Trade and Income – Exploiting Time Series in Geography*

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Abstract

Establishing a robust causal relationship between trade and income has been difficult. Frankel and Romer (1999) use geographic instruments to identify a positive effect of trade on income. Rodriguez and Rodrik (2000) show that these results are not robust to controlling for missing variables such as distance to the equator or institutions. This paper solves the missing variable problem by generating time varying geographic instruments. The quantity of world trade carried by air has been increasing over time. Estimates from a gravity model show an increase in the elasticity of bilateral trade with regard to air distance over time while the elasticity with regard to sea distance has declined. This change has heterogeneous effects on the trade between pairs of countries depending on the relative sea and air distances between them. This heterogeneity in geography can be used to generate geography based predictions for bilateral trade that vary over time. These predictions can be aggregated and used as instruments for trade in a regression of income on trade. The time series variation allows for controls for country fixed effects, eliminating the bias from any omitted time invariant variables such as distance from the equator or historically determined institutions. Trade has a significant effect on income with an elasticity of roughly one half. Differences in predicted trade growth can explain roughly 17 percent of the variation in cross country income growth between 1960 and 1995.

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Introduction

Does increased trade lead to higher income? The economics profession has historically tended to assume that the answer is yes. In the 1990's several very heavily cited empirical papers seemed to confirm this consensus.[1] These paper are not without critics. Though wealthier countries trade more than poor countries, it is difficult to know the direction of causality. Perhaps the most influential of these papers, Frankel and Romer (1999), attempts to resolve this through the use of geographic instruments. By using the distance between countries to predict trade between bilateral pairs, they construct an exogenous instrument for aggregate trade in each country.

While their instruments are free of reverse causality, they are correlated with geographic differences in outcomes that are not generated through trade. Countries that are closer to the equator generally have longer trade routes and may have low income due to unfavorable disease environments or unproductive colonial institutions.[2] Rodriguez and Rodrik (2000) and others have shown that Frankel and Romer (1999)'s results are not robust to the inclusion of geographic controls in the second stage.[3]

This debate has been difficult to resolve because the instruments are limited to a single cross section. Missing variable bias is essentially impossible to avoid and results will always be sensitive to the inclusion of additional regressors.[4] This paper will introduce *time varying* instruments based on geographic fundamentals which allow the examination of trade and income to be done in a panel. The time variation makes possible the inclusion of country fixed effects, which control perfectly for all time invariant correlates with income such as distance to the equator, disease environment and colonial history. It is therefore possible to bypass all the "deep

[1] Sachs and Warner (1995), Frankel and Romer (1999), Dollar (1992), and Edwards (1998) are among the most prominent papers finding a positive relationship between trade and income. Rodriguez and Rodrik (2000) critique this group. See Estevadeordal and Taylor (2008) for a more thorough summary of the debate.

[2] See Acemoglu, Johnson and Robinson (2001), Rodrik, Subramanian and Trebbi (2004), Glaeser, La Porta, Lopez-de Silanes and Shleifer (2004), McArthur and Sachs (2001), Gallup, Sachs and Mellinger (1999) on the relative importance of geography and institutions.

[3] See also Rodrik et al. (2004) and Irwin and Terviö (2002). Using a larger trade sample, Noguer and Siscart (2005) find that geographic controls reduce the effect of trade on income, but do not eliminate them. However, their conclusions are based on regressions that add a single additional control at a time.

[4] See Levine and Renelt (1992) and Sala-i-Martin (1997) on the robustness of growth regressions to additional regressors.

determinants" of income differences and generate identification purely through time series variation. This drastically limits the scope for missing variable bias compared to cross sectional studies.

How can one generate a time series in geography? This paper will start from the idea that distance is not nearly as static a concept as we tend to assume. As a practical matter, the shape and size of the world are not invariant over time. In particular, the rise of air transit has significantly altered the effective distances between countries compared to an era when the only way of crossing oceans was by ship. The position of land masses around the globe generates huge differences between bilateral distance by sea and the great circle distances more typical of air travel. Before 1960 the air transport share of trade for the United States was negligible.[5] By 2004, air transport carried over half of US exports by value (excluding Mexico and Canada). This technological change alters the impact of distance between countries over time. Regressions of bilateral trade over time will show that the relative importance of distance by air has been increasing while the importance of distance by sea is in decline.

These changes over time can be used to identify the effect of trade on income. The key insight is that the rise of air freight has differential consequences for different countries. Countries whose sea routes roughly match their air routes will see relatively less benefit from the rise of air transport than countries whose air trade routes cross land masses. This will result in differential impacts on trade for each country. Since these changes are a result of simple geography interacted with time varying coefficients, exogenous instruments for bilateral trade can be created. The time variation in these instruments ultimately comes from technological change which is shared equally across all countries but which has different consequences across pairs of countries based on geographic differences.

From this I can create a panel version of Frankel and Romer (1999). Bilateral predictions for trade can be summed to generate a panel of predictions for overall trade for each country in the world. These trade volumes can be used as instruments in panel regressions of trade on income per capita. The time series variation in the instruments is novel and allows for time and country specific effects to be included in the second stage.

To preview the results, trade is found to have a significant effect on income with

[5] Hummels (2007) documents the rise of air transport over time.

Figure 1: Air Freight Share of US Trade Value (excluding North America)

source: Hummels (2007), pp 133.

an elasticity of about one half. The point estimates are smaller than previous cross sectional studies, but within their error bands. The results are robust to changes in estimation method and sample. The inclusion of country controls eliminates all bias from the static geographic and institutional factors that affect Frankel and Romer (1999).

1 The Changing Shape of the Globe

Transport between countries has hardly been static over the last 50 years. Hummels (2007) documents the fall in price for air freight and the rise in the value of trade carried by air versus the sea. Between 1955 and 2004 the cost of air freight per ton fell by a factor of ten with a more rapid fall between 1955 and 1972.[6] By contrast, ocean freight has seen no downward trend over the same period. Unsurprisingly this has led to a dramatic shift toward the use of air in moving goods around the globe. Figure (1) shows the increase in the value of US trade carried by air over time. By 2004 over half of US exports to points outside North America were carried by air.

The shift away from sea transport toward air transport should have significant consequences for world trade patterns. Consider, for example, the distance between

[6]Hummels (2007), pp 137-138.

Japan and Northern Europe. Travel by sea from Japan to Germany requires a voyage of almost 12,000 nautical miles. The same voyage by air is less than 5000 nautical miles. From the east coast of the United States, the air and sea distances are nearly identical. Cheaper air transportation should therefore lead to a relative rise in bilateral trade between Japan and Germany compared to the United States and Germany.

While sea distance occasionally appears in gravity models, it has tended to be in the context of single country or regional studies.[7] As far as I know this is the first time sea distances have been exploited in a large examination of global trade.

As air transport becomes more important there should be shifts in the effect of various distance measures on trade. Sea distances should be declining in importance while air distance increases in importance. The next section will estimate a gravity model of trade to test this conjecture.

1.1 The Gravity Model

The gravity model has been an empirical workhorse in the trade literature for almost half a century. The idea that the distance between two countries has a strong influence on the volume of bilateral trade is intuitive and holds up well empirically. Over the last several years there has been much debate about the theoretical underpinnings of the gravity model and the proper way to estimate it. Anderson and van Wincoop (2003) develop a theoretical model to derive the gravity model. The basic gravity relationship derived by them is

$$x_{ij} = \frac{y_i y_j}{y_w}\left(\frac{t_{ij}}{P_i P_j}\right)^{1-\sigma} \quad (1)$$

where x_{ijt} is bilateral trade between country i and country j, y_i y_j and y_w are the incomes of country i, country j and the world, t_{ij} is a bilateral resistance term, and P_i and P_j are country specific multilateral resistance terms. Taking logs,

$$ln(x_{ij}) = ln(y_i) + ln(y_j) - ln(y_w) + (1-\sigma)(ln(t_{ij}) + ln(P_i) + ln(P_j)). \quad (2)$$

[7]Disdier and Head (2008) conduct a meta study of gravity model results and cite the use of sea distance as one differentiator between papers. However the use of sea distance is rare and seems to be limited to regional work. Coulibalya and Fontagne (2005) consider sea distance in an examination of African trade.

The bilateral resistance term, t_{ij}, in Equation (2) is assumed to be a log-linear function of air and sea distance, with the precise form of the relationship varying over time. The P and y terms can be controlled for in several ways. For most of the results, they will be controlled for using country dummies. This implicitly assumes that they are time invariant, which is obviously incorrect. Time effects will control for common rates of growth of all countries in the sample, but idiosyncratic growth rate differences will go into the error term. Given that the regressor in the second stage is going to be precisely these idiosyncratic growth differences, any accounting for them econometrically will contaminate the trade predictions in the second stage.[8] Some results will be presented that include a full set of country pair dummies. This specification has the added benefit of controlling for all time invariant trade resistances. The estimation equations are therefore

$$ln(x_{ijt}) = \alpha + \gamma_i + \gamma_j + \gamma_t + \beta_{sea,t} ln(seadist_{ij}) + \beta_{air,t} ln(airdist_{ij}) + \epsilon \qquad (3)$$

$$ln(x_{ijt}) = \alpha + \gamma_{ij} + \gamma_t + \beta_{sea,t} ln(seadist_{ij}) + \beta_{air,t} ln(airdist_{ij}) + \epsilon \qquad (4)$$

where Equation (3) includes country effects and Equation (4) includes bilateral pair effects.

Unlike many of the studies criticized by Anderson and van Wincoop (2003) and Baldwin and Taglioni (2006) the purpose of these regressions is not to consider comparative statics on the regressors. The goal is to describe the relative predictive power of the two different distance measures over time and then use that variation to generate exogenous indexes of distance to predict trade in the second stage. In the second stage the estimates of the dummies and coefficients on air and sea distance over time essentially will act as weights in averages of distance.

Because the aggregate instrument set is going to be built from averages of bilateral distances with weights that are equal across all countries, any arbitrary weights could be used in the creation of a valid instrument. By using weights generated from the estimation of a gravity equation I am attempting to maximize the predictive power of the instruments in the second stage.

[8] Baldwin and Taglioni (2006) suggests using a full set of country-year dummies which would obviously account for time varying incomes. This would similarly contaminate the predicted trade instrument with income information.

1.2 Data

Trade data was thoughtfully provided by Glick and Taylor (2008) who in turn are using the IMF Direction of Trade (DoT) data. In the DoT data for each bilateral pair in each year there are a potential of four observations – imports and exports are reported from both sides of the pair. An average of these four values is used, except in the case where none of the four is reported. These values are taken as missing. Robustness checks will also be performed on balanced panel with no missing variables.

Bilateral great circle distances (the measure of air distance) are from the CEPII.[9] The CEPII provide a number of different variations on the great circle distance described in more detail in Head and Mayer (2002). For this paper I use the population weighted distance. CEPII also provides a set of bilateral dummies indicating whether the two countries are contiguous, share a common language, have had a common colonizer after 1945, have ever had a colonial link, have had a colonial relationship after 1945, are currently in a colonial relationship, or share a common language. These controls are included in some of the regressions.

Bilateral sea distances were created by the author using raw geographic data. The globe was first split into a matrix of $1x1$ degree squares. The points representing points on land were identified using gridded geographic data from CIESIN.[10] The time needed to travel from any oceanic point on the grid to each of its neighbors was calculated assuming a speed of 20 knots and adding (or subtracting) the speed of the average ocean current along the path. Average ocean current data is from the National Center for Atmospheric Research.[11] The result of these calculations is a complete grid of the water of the globe with information on travel time between any two adjacent points. Given any two points in this network of points, the shortest travel time can be found using standard graph theory algorithms.[12]

The primary port for each country was identified and all pairwise distances were calculated. The distance between countries used in the regression is the number of days to make a round trip. Because countries need to abut the sea in order to be located on the oceanic grid, the sample excludes landlocked countries. Oil exporters were also left out of the sample because they have atypical trade patterns and have

[9] http://www.cepii.fr/anglaisgraph/bdd/distances.htm
[10] http://sedac.ciesin.columbia.edu/povmap/ds_global.jsp
[11] Meehl (1980), http://dss.ucar.edu/datasets/ds280.0/
[12] Specifically, Djikstra's algorithm.

an almost mechanical relationship between the value of trade and income. None of the results are sensitive to the inclusion of the oil producers.

Identifying the location for the primary port for the vast majority of countries was straightforward and for most countries choosing any point along the coast would not change the results. The major potential exceptions to this are the US and Canada, with major population on both coasts and massive differences in distance depending on which coast is chosen. For simplicity (and because the east-west distribution of economic activity in the US and Canada can be seen as an outcome) the trade of the US and Canada with all partners was split with 80 percent attributed to the east coast and 20 to the west coast for all years. This is based on the the US east-west population distribution for 1975, the middle of the sample. When generating predicted trade shares for the US and Canada, the trade with both ports were summed. Choosing just the east coast ports or removing all observations including the US and Canada has no effect on the results.

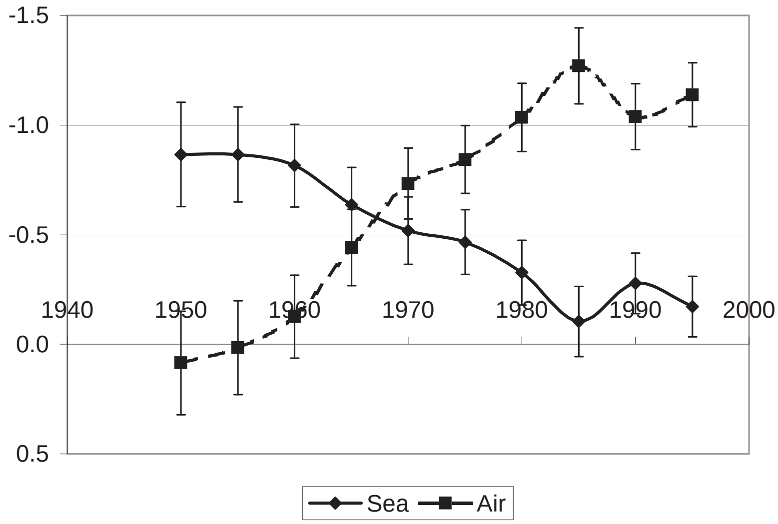
The trade panel is unbalanced. This is potentially problematic since there is some ambiguity about whether missing observations are truly missing or are actually zeros. In the next section, results will be presented for the unbalanced panel and for a balanced panel comprised of all pairs with continuous data from 1950 to 1997. The reduced sample results should be unaffected by problems with zeros in the data. This reduces the sample size from over 160 thousand observations to just above 50 thousand and does not significantly alter the results.

1.3 Results

Figures 2 and 3 plot the sequence of coefficients on air distance and sea distance found by estimating equations (3) and (4). Each point represents the elasticity of trade with regards to sea or air distance over a particular time period and are the β's from equations (3) and (4). The axes are inverted since the effect of distance is negative for trade. The error bars on each point represent two standard errors around the point estimates.

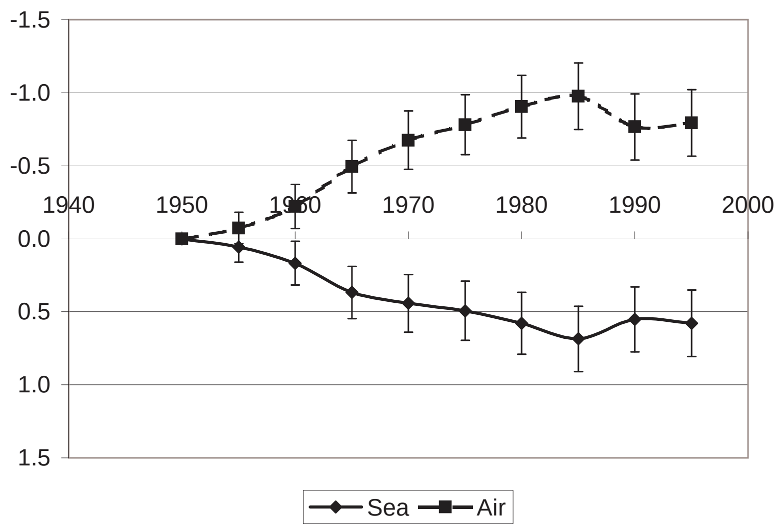
Figure 2 shows that the elasticity of trade with regards to sea distance between 1950 and 1955 was roughly -0.9. This elasticity falls in absolute value until the 1985-1990 period where is levels off near zero. In the same figure, the elasticity with regards to air distance starts out insignificantly different from zero in the 1950-1955 period and rises in absolute value to over -1 by the 1985-1990 period. These

Figure 2: The Change in Elasticity of Trade with Respect to Sea and Air Distance over Time



source: Coefficients from regression table 8 column 2.
Each point represents the coefficient on (sea or air) distance over a 5 year interval. Estimates are from a gravity model with country fixed effects.
Error bars represent plus or minus two standard errors for each coefficient.

Figure 3: The Change in Elasticity of Trade with Respect to Sea and Air Distance over Time



source: Coefficients from regression table 8 column 5.
Each point represents the coefficient on (sea or air) distance over a 5 year interval. Estimates are from a gravity model with country pair fixed effects.
Error bars represent plus or minus two standard errors for each coefficient.

movements are large relative to the standard errors and the changes are highly significant.

In 1950 a 10 percent increase in sea distance between two countries was associated with an 8.9 percent fall in trade. Air distance in 1950 had a negligible effect on trade. By 1985 this picture reverses. A 10 percent increase in air distance decreases trade by 13 percent while changes in sea distance have negligible effects.

The coefficients plotted in Figure 3 are from a regression that includes bilateral pair dummies so the absolute levels of the coefficients are not identified, only their movements over time. The values of the coefficients for the period 1950-1955 are omitted and the remaining coefficients represent deviations from the unknown initial level. The movements track the previous regressions almost exactly. Because of the bilateral pair controls, all the identification for these coefficients is coming from within pair variations in trade.

Table 8 (in an appendix) presents the results of estimating equations (3) and (4). The elasticities plotted in Figures 2 and 3 are taken from columns (2) and (5) of this table. Columns (1) through (4) are estimated using a full set of country dummies. Columns (5) and (6) are estimated using bilateral pair dummies. The omitted category for these columns are years 1950-1955. Coefficients in these columns should be seen as deviations from an unknown initial level. Columns (1), (2), and (5) are estimated on all the available trade data. The remaining columns are estimated on a panel with continuous bilateral trade data from 1950-1997. Columns (2) and (4) include a standard set of bilateral controls from the CEPII data set. All regressions have unreported year dummies and all standard errors are clustered at the bilateral pair level.

These variations all tell a similar story. The elasticity of trade with regards to sea distance becomes less negative between 1950 and 1995. The elasticity of trade with regards to air distance becomes more negative over the same period. This pattern holds true for all estimation variations in the table. This shows that sea distance is diminishing in importance over time and air distance is rising and is consistent with the rise in air freight described earlier.

One potential complication with the conceptual splitting of air and sea distance is ground travel. This is clearly as issue for the European counties where much trade between countries takes place by truck and train and where the shift between air and sea may be less relevant. One way to check this is to run the previous regressions excluding all trade within Western Europe or by excluding trade between contiguous countries. Neither of these exercises changes the results.

The increase in the absolute value of coefficients on great circle distance over time is not a new finding. Disdier and Head (2008) survey estimates of gravity models and find an increase in coefficients on distance over time.[13] However, none of these studies included sea distances along with the standard great circle bilateral distances. Table 9 shows the results of regressions including only the standard great circle distances. These results are consistent with the earlier studies in finding that the absolute value of the elasticity is increasing. However, the rise is only about half as large as when sea distance is also included. The increases in the effect of sea distance could be interpreted as a function of omitted variables with sea distance being the main missing variable. As air transport becomes more important its explanatory power increases while the explanatory power of sea distance falls.

The changes in the coefficients on air distance and sea distance over time make intuitive sense. In 1950 commercial air freight was expensive and rare. Most goods were traded over long distances by sea. The changes over time reflect the growth and technological improvement of air freight as documented by Hummels (2007). Because this technological change is shared by all countries, it will act as an exogenous shock to distance with heterogeneous effects across pairs of countries. I can exploit this technological change to generate a time series in effective bilateral distances between countries. This time series can then be used as an instrument for trade over time.

1.4 Predicting Total trade

The predicted values from the coefficients reported in Table 8 are used to construct predicted values for bilateral trade for each pair of countries for each year. The predicted values are derived from equations (3) and (4) and are therefore comprised of a time effect, a bilateral pair effect (or a pair of country effects and bilateral controls), and the distance effects. These predicted trade volumes can be summed in order to arrive at a prediction for aggregate trade in each country for each year.

[13] Brun, Carrère, Guillaumont and de Melo (2005) and Coe, Subramanian and Tamirisa (2007) are quite similar to this paper in their use of the DoT data in a panel. Both find increasing an effect of distance over time for standard gravity model estimations. Berthelon and Freund (2008) find similar effects in disaggregated trade. See Disdier and Head (2008) for a full survey of papers on the "Death of Distance."

These predictions can easily be made out of sample. As long as there is a single observation of bilateral trade between two countries, an estimate for the bilateral pair can be generated in every year since distance is always available. This has the advantage of keeping the set of bilateral pairs constant over time for the predicted trade, avoiding the problem of changes to aggregate trade driven by the appearance and disappearance of trade data for a particular pair.[14]

Because the goal is to instrument the actual trade share with the predicted trade share in a regression of trade on per capita GDP, these out of sample predictions create some difficulties because there are observations where there is a predicted trade value, but not an actual trade value. This matters because the instruments and observations of trade volumes need to be matched for the IV regressions.

Two different methods are used to deal with these holes. First, the missing values of real trade are imputed using a full set of country pair and time dummies. These imputations are based entirely on information that is controlled for in the second stage and should not affect the results. They are only necessary to keep the scaling of the actual changes in trade consistent. In order to confirm that these imputations are not driving the results I will also report results where the sample is restricted to country pairs with a full panel of observations from 1950-1997. This eliminates out of sample predictions and imputations at the cost of reducing the number of countries from 101 to 62 and biasing the sample toward wealthier countries.

Following Frankel and Romer (1999), unlogged versions of these bilateral relationships are summed to obtain a prediction for total trade for each country. The actual trade figures are similarly summed to arrive at a value for total trade.

$$\begin{aligned} predicted\ trade_{i,t} &= \sum_{i \neq j} e^{\gamma_t + \gamma_{i,j} + ln(air_{i,j})*\beta_{air,t} + ln(sea_{i,j})*\beta_{sea,t}} \\ &= e^{\gamma_t} \sum_{i \neq j} e^{\gamma_{i,j}} e^{ln(air_{i,j})*\beta_{air,t} + ln(sea_{i,j})*\beta_{sea,t}} \end{aligned} \tag{5}$$

$$predicted\ trade_{i,t} = \sum_{i \neq j} e^{\gamma_t + \gamma_i + \gamma_j + ln(air_{i,j})*\beta_{air,t} + ln(sea_{i,j})*\beta_{sea,t}} \tag{6}$$

[14] For the case where the gravity model is estimated using country level dummies one could, in theory, predict trade between any two countries even if they lacked a single observation in the bilateral trade data. In practice, predictions for trade are only made for country pairs that exist in the data so that the two methods of estimating the gravity model are consistently applied.

$$= \quad e^{\gamma_t} e^{\gamma_i} \sum_{i \neq j} e^{\gamma_j} e^{ln(air_{i,j})*\beta_{air,t}+ln(sea_{i,j})*\beta_{sea,t}}$$

For the predictions using country-pair dummies, the country pair effects act as weights in an average of distances. The relative weights of sea and air distance vary over time as described in Table 8 and Figures 2 and 3. Because the country level regressions will include country and time fixed effects, all the identification will be from the within country variation over time. None of the identifying time variation is generated from the bilateral or time effects.

The predictions using individual country dummies are similar. Both the time and own country effects can be taken outside the summation. Since the second stage will include country and time fixed effects, these effects will be removed in the country level GDP regressions. The predicted trade values are therefore weighted averages of bilateral sea and air distance effects where the weights are provided by the value of the dummy for the other country in the pair. Once again, all the idiosyncratic time variation is provided by the different distance measures and the changing β's.

For the purposes of estimating the effect of trade on GDP the time variation is exogenous with regard to any individual country. The rise of the importance of air travel reflects technological change that is exogenous with respect to any given country but which has differential effects across countries based on their exogenous geographical characteristics. Countries whose proximity to the rest of the world is differentially improved by air travel benefit more from this technological change.

2 The Effect of Trade on Income

The predicted trade volumes generated in the previous section derive their within country variation entirely from differences in bilateral land and sea distances. The overall time variation is being driven by technological change which is exogenous with respect to any given country. This makes the predicted trade a useful instrument for investigating the effect of trade on income.

Obviously, this approach is similar to the identification strategy from Frankel and Romer (1999) but it improves upon it in several important respects. Because the predicted values are from a panel one can include country effects in the second stage regression, deriving all the identification from changes over time. This is useful because one possible problem with the Frankel and Romer (1999) identification approach is that geography may be correlated with other characteristics of a country beyond trade. For example, countries that are geographically closer to the rest of the world may have developed better institutions over time. Their instrument may be picking up these long run effects and not the immediate effect of trade. Remoteness also correlates with being nearer to the equator which is correlated with worse health conditions and institutions. Rodrik et al. (2004) show that the Frankel and Romer (1999) results are not robust to controlling for geography and modern institutions. Country effects will remove any of these deep determinants of income differences.

Frankel and Romer (1999) also suffers from concerns about whether trade is the only bilateral factor shaped by distance. Bilateral trade may be a proxy for technology exchange[15] or foreign direct investment. In a limited way, the identification offered here may suffer from the same flaw. It may be that the changes to trade patterns brought about by technological change correlate with changes to other explanatory variables. Foreign direct investment, the presence of multinationals, technology transfers and other potentially productivity increasing activity may be correlated with an enhanced ability to travel around the globe. It should be noted that any non-trade channels for the instruments to act on income are limited to time varying bilateral relationships. This dramatically limits the scope of omitted variable bias, particularly compared to previous studies of trade and income. Even if one allows for these types of missing variables, the reduced form regressions can be seen as describing the general effects of economic geography. The predicted changes in trade should be exogenous with respect to income and reflect real causal effects of changes in geography on income.

2.1 Long Differences

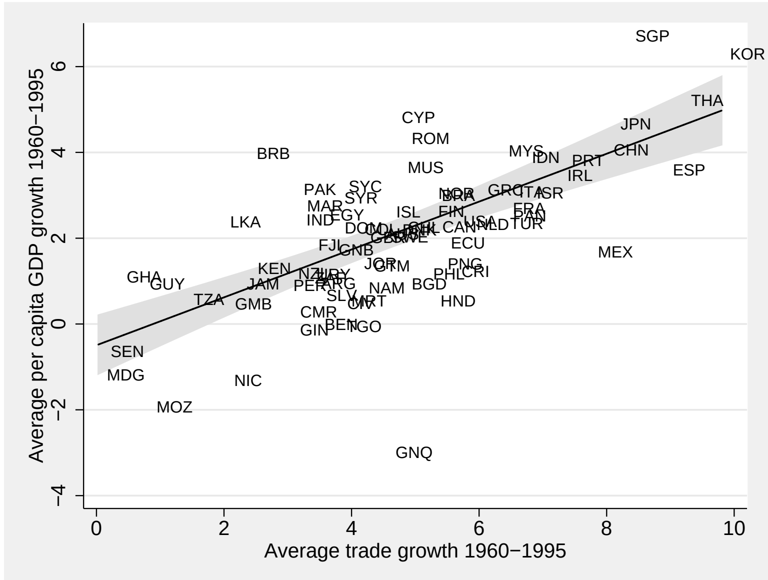
Before moving on to the full panel results this section will examine the change in GDP per capita from 1960 to 1995 against changes in actual and predicted trade over the same period.[16] While less precise than the panel regressions, this exercise can show the basic relationships visually.

Figure 4 shows the relationship between the growth of trade and the growth of per capita GDP. This relationship is obviously highly significant. Of course,

[15] Keller (2002)

[16] The start point of 1960 is chosen to maximize the number of countries with GDP data.

Figure 4: Average Per Capita GDP Growth versus Trade Growth 1960-1995



source: Penn World Tables 6.2, IMF Direction of Trade database.

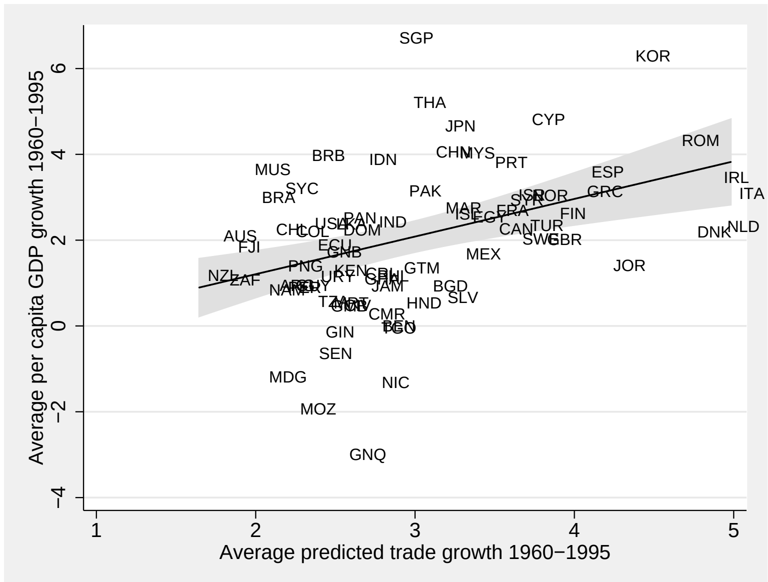
the direction of causality is clearly unknown as rising incomes may be leading to increased trade. To deal with this, the change in trade predicted in the previous section can be used as an instrument for the change in actual trade. Figure 6 (in an appendix) shows the relationship between the predicted change in trade and the actual change in trade. The relationship is very strong with a point estimate of 1.28 and a t-statistic of almost 5.

Figure 5 shows the relationship between the growth in per capita GDP and the predicted growth in trade. This relationship has a point estimated of 0.877 and a standard error of 0.225. The R^2 of 0.170 suggests that changes in predicted trade can explain 17 percent of the observed cross country differences in growth rates from 1960 to 1995.

More formally, I can run the IV regression of trade growth versus GDP growth instrumenting actual trade growth with predicted trade growth. Table 1 shows the results of regressing the change in income from 1960 to 1995 against actual trade and predicted trade. Column (1) is the OLS regression on actual trade corresponding to Figure 4. Column (2) is the reduced form regression on the instrument corresponding to Figure 5. Columns (3) and (4) are IV estimates. Column (4) also includes a control for countries located in the tropics.[17] In this specification the tropical

[17] Controlling for absolute latitude is an alternative to a tropical dummy. Including the absolute

Figure 5: Average Per Capita GDP Growth versus Predicted Trade Growth 1960-1995



source: Penn World Tables 6.2, author's calculations.

Table 1: The Effect of Trade Growth on per capita GDP growth 1960-1995

	(1)	(2)	(3)	(4)
	Annual per capita GDP growth 1960-1995			
	OLS	OLS	IV	IV
Trade growth	0.558		0.688	0.517
	(0.070)**		(0.111)**	(0.127)**
Predicted trade growth		0.877		
		(0.225)**		
Tropical Dummy				-0.618
				(0.325)+
Observations	76	76	76	76
R-squared	0.464	0.170		

In columns (3) and (4) actual trade is instrumented with predicted trade.
+ significant at 10%; * significant at 5%; ** significant at 1%

control accounts for potential differences in trend growth between tropical and non-tropical countries. Since the instrument is driven by geography, one might worry that changes in relative distance are correlated with distance from the equator and the results are being driven by this relationship. Column (4) shows that this is not the case.

2.2 Panel Regressions of Trade on Income

This section will repeat the exercises of the previous section with panel regressions. Trade predictions are made at five year intervals from 1950 to 1995. These predicted trade volumes are used as instruments in a panel regression of income on per capita GDP on trade. With a panel of exogenous instruments at hand, the regression specification can be kept extremely simple. Country effects control for a host of time invariant factors like the distance to the equator and colonial history. The country effect will also absorb all static institutional variation. Given the slow moving nature of institutions, this should control for the vast majority of institutional differences. The regression specification for the country level regressions is

$$ln(y_{it}) = \gamma_i + \gamma_t + \beta\ ln(trade_{it}) + \epsilon_{it} \tag{7}$$

where $y_{i,t}$ is real GDP per capita from the Penn World Tables,[18] γ_i and γ_t are country and time effects and $\epsilon_{i,t}$ is a disturbance term. In order to deal with endogeneity in the volume of trade, $ln(trade)$ will be instrumented with the predicted trade developed earlier. All estimation is done on a panel with observations every 5 years.

2.3 Results

Table 2 presents the OLS results of regressing per capita GDP on the natural log of trade volume. The country count drops to 62 for column (2) because the the data were limited to a set of bilateral country pairs that had continuous trade data from 1950 to 1997. Column (1) is based on the full sample and column (2) is the reduced sample. Table 10 (in an appendix) shows the results from a first stage regression of actual trade versus predicted trade. The relationship between predicted trade and actual trade is very strong.

value of latitude also fails to change the relationship between trade and income.

[18]Specifically, the rgdpc series in the Penn world Tables version 6.1 is used.

Table 2: OLS Estimates of Trade on per capita GDP

	ln(Real GDP per Capita)	
ln(trade)	0.446	0.398
	(0.041)**	(0.038)**
Observations	774	560
Countries	101	62
Years	10	10
R-squared	0.965	0.978

All regressions are on data at 5 year intervals from 1950 to 1995
All regressions include a full set of time and country dummies.
Standard errors clustered by country
+ significant at 10%; * significant at 5%; ** significant at 1%

Table 3: IV Estimates of Trade on per capita GDP

	(1)	(2)	(3)	(4)	(5)	(6)
			ln(Real GDP per Capita)			
ln(trade)	0.578	0.589	0.427	0.429	0.459	0.417
	(0.082)**	(0.089)**	(0.076)**	(0.073)**	(0.097)**	(0.092)**
Observations	774	774	560	560	774	560
Countries	101	101	62	62	101	62
Years	10	10	10	10	10	10
			characteristics of predicted trade regressions			
Bilateral Controls	no	yes	no	yes	—	—
Balanced Panel	no	no	yes	yes	no	yes
Country dummies	yes	yes	yes	yes	no	no
Pair Dummies	no	no	no	no	yes	yes

All regressions are on data at 5 year intervals from 1950 to 1995
All regressions include a full set of time and country dummies.
All columns in this table correspond to similarly numbered columns in Table 8
Standard errors clustered by country
+ significant at 10%; * significant at 5%; ** significant at 1%

Table 4: The Reduced Form – The effect of predicted trade on per capita gdp

	(1)	(2)	(3)	(4)	(5)	(6)
	ln(Real GDP per Capita)					
ln(predicted trade)	0.573	0.555	0.877	0.873	0.636	0.708
	(0.116)**	(0.119)**	(0.242)**	(0.234)**	(0.185)**	(0.226)**
Observations	774	774	560	560	774	560
Countries	101	101	62	62	101	62
Years	10	10	10	10	10	10
R-squared	0.947	0.947	0.958	0.959	0.943	0.956
characteristics of predicted trade regressions						
Bilateral Controls	no	yes	no	yes	—	—
Balanced Panel	no	no	yes	yes	no	yes
Country dummies	yes	yes	yes	yes	no	no
Pair Dummies	no	no	no	no	yes	yes

All regressions are on data at 5 year intervals from 1950 to 1995
All regressions include a full set of time and country dummies.
All columns in this table correspond to similarly numbered columns in Table 8
Standard errors clustered by country
+ significant at 10%; * significant at 5%; ** significant at 1%

Table 3 presents the IV results with actual trade instrumented with predicted trade. The differences between the columns in the IV table are driven by changes in the construction of the instrument set. In each case the columns correspond to instruments generated from the corresponding column in Table 8. Columns (3), (4), and (6) have a smaller sample size driven by the need for a balanced panel. For these columns the total trade is just the summation of trade from the complete bilateral series and the instrument is derived entirely from in sample predictions. For the larger sample, the instrument is generated from a regression using all possible data points and out of sample predictions are made where needed to balance the panel. As described earlier, the trade data is also imputed using country pair and time dummies where needed to balance the panel.

It turns out to matter very little what instrument set or sample is used. The estimates are all extremely similar and the error bands overlap. The IV results are nearly identical to the OLS results. The coefficients suggest an elasticity of about one half between trade and per capita income.

Table 4 shows the reduced form corresponding to Table 3. The results are quite

Table 5: IV Estimates of Trade on per capita GDP

	(1)	(2)	(3)	(4)	(5)	(6)
	Δ ln(Real GDP per Capita)					
Δ ln(trade)	0.739	0.782	0.470	0.478	0.540	0.460
	(0.149)**	(0.175)**	(0.129)**	(0.127)**	(0.152)**	(0.135)**
Observations	673	673	498	498	673	498
Countries	93	93	61	61	93	61
Years	9	9	9	9	9	9
characteristics of predicted trade regressions						
Bilateral Controls	no	yes	no	yes	—	—
Balanced Panel	no	no	yes	yes	no	yes
Country dummies	yes	yes	yes	yes	no	no
Pair Dummies	no	no	no	no	yes	yes

All regressions are on data at 5 year intervals from 1955 to 1995
All regressions include a full set of time dummies.
All columns in this table correspond to similarly numbered columns in Table 8
Standard errors clustered by country
+ significant at 10%; * significant at 5%; ** significant at 1%

similar to IV. The only notable difference is that the coefficients on trade are a bit larger in the smaller sample. The increase is not statistically significant.

The model can also be estimated in differences. This has two advantages. First, because the errors are clustered at the country level, the differenced regressions will have standard errors robust to serial correlation. Second, by estimating in differences regressors can be included that control for systematic differences in trend growth. Table 5 shows results for a set of differenced regressions that correspond to Table 3. The change in estimation method make no difference for the results.

Compared to Frankel and Romer (1999) controlling for country fixed effects eliminates missing variable bias from time invariant factors. However, there still is the possibility of geography being correlated with trend growth. Given the potential for correlated instruments between adjacent countries, one might worry that the results are simply picking up the difference between trend growth rates in Africa and East Asia. Table 6 shows that this is not the case by adding a set of regional dummies and a tropical dummy. This allows each region to have different trend growth throughout the sample and is identified from differences within each region.[19]

[19] The excluded region is Sub Saharan Africa

Table 6: IV Estimates of Trade on per capita GDP

	(1)	(2)	(3)	(4)
	Δ ln(Real GDP per Capita)			
Δ ln(trade)	0.739	0.675	0.685	0.687
	(0.149)**	(0.186)**	(0.283)*	(0.284)*
Tropical		-0.015		-0.011
		(0.018)		(0.014)
Region = East Asia			0.023	0.019
			(0.059)	(0.060)
Region = East Central Asia			-0.040	-0.045
			(0.081)	(0.085)
Region = Middle East & N. Afr.			0.050	0.040
			(0.040)	(0.044)
Region = South Asia			0.067	0.059
			(0.033)*	(0.034)+
Region = W. Europe			0.025	0.015
			(0.048)	(0.053)
Region = North America			-0.004	-0.015
			(0.043)	(0.047)
Region = Latin America			0.027	0.026
			(0.023)+	(0.023)+
Observations	673	672	673	672

All regressions are on data at 5 year intervals from 1955 to 1995
All regressions include a full set of time dummies.
The excluded region is Sub Saharan Africa
+ significant at 10%; * significant at 5%; ** significant at 1%

Differences in trend growth by region are not driving the basic relationship between trade growth and income growth.

Regardless of sample, instrument set or estimation method trade is positively associated with income per capita. The elasticity of income per capita with respect to trade is roughly one half and may be as large as one. An increase in the volume of trade of 10 percent will raise per capita income by over 5 percent. These point estimates are smaller than those found in Frankel and Romer (1999) and about one half the values found by Noguer and Siscart (2005) which includes geographic controls. They are, however, within the confidence bounds of both papers. By controlling for some geographic features Noguer and Siscart (2005) eliminate some of the missing variable bias from Frankel and Romer (1999) with a corresponding drop in elasticity. The fact that the point estimates of this paper are smaller should come as no surprise given the impossibility of controlling for all missing variables using a single cross section. The advantage of the panel approach is the complete removal of time invariant omitted variables.

2.4 Channels

What mechanism is generating the increase in income with increased trade? This section will examine the effect of trade on a decomposition of income into physical capital, human capital, and the productivity residual to see what channels are driving the income result.

Data on capital income ratios are taken from Caselli (2005). Human capital stocks are constructed following Hall and Jones (1999) using school attainment data from the Barro and Lee data set. The human capital production function takes a Mincer form

$$h_{i,t} = e^{\phi(s_{i,t})} \tag{8}$$

where $\phi(s)$ is an increasing function that is assumed to be piecewise linear with decreasing returns to scale. The coefficients are taken from Psacharopoulos (1994), which surveys the literature on returns to schooling.[20]

The productivity residual is calculated assuming a Cobb-Douglas production

[20] The choice of coefficients follows Hall and Jones (1999). For the first four years of schooling the return to schooling in sub-Saharan Africa, 13.4 percent, is used. For schooling from four to eight years the world average return to schooling, 10.1 percent, is used. For schooling beyond 8 years the OECD return to schooling, 6.8 percent, is used.

Table 7: Decomposing the effect of trade on output

	OLS			
	ln(gdpc)	ln(A)	$\frac{\alpha}{1-\alpha} ln(\frac{K}{Y})$	log(h)
ln(trade)	0.483	0.328	0.078	0.077
	(0.089)**	(0.138)*	(0.084)	(0.047)
Observations	534	534	534	534
R-squared	0.975	0.869	0.882	0.972

	IV			
	ln(gdpc)	ln(A)	$\frac{\alpha}{1-\alpha} ln(\frac{K}{Y})$	log(h)
ln(trade)	0.452	0.388	0.031	0.033
	(0.052)**	(0.067)**	(0.043)	(0.014)*
Observations	534	534	534	534

	Reduced Form			
	ln(gdpc)	ln(A)	$\frac{\alpha}{1-\alpha} ln(\frac{K}{Y})$	log(h)
ln(predicted trade)	0.504	0.342	0.082	0.080
	(0.142)**	(0.161)*	(0.089)	(0.052)
Observations	534	534	534	534
R-squared	0.955	0.824	0.884	0.974

All regressions are on data at 5 year intervals from 1960 to 1995.
All regressions include a full set of time and country dummies.
Standard errors clustered by country.
Predicted trade is from column (1) of Table 8.
+ significant at 10%; * significant at 5%; ** significant at 1%

function taking physical capital, human capital, and productivity as inputs.

$$y_{i,t} = k_{i,t}^{\alpha}(A_{i,t}\ h_{i,t})^{1-\alpha} \tag{9}$$

where $y_{i,t}$ is income per capita, $k_{i,t}$ is capital per capita, $h_{i,t}$ is human capital per person, and $A_{i,t}$ represents productivity. This can be rewritten in terms of the capital-income ratio, and solved for the productivity term.[21]

$$A_{i,t} = \frac{y_{i,t}}{\left(\frac{K_{i,t}}{Y_{i,t}}\right)^{\frac{\alpha}{1-\alpha}} h_{i,t}} \tag{10}$$

Table 7 shows the channels through which trade moves income per capita. The sample size is somewhat reduced compared to the earlier regressions because school-

[21]For simplicity, capital's share of income is assumed to be 1/3 in all countries.

ing data only starts in 1960. Since the regressors are related according to equation (10), the coefficients of the three components will sum to the coefficient on income by construction. The relative magnitudes of the coefficients can be interpreted as a measure of their importance in moving income. The magnitude of the productivity residual is substantially larger than the others in all specifications, suggesting that increased trade is affecting income per capita largely through productivity increases.

In the IV specification, the coefficient on the productivity residual is about 85 percent of the value of the coefficient on output. This indicates that the vast majority of the effect of trade is coming through the productivity residual. The remaining 15 percent is split evenly between physical capital and output. The small effects from the accumulable factors are well estimated. The productivity channel represents significantly more than half of the effect of trade on income in all specifications. This is similar to results in Frankel and Romer (1999) but much more tightly estimated.

3 Conclusion

Geography looms large in recent discussion of aggregate economic outcomes. Rodriguez and Rodrik (2000), Acemoglu et al. (2001), Rodrik et al. (2004), Glaeser et al. (2004), McArthur and Sachs (2001), Gallup et al. (1999) and many others have been engaged in a debate about the importance of geography and the channels through which geography acts.

This paper is an attempt to take a fresh look at geography as an explanatory variable by introducing the idea that distance is not static. Technology changes the nature of distance over time. These changes can be exploited to identify the effect of geography on economic outcomes in ways that are not possible with a static view of geography. The time variation makes it possible to isolate the discussion to bilateral outcomes that vary over time. This drastically limits the number of possible interpretations of the results compared to cross sectional studies. It also allows the results to be much more tightly estimated. These results should substantially increase confidence in the positive relationship between trade and income.

Table 8: Gravity Model Estimation – The Changing Elasticity of Sea and Air Distance Over Time

	(1) ln(trade)	(2) ln(trade)	(3) ln(trade)	(4) ln(trade)	(5) ln(trade)	(6) ln(trade)
ln(Sea Dist) x	-0.848	-0.885	-0.367	-0.429		
I(1950≤year<1955)	(0.130)**	(0.119)**	(0.102)**	(0.100)**		
ln(Sea Dist) x	-0.858	-0.883	-0.321	-0.382	0.056	0.046
I(1955≤year<1960)	(0.117)**	(0.108)**	(0.099)**	(0.096)**	(0.052)	(0.047)
ln(Sea Dist) x	-0.8	-0.832	-0.194	-0.256	0.167	0.173
I(1960≤year<1965)	(0.104)**	(0.094)**	(0.090)*	(0.084)**	(0.075)*	(0.070)*
ln(Sea Dist) x	-0.616	-0.653	-0.09	-0.151	0.368	0.277
I(1965≤year<1970)	(0.095)**	(0.086)**	(0.090)	(0.084)+	(0.089)**	(0.087)**
ln(Sea Dist) x	-0.496	-0.533	-0.117	-0.178	0.442	0.25
I(1970≤year<1975)	(0.085)**	(0.078)**	(0.087)	(0.081)*	(0.099)**	(0.094)**
ln(Sea Dist) x	-0.437	-0.481	-0.152	-0.214	0.493	0.215
I(1975≤year<1980)	(0.080)**	(0.074)**	(0.082)+	(0.078)**	(0.101)**	(0.097)*
ln(Sea Dist) x	-0.29	-0.343	-0.159	-0.221	0.578	0.208
I(1980≤year<1985)	(0.079)**	(0.075)**	(0.077)*	(0.073)**	(0.106)**	(0.097)*
ln(Sea Dist) x	-0.065	-0.12	-0.024	-0.086	0.685	0.343
I(1985≤year<1990)	(0.084)	(0.080)	(0.077)	(0.074)	(0.112)**	(0.109)**
ln(Sea Dist) x	-0.268	-0.302	-0.018	-0.079	0.561	0.35
I(1990≤year<1995)	(0.077)**	(0.071)**	(0.076)	(0.073)	(0.112)**	(0.109)**
ln(Sea Dist) x	-0.263	-0.277	-0.086	-0.147	0.563	0.281
I(1995≤year<1997)	(0.076)**	(0.070)**	(0.079)	(0.075)+	(0.114)**	(0.109)**
ln(Air Dist) x	-0.071	0.102	-0.475	-0.302		
I(1950≤year<1955)	(0.131)	(0.118)	(0.101)**	(0.102)**		
ln(Air Dist) x	-0.132	0.031	-0.534	-0.36	-0.074	-0.059
I(1955≤year<1960)	(0.118)	(0.107)	(0.098)**	(0.098)**	(0.054)	(0.050)
ln(Air Dist) x	-0.274	-0.111	-0.683	-0.51	-0.221	-0.208
I(1960≤year<1965)	(0.107)*	(0.095)	(0.091)**	(0.089)**	(0.075)**	(0.072)**
ln(Air Dist) x	-0.59	-0.426	-0.859	-0.686	-0.494	-0.384
I(1965≤year<1970)	(0.098)**	(0.087)**	(0.093)**	(0.090)**	(0.090)**	(0.090)**
ln(Air Dist) x	-0.879	-0.718	-0.897	-0.724	-0.675	-0.422
I(1970≤year<1975)	(0.088)**	(0.081)**	(0.090)**	(0.088)**	(0.100)**	(0.097)**
ln(Air Dist) x	-1.001	-0.829	-0.944	-0.771	-0.781	-0.469
I(1975≤year<1980)	(0.083)**	(0.077)**	(0.084)**	(0.083)**	(0.102)**	(0.099)**
ln(Air Dist) x	-1.193	-1.021	-0.966	-0.792	-0.904	-0.49
I(1980≤year<1985)	(0.082)**	(0.078)**	(0.080)**	(0.079)**	(0.107)**	(0.100)**
ln(Air Dist) x	-1.431	-1.256	-1.082	-0.908	-0.975	-0.607
I(1985≤year<1990)	(0.089)**	(0.087)**	(0.079)**	(0.081)**	(0.114)**	(0.111)**
ln(Air Dist) x	-1.177	-1.014	-1.175	-1.001	-0.775	-0.699
I(1990≤year<1995)	(0.082)**	(0.078)**	(0.079)**	(0.081)**	(0.113)**	(0.109)**
ln(Air Dist) x	-1.186	-1.039	-1.101	-0.927	-0.78	-0.626
I(1995≤year<1997)	(0.079)**	(0.074)**	(0.081)**	(0.082)**	(0.114)**	(0.107)**
Observations	163,690	163,690	51,888	51,888	163,690	51,888
Country Pairs	6,950	6,950	1,081	1,081	6,950	1,081
R-squared	0.703	0.691	0.812	0.797	0.847	0.887
Bilateral Controls	no	yes	no	yes	—	—
Balanced Panel	no	no	yes	yes	no	yes
Country dummies	yes	yes	yes	yes	no	no
Pair Dummies	no	no	no	no	yes	yes

All regressions are on yearly data (1950-1997) and include a full set of time dummies
Standard Errors Clustered at the country pair level
+ significant at 10%; * significant at 5%; ** significant at 1%

Table 9: Gravity Model Estimation – The Changing Elasticity of Great Circle Distance Over Time

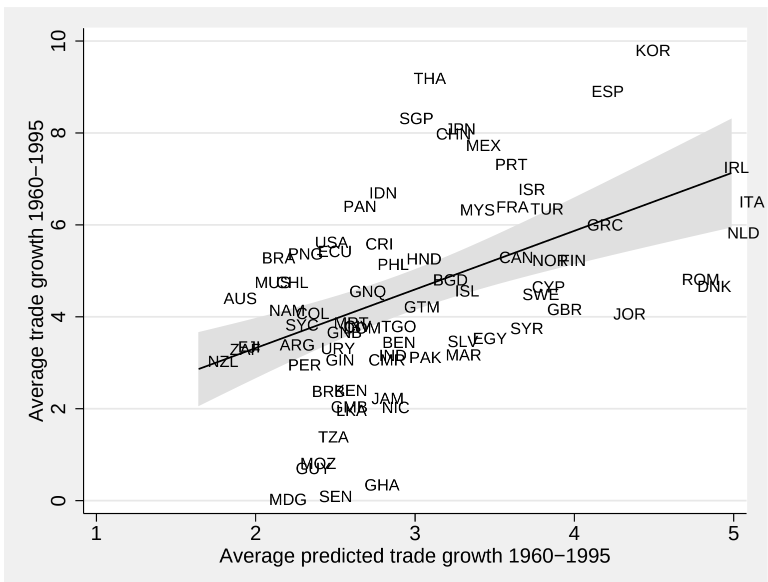
	(1) ln(trade)	(2) ln(trade)	(3) ln(trade)	(4) ln(trade)	(5) ln(trade)	(6) ln(trade)
ln(Air Dist) x	-0.857	-0.722	-0.819	-0.711		
I(1950≤year<1955)	(0.045)**	(0.047)**	(0.046)**	(0.048)**		
ln(Air Dist) x	-0.929	-0.795	-0.835	-0.727	-0.024	-0.016
I(1955≤year<1960)	(0.040)**	(0.042)**	(0.043)**	(0.045)**	(0.024)	(0.020)
ln(Air Dist) x	-1.032	-0.903	-0.867	-0.758	-0.076	-0.048
I(1960≤year<1965)	(0.037)**	(0.038)**	(0.040)**	(0.042)**	(0.034)*	(0.029)
ln(Air Dist) x	-1.177	-1.051	-0.947	-0.838	-0.16	-0.127
I(1965≤year<1970)	(0.035)**	(0.035)**	(0.041)**	(0.042)**	(0.039)**	(0.038)**
ln(Air Dist) x	-1.353	-1.232	-1.009	-0.901	-0.271	-0.19
I(1970≤year<1975)	(0.033)**	(0.034)**	(0.038)**	(0.040)**	(0.042)**	(0.042)**
ln(Air Dist) x	-1.42	-1.295	-1.089	-0.98	-0.329	-0.27
I(1975≤year<1980)	(0.031)**	(0.032)**	(0.037)**	(0.040)**	(0.042)**	(0.044)**
ln(Air Dist) x	-1.472	-1.353	-1.117	-1.008	-0.37	-0.298
I(1980≤year<1985)	(0.032)**	(0.033)**	(0.036)**	(0.040)**	(0.044)**	(0.044)**
ln(Air Dist) x	-1.494	-1.375	-1.108	-1	-0.339	-0.289
I(1985≤year<1990)	(0.035)**	(0.037)**	(0.035)**	(0.039)**	(0.045)**	(0.048)**
ln(Air Dist) x	-1.434	-1.308	-1.195	-1.086	-0.258	-0.375
I(1990≤year<1995)	(0.033)**	(0.034)**	(0.035)**	(0.038)**	(0.046)**	(0.047)**
ln(Air Dist) x	-1.437	-1.308	-1.184	-1.076	-0.262	-0.365
I(1995≤year<1997)	(0.033)**	(0.034)**	(0.036)**	(0.039)**	(0.047)**	(0.048)**
Observations	163,690	163,690	51,888	51,888	163,690	51,888
Country Pairs	6,950	6,950	1,081	1,081	6,950	1,081
R-squared	0.689	0.701	0.796	0.811	0.846	0.887
Bilateral Controls	no	yes	no	yes	—	—
Balanced Panel	no	no	yes	yes	no	yes
Country dummies	yes	yes	yes	yes	no	no
Pair Dummies	no	no	no	no	yes	yes

All regressions are on yearly data (1950-1997) and include a full set of time dummies

Standard Errors Clustered at the country pair level

+ significant at 10%; * significant at 5%; ** significant at 1%

Figure 6: Predicted Trade Growth versus Actual Trade Growth 1960-1995



source: IMF Direction of Trade database, author's calculations.

Table 10: First Stage Regressions – Actual versus predicted trade

	(1)	(2)	(3)	(4)	(5)	(6)
			ln(tradeshare)			
ln(predicted trade)	0.993	0.942	2.055	2.033	1.385	1.696
	(0.144)**	(0.145)**	(0.418)**	(0.410)**	(0.251)**	(0.365)**
Observations	774	774	560	560	774	560
Countries	101	101	62	62	101	62
Years	10	10	10	10	10	10
R-squared	0.975	0.975	0.958	0.958	0.973	0.954
		characteristics of predicted trade regressions				
Bilateral Controls	no	yes	no	yes	—	—
Balanced Panel	no	no	yes	yes	no	yes
Country dummies	yes	yes	yes	yes	no	no
Pair Dummies	no	no	no	no	yes	yes

All regressions are on data at 5 year intervals from 1950 to 1995
All regressions include a full set of time and country dummies.
All columns in this table correspond to similarly numbered columns in Table 8
Standard errors clustered by country
+ significant at 10%; * significant at 5%; ** significant at 1%

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