 10% level, ** at the 5% level, and *** at the 1% level.
Note: Estimates were obtained from OLS on pooled data compiled by Rose (2003), http://www.has.berkeley.edu/~arose/. The Rose dataset was modified with respect to the definition of CU, regional, interregional, and individual RTA dummy variables. CU countries include, for different years, those in the are of the U.S. dollar (The United States, Dominican Republic, Guatemala, Panama, Bahamas, Bermuda, and Liberia), East Caribbean dollar (Antigua & Barbuda, Dominica, Grenada, St. Vincent and the Grenadines, St. Christopher Kitts-Nevis, and St. Lucia), pound (United Kingdom, Guyana, Ireland, Malta, Cyprus, Oman, Gambia, Malawi, Mauritius, Seychelles, Trinidad & Tobago, Kenya, Tanzania, Uganda, Somalia, Malaysia, and Singapore), the CFA (Central African Republic, Cameroon, Chad, Republic of Congo, Equatorial Guinea, Gabon, Benin, Burkina Faso, Ivory Coast, Mali, Niger, Senegal, and Togo), franc area (France, Comoros, Madagascar, and Mauritania), Australian dollar (Australia, Kiribati, Solomon Islands, and Tonga), riyal (Qatar and United Arab Emirates) Indian rupee (India and Bhutan), Portuguese escudo(Portugal, Angola, Cape Verde, Guinea-Bissau, and Mozambique), euro (Austria, Belgium, Finland, France, Germany, Ireland, Italy, Luxembourg, Netherlands, Spain, and Portugal), rand (South Africa, Botswana, Lesotho, Namibia, and Swaziland), and Pakistani rupee (Pakistan and Burma).
Note: Regionalism was defined in terms of 11 RTAs: ANDEAN (Bolivia, Colombia, Ecuador, Peru, and Venezuela), ASEAN (Philippines, Indonesia, Malaysia, Singapore, Thailand, Vietnam, Laos, Burma, and Cambodia), CARICOM **(**Antigua and Barbuda, Bahamas, Barbados, Belize, Dominica, Grenada, Guyana, Haiti, Jamaica, St. Kitts and Nevis, St. Lucia, St. Vincent and Grenadines, Suriname, and Trinidad and Tobago), CACM **(**Costa Rica, El Salvador, Guatemala, Honduras, and Nicaragua), NAFTA (Canada, the United States, and Mexico), MERCOSUR (Argentina, Brazil, Paraguay, and Uruguay), USIS (the United States and Israel), PATCRA (Australia and Papua New Guinea), ANZCERTA (Australia and New Zealand), SPARTECA (Australia, New Zealand, Fiji, Kiribati, Papua New Guinea, Solomon Islands, Tonga, Vanuatu, and Samoa), and EC/EU (Belgium, France, Germany, Italy, Luxembourg, Netherlands, Denmark, Ireland, United Kingdom, Greece, Portugal, Spain, Austria, Finland, and Sweden). The regional dummy is equal to one when the countries in the pair belong to the same RTA; otherwise it is zero. The interregional dummy is equal to one when the countries in the pair belong to different RTAs; otherwise it is zero

Table 2: Estimates from extended gravity equation

Variables	OLS Estimate	Frontier Estimate
Intercept	-30.00*** (0.218)	-24.45*** (0.193)
Log of real GDP	0.89*** (0.004)	0.81*** (0.004)
Log of real GDP per capita	0.43*** (0.007)	0.39*** (0.006)
Log of distance	-1.17 *** (0.014)	-1.05*** (0.014)
Common currency dummy	0.92*** (0.036)	0.75*** (0.077)
Common land border dummy	0.48*** (0.067)	0.57*** (0.064)
Common colonizer before 1945 dummy	0.60*** (0.038)	0.67*** (0.028)
Common country dummy	1.15* (0.660)	1.07 (0.870)
Colonial relationship dummy	1.58*** (0.077)	1.51*** (0.097)
Common language dummy	0.28*** (0.027)	0.28*** (0.028)
1975, 1980, 1985, 1990, 1995, and 1999 year dummies		
ASEAN dummy	1.75*** (0.222)	1.79*** (0.270)
ANDEAN dummy	0.72* (0.380)	0.50 (0.543)
CARICOM dummy	2.00*** (0.131)	1.50*** (0.142)
CACM dummy	2.03*** (0.257)	1.59** (0.521)
European Community/EU dummy	-0.62*** (0.125)	-0.22 (0.182)
MERCOSUR dummy	0.94 (0.600)	0.76 (1.391)
NAFTA dummy	0.14 (0.784)	0.42 (3.656)
SPARTECA dummy	3.10*** (0.208)	2.61*** (0.243)
USIS dummy	1.35 (1.036)	1.44 (3.331)
PATCRA dummy	-0.67 (0.943)	-0.32 (1.234)
ANZCERTA dummy	-0.92 (1.055)	0.42 (3.260)
Number of observations	43,746	43,746
R^2	0.64	
MLE		-91,779

Note: See notes to Table 1.

Table 3: Efficiency measures for each country

Country	OBS	EFF	OLS	EFF Rank	OLS rank
ALBANIA	64	0.10	-1.08	175	172
ALGERIA	587	0.18	-0.38	103	128
ANGOLA	400	0.31	1.06	7	9
ANTIGUA AND BARBUDA	214	0.19	0.03	88	73
ARGENTINA	804	0.17	-0.34	121	121
ARMENIA	117	0.17	-0.25	115	114
AUSTRALIA	928	0.19	-0.11	87	99
AUSTRIA	942	0.17	-0.15	128	105
AZERBAIJAN	75	0.23	0.50	49	34
BAHAMAS	531	0.20	-0.03	77	87
BAHRAIN	355	0.24	0.41	36	41
BANGLADESH	667	0.15	-0.39	150	129
BARBADOS	591	0.13	-0.80	168	164
BELARUS	109	0.16	-0.53	145	144
BELGIUM	155	0.21	-0.09	65	95
BELIZE	458	0.15	-0.58	155	150
BENIN	436	0.17	-0.63	131	155
BERMUDA	443	0.15	-0.43	153	135
BHUTAN	73	0.12	-0.98	172	169
BOLIVIA	480	0.14	-0.90	164	166
BOTSWANA	265	0.16	-0.54	133	147
BRAZIL	935	0.19	-0.14	96	103
BULGARIA	547	0.16	-0.38	141	127
BURKINA FASO	388	0.15	-0.57	159	149
BURMA(Myanmar)	389	0.15	-0.98	151	168
BURUNDI	357	0.19	-0.01	97	82
CAMBODIA	59	0.18	-0.07	114	92
CAMEROON	634	0.17	-0.32	127	119
CANADA	948	0.18	-0.11	107	97
CAPE VERDE	234	0.28	1.02	14	10
CENTRAL AFRICAN REP.	409	0.16	-0.40	146	131
CHAD	306	0.15	-0.64	158	157
CHILE	641	0.23	0.26	51	53
CHINA	911	0.24	0.44	39	38
COLOMBIA	753	0.12	-1.04	171	171
COMOROS	188	0.27	1.01	21	12
CONGO, DEM. REP. OF (ZAIRE)	441	0.23	0.13	44	64
CONGO, REP. OF	538	0.17	-0.35	129	122
COSTA RICA	608	0.18	-0.14	102	104
COTE D'IVORIE (IVORY COAST)	660	0.25	0.60	30	31
CROATIA	80	0.12	-0.73	169	162
CYPRUS	730	0.16	-0.21	139	111
CZECH REPUBLIC	265	0.21	0.35	63	48
DENMARK	1000	0.21	0.28	62	51

DJIBOUTI	144	0.30	1.35	8	5
DOMINICA	306	0.20	0.03	72	75
DOMINICAN REP.	502	0.17	-0.31	126	118
ECUADOR	538	0.18	-0.19	100	110
EGYPT	765	0.15	-0.76	154	163
EL SALVADOR	460	0.16	-0.52	148	143
EQUATORIAL GUINEA	138	0.23	0.39	47	45
ESTONIA	228	0.21	0.21	64	59
ETHIOPIA	513	0.20	0.03	78	72
FIJI	447	0.18	-0.16	104	107
FINLAND	934	0.19	-0.02	99	85
FRANCE	992	0.22	0.22	58	57
GABON	454	0.20	0.03	71	74
GAMBIA	401	0.23	0.37	48	47
GEORGIA	129	0.18	-0.16	101	106
GERMANY	994	0.26	0.54	25	33
GHANA	631	0.20	-0.08	76	94
GREECE	932	0.16	-0.36	140	125
GRENADA	304	0.19	0.12	95	65
GUATEMALA	538	0.18	-0.24	110	113
GUINEA	376	0.21	0.01	67	80
GUINEA-BISSAU	254	0.27	0.81	20	22
GUYANA	495	0.20	0.01	83	79
HAITI	484	0.13	-1.12	167	173
HONDURAS	522	0.21	0.08	60	69
HONG KONG	941	0.33	1.40	3	4
HUNGARY	726	0.15	-0.35	149	124
ICELAND	654	0.14	-0.61	162	153
INDIA	948	0.15	-0.50	157	141
INDONESIA	771	0.22	0.13	57	63
IRAN	628	0.18	-0.66	106	158
IRAQ	296	0.20	-0.53	74	145
IRELAND	943	0.20	0.22	79	58
ISRAEL	692	0.17	-0.29	118	117
ITALY	995	0.23	0.34	50	50
JAMAICA	674	0.17	-0.27	122	116
JAPAN	993	0.30	0.94	10	15
JORDAN	563	0.20	0.06	82	71
KAZAKHSTAN	165	0.25	0.62	29	28
KENYA	662	0.24	0.42	40	39
KIRIBATI	118	0.31	1.48	5	3
KOREA,SOUTH(R)	813	0.28	0.86	16	19
KUWAIT	456	0.19	-0.45	94	137
KYRQYZ REPUBLIC	113	0.23	0.18	45	61
LAO PEOPLE'S DEM. REP.	167	0.09	-1.85	176	176
LATVIA	188	0.19	0.07	93	70
LESOTHO	169	0.13	-0.67	165	160
LIBERIA	322	0.29	1.02	12	11

LIBYA	459	0.20	-0.48	85	139
LITHUANIA	193	0.22	-0.01	55	83
LUXEMBOURG	127	0.05	-2.19	177	177
MACEDONIA	74	0.19	0.14	91	62
MADAGASCAR	524	0.17	-0.21	119	112
MALAWI	479	0.27	0.85	22	20
MALAYSIA	887	0.25	0.67	33	26
MALDIVES	138	0.22	0.41	53	43
MALI	443	0.17	-0.26	123	115
MALTA	628	0.17	-0.12	124	101
MAURITANIA	411	0.25	0.56	32	32
MAURITIUS	626	0.17	-0.37	117	126
MEXICO	719	0.11	-1.23	173	174
MOLDVA	132	0.25	0.72	31	24
MONGOLIA	164	0.16	-0.60	135	152
MOROCCO	714	0.18	-0.05	105	90
MOZAMBIQUE	457	0.21	0.01	66	78
NAMIBIA	178	0.16	-0.56	138	148
NEPAL	286	0.10	-1.43	174	175
NETHERLANDS	994	0.32	1.17	4	6
NEW ZEALAND	876	0.24	0.40	38	44
NICARAGUA	430	0.19	-0.02	89	84
NIGER	385	0.14	-0.51	161	142
NIGERIA	691	0.19	-0.61	90	154
NORWAY	966	0.20	0.22	69	56
OMAN	426	0.19	-0.45	98	138
PAKISTAN	905	0.18	-0.12	112	100
PANAMA	593	0.28	0.94	13	16
PAPUA N.GUINEA	449	0.19	-0.04	92	88
PARAGUAY	462	0.17	-0.35	125	123
PERU	664	0.17	-0.33	130	120
PHILIPPINES	787	0.18	-0.18	111	109
POLAND	808	0.15	-0.44	152	136
PORTUGAL	938	0.20	0.10	80	67
QATAR	360	0.17	-0.53	120	146
REUNION	178	0.29	1.08	11	8
ROMANIA	753	0.25	0.70	28	25
RUSSIA	136	0.30	1.01	9	13
RWANDA	353	0.14	-0.64	163	156
SAMOA	166	0.23	0.08	43	68
SAO TOME & PRINCIPE	51	0.28	0.84	15	21
SAUDI ARABIA	791	0.22	-0.05	54	89
SENEGAL	651	0.20	-0.03	81	86
SEYCHELLES	277	0.26	0.87	26	18
SIERRA LEONE	445	0.16	-0.81	147	165
SINGAPORE	800	0.39	1.89	1	1
SLOVAK REPUBLIC	271	0.14	-0.41	160	132
SLOVENIA	261	0.21	0.34	61	49

SOLOMON ISLANDS	195	0.27	0.62	17	27
SOMALIA	222	0.18	-0.05	109	91
SOUTH AFRICA	645	0.25	0.37	27	46
SPAIN	966	0.18	-0.13	108	102
SRI LANKA	731	0.19	0.11	86	66
ST. KITTS&NEVIS	152	0.15	-0.43	156	134
ST.LUCIA	188	0.16	-0.18	132	108
ST.VINCENT&GRE	267	0.16	-0.48	134	140
SUDAN	452	0.16	-0.67	136	161
SURINAME	395	0.26	0.87	23	17
SWAZILAND	280	0.20	0.23	73	55
SWEDEN	974	0.23	0.50	42	36
SWITZERLAND	980	0.23	0.50	41	35
SYRIA	502	0.12	-1.02	170	170
TAJIKISTAN	55	0.26	0.61	24	29
TANZANIA	590	0.23	0.41	52	42
THAILAND	889	0.24	0.49	37	37
TOGO	482	0.27	0.96	18	14
TONGA	197	0.21	0.26	68	52
TRINIDAD&TOBAGO	602	0.16	-0.59	144	151
TUNISIA	716	0.17	-0.11	116	98
TURKEY	804	0.13	-0.91	166	167
TURKMENISTAN	64	0.20	-0.08	84	93
UGANDA	441	0.16	-0.40	142	130
UKRAINE	159	0.31	1.13	6	7
UNITED ARAB EMIRATES	406	0.22	0.02	59	77
UNITED KINGDOM	1013	0.22	0.25	56	54
UNITED STATES	994	0.25	0.41	34	40
URUGUAY	657	0.18	-0.10	113	96
UZBEKISTAN	61	0.20	0.00	70	81
VANUATU	167	0.27	0.72	19	23
VENEZUELA	628	0.16	-0.67	143	159
VIETNAM	126	0.35	1.67	2	2
YEMEN, REPUBLIC OF	167	0.24	0.61	35	30
YUGOSLAVIA	610	0.16	-0.41	137	133
ZAMBIA	569	0.23	0.18	46	60
ZIMBABWE	447	0.20	0.03	75	76
Correlation between efficiencies			0.96		
Correlation between rankings					0.95

Note: EFF is the efficiency measure from the stochastic frontier estimation and that from the OLS residuals. They are from Table 1 results, without separate RTAs. EFF rank and OLS rank are the rankings of the most efficient countries. OBS shows the effective number of observations for each country.

Table 4: Efficiency of geographical groups of countries

Groups	EFF	OLS
East Asia and Pacific	0.19	-0.31
High Income Economies	0.22	0.26
Sub-Saharan Africa	0.21	0.03
Low Income Countries	0.20	0.20
EU	0.21	0.21
OECD	0.21	0.13
Europe and Central Asia	0.19	-0.10
Middle East And North Africa	0.19	-0.31
Latin America and Caribbean	0.17	-0.31
South Asia	0.16	-0.32
Correlation between efficiencies		0.90

Note: EU and OECD countries are based on their memberships as of 1999.
Note: Other groups are based on the classification from the World Bank at http://www.worldbank.org/data/countryclass/classgroups.htm. EFF and OLS are weighted averages of member countries shown in Table 3. When both trading partners belong to the same group, those observations therefore are counted twice in the computation.

Table 5: Efficiencies of eleven RTAs.

RTAs	EFF	OLS
EU	0.21	0.21
US-IS	0.22	0.13
NAFTA	0.19	-1.15
CARICOM	0.17	-0.29
PATCRA	0.21	0.10
ANZCERTA	0.22	0.63
CACM	0.18	-0.16
MERCOSUR	0.18	-0.22
ASEAN	0.24	0.41
SPARTCEA	0.22	0.15
ANDEAN	0.15	-0.64
Correlation between efficiencies		0.74

Note: For classifications of eleven RTAs, see note to Table 1.