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# 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 a geographic instrument to identify a positive effect of trade on income. Rodriguez and Rodrik (2000) show that these results are not robust to controlling for omitted variables such as distance to the equator or institutions. This paper solves the omitted variable problem by generating a time varying geographic instrument. Improvements in aircraft technology have caused the quantity of world trade carried by air to increase over time. Country pairs with relatively short air routes compared to sea routes benefit more from this change in technology. This heterogeneity can be used to generate a geography based instrument for trade that varies over time. The time series variation allows for controls for country fixed effects, eliminating the bias from 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 heavily cited empirical papers seemed to confirm this consensus.[1] These papers 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 a geographic instrument. 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 instrument is free of reverse causality, it is 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 instrument is 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 a *time varying* instrument 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 determinants" of income differences and generate identification purely through time

[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.

series variation. This drastically limits the scope for omitted 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. The interaction of physical geography with transportation technology is the true determinant of effective distances around the world. Changes in transportation technology over time therefore change the shape of the globe. As long as changes in transportation technologies are shared by all countries, these time series changes to effective geography will be exogenous with respect to any particular country.

This paper will exploit the particular case of air transportation. The rise of air freight 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. Between 1955 and 2004 the cost of moving goods by air fell by a factor of ten.[5] This has led to a substantial shift toward air freight in transporting goods around the globe. Before 1960 the air transport share of trade for the United States was negligible. By 2004, air transport carried over half of US exports by value (excluding Mexico and Canada). This technological change alters the impact of physical distance between countries over time.

These changes over time can be used to identify the effect of trade on income. The key insight is that improvements in the technology of air transport have 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 changes in transportation technology, an exogenous instrument for bilateral trade can be created. The time variation in the instrument 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). Regressions

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

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. Bilateral predictions for trade can be summed to generate a panel of predictions for overall trade for each country in the world. These trade predictions can be used as an instrument in panel regressions of trade on income per capita. The time series variation in the instrument 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 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 controlling for differential growth rates across regions. 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

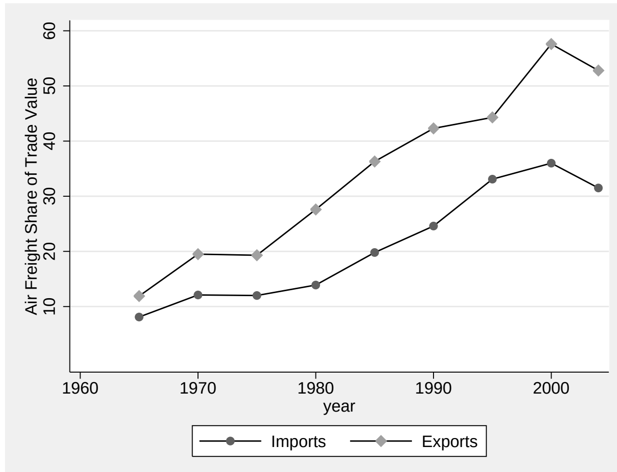
Transport between countries has hardly been static over the last 50 years. Hummels (2007) documents the fall in price for air freight and the rise in the value of trade carried by air versus the sea. Between 1955 and 2004 the cost of air freight per ton fell by a factor of ten with a more rapid fall between 1955 and 1972.[6] These decreases were relatively uniform across the globe and effected all regions. Ocean freight prices did not fall as rapidly as air freight. 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 and over 30 percent of US imports (excluding Mexico and Canada) were carried by air.

## 1.1 What Goods Travel by Air?

Table 1 lists the top 20 Harmonized System (HS) trade categories imported to the US by air. Unsurprisingly, air transport is concentrated in high value to weight products. The top two categories by value are dominated by electronics. HS 85 is largely comprised of computers and parts. HS 84 contains integrated circuits and

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

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




source: Hummels (2007), pp 133.

consumer electronics. Overall about 40 percent of goods in these two categories are transported by air. Goods in HS 71, made up of jewelry and precious metals and stones, are predominantly transported by air. The remainder of the categories fall into a few general areas. The majority of pharmaceuticals and organic chemicals travel by air. Luxury goods such as watches, works of art, and leather goods are often transported by air. A substantial value in apparel (over 15 percent) is transported by air though the majority of apparel is transported by sea.

Table 2 lists the top 20 countries by value of imports into the US by air. There is substantial variation amongst US trading partners in the proportion of trade by air. Japan shipped only 27 percent by air and China only 13 percent by air. Singapore, Malaysia, and the Philippines shipped the majority of their exports to the US by air. Figure 2 is a scatter plot showing the percentage of exports sent to the US by air versus the log of gdp per worker in 1960. There is no significant relationship between income per worker in 1960 (before the advent of air freight) and the percentage of trade by air in 2001.

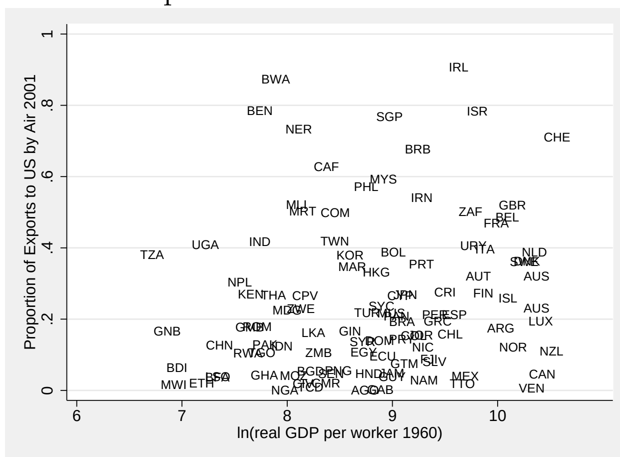
Table 8 (in an appendix) lists the top overall importers to the US, their share of imports to the US by air and the HS4 category with the highest value of goods transported by air to the US. The primary air export varies quite a bit from country to country. Many of the Asian countries export computers and parts to the US by air. European countries export chemicals and pharmaceuticals to the US by air. Many developing countries export precious metals and jewelry to the US by air.

Table 1: Top 20 HS2 trade categories by Air

| HS Code | Description | Air Import Value (billion $) | Percent by Air |
|---|---|---|---|
| 85 | electrical machinery & equip. & parts, telecommunications equip., sound recorders, television recorders | 64.97 | 42.0% |
| 84 | machinery and mechanical appliances, including parts | 64.26 | 39.8% |
| 71 | pearls, stones, prec. metals, imitation jewelry, coins | 23.03 | 88.1% |
| 90 | optical, photographic, cinematographic, measuring, checking, precision, medical or surgical instruments & accessories | 20.63 | 59.2% |
| 29 | organic chemicals | 20.28 | 63.9% |
| 98 | agric, construction, trans, electric/ gas/ sanitary, eng & mgmt & envir. quality services | 18.23 | 51.5% |
| 30 | pharmaceutical products | 12.37 | 77.6% |
| 62 | articles of apparel, accessories, not knit or crochet | 5.32 | 16.8% |
| 97 | works of art, collectors pieces and antiques | 4.45 | 81.7% |
| 61 | articles of apparel, accessories, knit or crochet | 3.75 | 13.9% |
| 88 | aircraft, spacecraft, & parts thereof | 3.45 | 16.3% |
| 95 | toys, games & sports equip, parts & acces. | 2.22 | 11.0% |
| 91 | clocks & watches & parts thereof | 2.07 | 68.0% |
| 64 | footwear, gaiters and the like, parts thereof | 1.61 | 10.6% |
| 38 | miscellaneous chemical products | 1.53 | 33.5% |
| 42 | articles of leather, animal gut, harness, travel good | 1.48 | 20.7% |
| 87 | vechicles other than railway, parts and accessories | 1.29 | 0.8% |
| 39 | plastics and articles thereof | 1.20 | 6.3% |
| 82 | tools, implements, cutlery, spoons and forks, of base metal and parts | 1.11 | 25.8% |
| 3 | fish, crustaceans, molluscs, aquatic invertebrates ne | 0.93 | 11.8% |

source: US Census Bureau – US Imports of Merchandise 2001.

Figure 2: 2001 Air Imports to the US versus 1960 GDP per capita




source: US Census Bureau – US Imports of Merchandise 2001, Penn World Tables 6.1.

Table 2: Top 20 Countries for US Imports by Air

| Country | Air Import Value (billion $) | Percent by Air |
|---|---:|---:|
| Japan | 34.1 | 26.9% |
| UK | 21.5 | 52.0% |
| Germany | 17.8 | 30.2% |
| Ireland | 16.8 | 90.7% |
| France | 14.2 | 47.0% |
| Taiwan | 14.0 | 41.9% |
| South Korea | 13.4 | 37.9% |
| Malaysia | 13.3 | 59.3% |
| China | 13.0 | 12.7% |
| Singapore | 11.5 | 76.8% |
| Canada | 9.8 | 4.5% |
| Italy | 9.5 | 39.7% |
| Israel | 9.4 | 78.3% |
| Switzerland | 6.8 | 71.1% |
| Philippines | 6.5 | 57.2% |
| Mexico | 5.3 | 4.0% |
| Belgium | 4.9 | 48.6% |
| India | 4.1 | 41.7% |
| Thailand | 3.9 | 26.7% |
| Netherlands | 3.7 | 38.8% |

source: US Census Bureau – US Imports of Merchandise 2001.

Fresh fish and flowers are also important air exports for developing countries. There appear to be a diverse group of other commodities that travel by air. From Pakistan, 55 percent of knotted carpets travel by air to the US. From Spain, 54 percent of leather shoes arrive in the US by air. For a few countries such as Bangladesh and Guatemala the largest air category to the US is clothing.

Air transport is important for a variety of goods exported by countries at different levels of development. The overall importance of air transport appears to be uncorrelated with development before the sample period. We should therefore expect to see the rise of air transport affect the quantity of trade between all trading partners.

## 1.2 Differential Consequences

The shift away from sea transport toward air transport should have significant consequences for world trade patterns. The reduction in costs overall has almost certainly increased the total volume of trade relative to a world where goods could only travel by land or sea.

One potential way to examine the importance of this shift would be to look at the simple relationship between output per capita in a country and the volume of trade that goes by air. Unfortunately, this strategy suffers from problems or reverse causality. Countries that develop faster for other reasons may develop a taste for high value to weight luxury goods that is due to increasing income and not the other way around. Increasing integration with the rest of the world may generate greater returns to speed in shipping. This paper will deal with this issue by exploiting the geography of air travel.

In particular, the rise of air transport should differentially increase trade between pairs of countries that are relatively remote by sea. Consider, for example, 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 5,000 nautical miles. By comparison, the air and sea distances between the east coast of the United States and Germany are nearly identical. Improvements in air transportation should therefore lead to a relative rise in bilateral trade between Japan and Germany compared to the United States and Germany. These differential changes are generated by the interaction between geography and shared transportation technology and will therefore be exogenous with regards to any particular country.

As an empirical matter, the shift toward air travel implies that there should be changes in the effect of various distance measures on trade over time. Sea distances should be declining in importance while air distance increases in importance as the volume of trade shifts toward air transport. The next section will estimate a gravity model of trade to test this conjecture.

# 2 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.

Interestingly, the distance measures that are used in estimating gravity models are typically point to point great circle distances. For contiguous countries this is a reasonable choice, but for countries separated by oceans and land masses, this may be the wrong measure, particularly before the advent of relatively inexpensive air travel. 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.

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

$$trade_{ijt} = \frac{y_{it}y_{jt}}{y_{wt}} \left( \frac{\tau_{ijt}}{P_{it}P_{jt}} \right)^{1-\sigma} \quad (1)$$

where $trade_{ij}$ is bilateral trade between country $i$ and country $j$ at time $t$, $y_{it}$ $y_{jt}$ and $y_{wt}$ are the incomes of country $i$, country $j$ and the world, $\tau_{ijt}$ is a bilateral resistance term, and $P_{it}$ and $P_{jt}$ are country specific multilateral resistance terms. Taking logs,

$$ln(trade_{ijt}) = ln(y_{it}) + ln(y_{jt}) - ln(y_{wt}) + (1-\sigma)(ln(\tau_{ijt}) + ln(P_{it}) + ln(P_{jt})). \quad (2)$$

[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, $\tau_{ijt}$, in Equation (2) is assumed to be a function of air and sea distance with the exact relationship changing over time. The key assumption is that all country pairs share the same bilateral resistance function for each time period,

$$ln(\tau_{ijt}) = f_t(airdist_{ij}, seadist_{ij}) = \beta_{sea,t} ln(seadist_{ij}) + \beta_{air,t} ln(airdist_{ij}) + \beta X_{ij} \quad (3)$$

The change in this function over time is assumed to be driven by changes in transportation technology that are shared across all countries. As is typical in the gravity literature the bilateral resistance term is assumed to be log linear in distance. This paper differs in using both air and sea distances and by allowing the coefficients to be time varying. The changing technology will be captured by the time varying $\beta$'s that all countries have in common. The vector $X_{ij}$ is a set of controls for time invariant characteristics of the pair such as colonial relationship and shared borders and is included in some specifications. In other specifications this vector of controls is replaced by a full set of pair effects.

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 a simplification. 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 in the trade regressions will contaminate the 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

$$ln(trade_{ijt}) = \alpha + \gamma_i + \gamma_j + \gamma_t + \beta_{sea,t} ln(seadist_{ij}) + \beta_{air,t} ln(airdist_{ij}) + \beta X_{ij} + \epsilon \quad (4)$$

$$ln(trade_{ijt}) = \alpha + \gamma_{ij} + \gamma_t + \beta_{sea,t} ln(seadist_{ij}) + \beta_{air,t} ln(airdist_{ij}) + \epsilon \quad (5)$$

where Equation (4) includes country effects and Equation (5) includes bilateral pair effects.

[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.

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. Estimates of equations (4) and (5) should not be taken as causal estimates of the effect of distance on trade. The goal is to describe the correlation between trade and the two different distance measures over time and then use that variation to generate exogenous predictions for trade.

## 2.1 An Exogenous Instrument for Trade

Predictions for bilateral trade can be generated by estimating equations (4) and (5) and generating fitted values for the log of bilateral trade for each pair of countries in each year. These predictions are 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 aggregated to arrive at a prediction for aggregate trade in each country for each year.[9]

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.

$$\begin{aligned} predicted\ trade_{it} &= \sum_{i \neq j} e^{\hat{\gamma}_t + \hat{\gamma}_i + \hat{\gamma}_j + \hat{\beta}_{air,t} * ln(airdist_{ij}) + \hat{\beta}_{sea,t} * ln(seadist_{ij})} \\ &= e^{\hat{\gamma}_t} e^{\hat{\gamma}_i} \sum_{i \neq j} e^{\hat{\gamma}_j} e^{\hat{\beta}_{air,t} * ln(airdist_{ij}) + \hat{\beta}_{sea,t} * ln(seadist_{ij})} \end{aligned} \quad (6)$$

[9]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.Because the goal is to instrument actual trade with predicted trade, 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 actual 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.

$$\begin{aligned} predicted\ trade_{it} &= \sum_{i \neq j} e^{\hat{\gamma}_t + \hat{\gamma}_{ij} + \hat{\beta}_{air,t} * ln(airdist_{ij}) + \hat{\beta}_{sea,t} * ln(seadist_{ij})} \\ &= e^{\hat{\gamma}_t} \sum_{i \neq j} e^{\hat{\gamma}_{ij}} e^{\hat{\beta}_{air,t} * ln(airdist_{ij}) + \hat{\beta}_{sea,t} * ln(seadist_{ij})} \end{aligned} \quad (7)$$

Equation 6 describes the predictions using individual country dummies. 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 remaining terms inside the summation are weighted averages of bilateral sea and air distance effects where the weights are derived from the value of the dummy for the other country in the pair. The only terms indexed by $i$ in the summation are the time invariant distance measures. The idiosyncratic time variation is provided by the changing $\hat{\beta}$'s which all countries share in common and which represent technological shocks common to all countries.

These predictions should be free of reverse causality from income. The time and country level dummies in the second stage will control for the terms outside the summation.[10] Within the summation, the bilateral distance measures are time invariant and exogenous. The dummy values for each of the other countries in the sample and the $\beta$'s are shared by all countries in the sample. Given the relatively large number of countries, these shared values are assumed to be fixed with regards to income movements in any particular country in the sample.[11]

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 instrument.

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 independent of any particular country but which has differential effects across countries based on their exogenous geographical

[10]These terms can be left off the trade predictions without affecting the results.

[11]One potential objection to this last assumption would be the small set of countries that dominated the development of modern air travel - the US, UK, and France. All the results which will be reported later in the paper are robust to the exclusion of these three countries.

characteristics. Countries whose proximity to the rest of the world is differentially improved by air travel benefit more from this technological change.

## 2.2 A Simple Instrument

The gravity model based instrument described above provides a full panel of trade predictions which will be used in estimating the impact of trade on income. Before performing the full panel analysis I will present long difference results examining average trade and income growth over the entire sample period. By doing so, it becomes possible to dispense with the formal gravity model entirely and generate an instrument based more directly on geography. This is similar in spirit to the gravity model based instrument, but requires no estimation in the construction of the instrument.

Countries that are differentially closer to their trading partners by air should see more rapid growth in trade than those who have very similar air and sea trade routes. A natural instrument for trade growth is therefore the trade weighted log difference between air and sea trade distances.

$$distance\_change_i = ln\left(\frac{\sum_{i\neq j}\overline{trade_j} * seadist_{ij}}{\sum_{i\neq j}\overline{trade_j}}\right) - ln\left(\frac{\sum_{i\neq j}\overline{trade_j} * airdist_{ij}}{\sum_{i\neq j}\overline{trade_j}}\right) \quad (8)$$

The weight on each distance, $\overline{trade_j}$ is the average yearly trade of each potential trading partner during the sample period. Intuitively, the two terms represent the log of the average distance to a unit of world trade by air and by sea. The instrument is comprised of exogenous distances and information about other countries in the sample. Shocks to income in country $i$ therefore have no impact on the instrument for country $i$. This instrument is confined to predicting the growth in trade over the sample period and is therefore not useful for the full panel estimation. It is, however, a useful instrument for examining growth rate differences over the entire sample period.

# 3 Data

Trade data was 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 values.

Bilateral great circle distances (the measure of air distance) are from the CEPII.[12] The CEPII provide several different variations for measuring the great circle distance between countries.[13] Throughout this paper I use the population weighted distance which incorporates information about the internal distribution of the population within countries. The results are not significantly different using any of the alternative distance measures. 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.[14] 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.[15] 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.[16] 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

[12]http://www.cepii.fr/anglaisgraph/bdd/distances.htm

[13]Distance between countries is available in the following variations: between the most populous cities, between capitals, and population weighted distances between countries. The latter uses city level data to incorporate the internal distribution of population. See Mayer and Zignago (2006) for a more complete description. Head and Mayer (2002) develop the methodology for the weighted measures.

[14]http://sedac.ciesin.columbia.edu/povmap/ds_global.jsp

[15]Meehl (1980), http://dss.ucar.edu/datasets/ds280.0/

[16]Specifically, Djikstra's algorithm as implemented in the Perl module Boost-Graph-1.4 http://search.cpan.org/ dburdick/Boost-Graph-1.2/Graph.pm.

oceanic grid, the sample excludes landlocked countries. Oil exporters were also left out of the sample because they have atypical trade patterns and have an almost mechanical relationship between the value of trade and income. None of the results are sensitive to the inclusion of the oil producers.

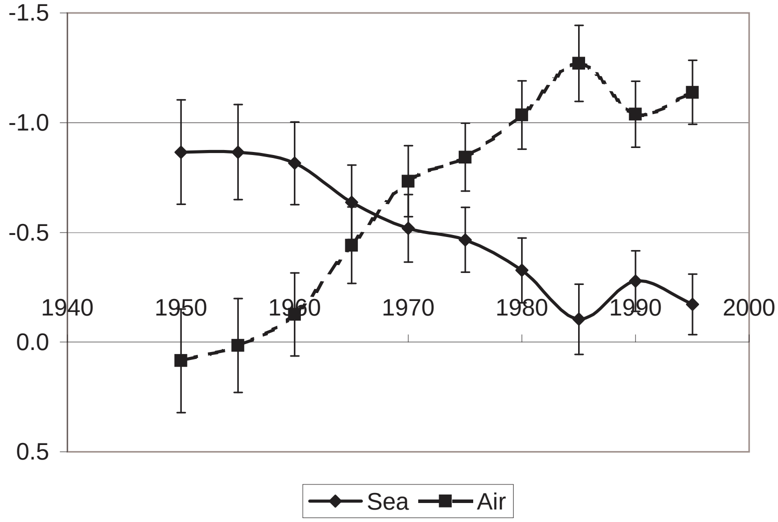
Identifying the location for the primary port for the vast majority of countries was straightforward and for most countries choosing any point along the coast would not change the results. The major potential exceptions to this are the US and Canada, with significant populations on both coasts and massive 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. In effect, the US and Canada are each split in two with regards to the trade regressions, with each country in the world trading with each coast independently based on appropriate sea distances (air distances are the same for both coasts). When generating predicted trade shares for the US and Canada, the trade with both halves are summed. Choosing just the east coast sea distances, changing the relative east-west weights, or even removing all observations including the US and Canada has no significant 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.

# 4 Trade Regression Results

Figures 3 and 4 plot the sequence of coefficients on air distance and sea distance found by estimating equations (4) and (5). Each point represents the elasticity of trade with regards to sea or air distance over a particular time period and are the $\beta$'s from equations (4) and (5). The axes are inverted since the effect of distance

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

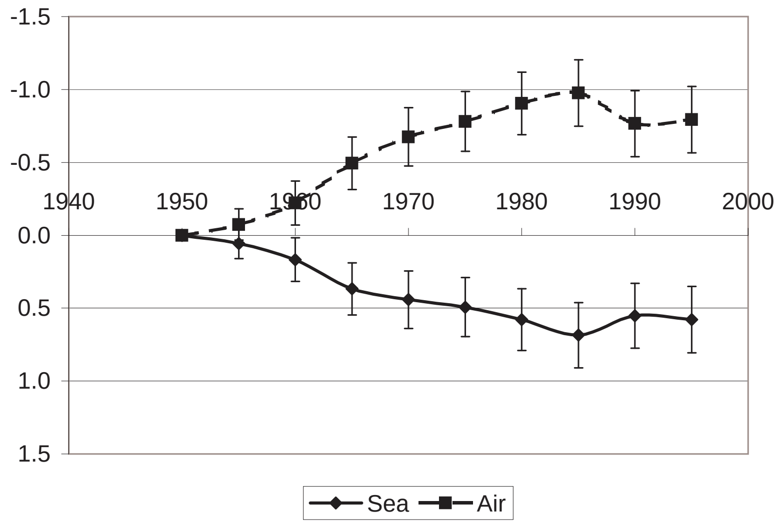



source: Coefficients from regression table 9 column 2.

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




source: Coefficients from regression table 9 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.

is negative for trade. The error bars on each point represent two standard errors around the point estimates.

Figure 3 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 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 4 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. Countries that are relatively closer by air versus sea are seing larger increases in trade.

Table 9 (in an appendix) presents the results of estimating equations (4) and (5). The elasticities plotted in Figures 3 and 4 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 in a significant way.

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.[17] However, none of these studies included sea distances along with the standard great circle bilateral distances. Table 10 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 omitted 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.

[17]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."

## 5 The Effect of Trade on Income

Using the coefficients estimated in the previous section, equations (6) and (7) were used to calculate predictions for trade for each country in each year. These predicted trade volumes 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 these trade predictions 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[18] 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 instrument 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. All the potential channels that fit this description can easily be categorized as increases

[18] Keller (2002)

in integration between countries. The reduced form regressions can be seen as describing the general effects of globalization. The predicted changes in trade should be exogenous with respect to income and reflect real causal effects of changes in geography on income.

## 5.1 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.[19] While less precise than the panel regressions, this exercise can show the basic relationships visually. The basic estimating equation in this section is

$$\Delta ln(y_i) = \beta \Delta ln(trade_i) + \gamma + \epsilon \tag{9}$$

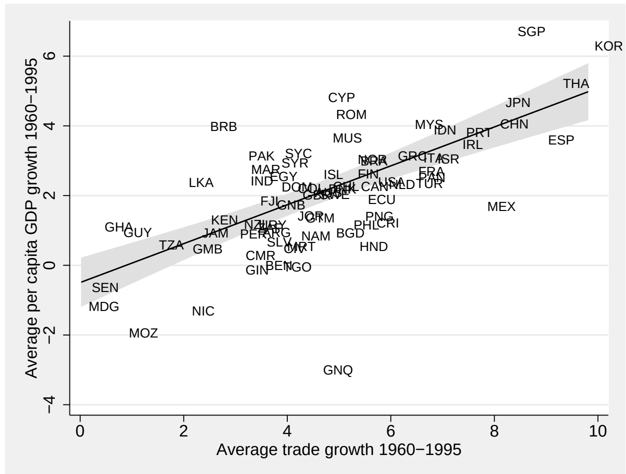
where the individual country effects are controlled for by taking the difference and the overall time trend is absorbed in the constant. Unlike in Frankel and Romer (1999) the key right hand side variable is the log of trade, not trade as a percentage of GDP (trade share). The use of trade share as a right hand side variable is inherently problematic because trades hare is a function of trade, GDP per capita, and population. In using trade share, GDP per capita appears on both sides of the regression, making the interpretation of the coefficient problematic.[20] The literature has used trade share to this point to solve the problem of scaling in a cross section. If you simply run gdp against total trade you will obviously get a large positive coefficient based on variation in country size alone. By estimating in differences (or including country level effects) different country sizes are controlled for. This greatly simplifies the interpretation of the coefficients. Regressions run using trade share generate similar results to the regressions reported here.

Figure 5 shows the relationship between the growth of trade and the growth of per capita GDP. This relationship is obviously highly significant. Of course, the direction of causality is clearly unknown as rising incomes may be leading to increased trade. To deal with this, two different instruments will be used for the change in trade between 1960 and 1995. First, the log change in predicted trade between 1995 and 1960 from the formal gravity model described in Equation 6.

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

[20] Imagine that the elasticity of income with respect to trade were one. A shock to trade would results in no movement in trade share.

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




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

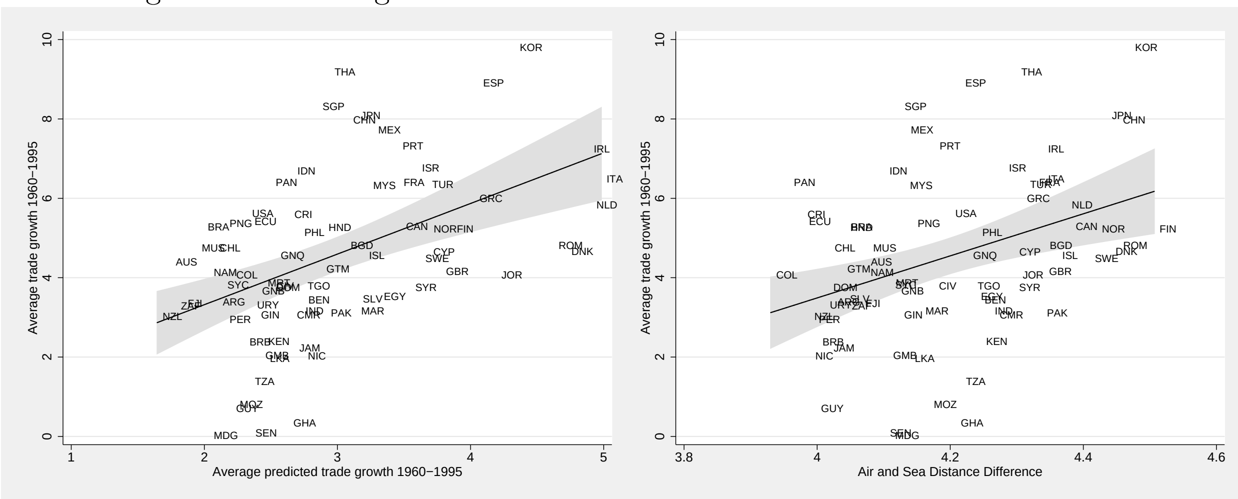
Second, the simple instrument described in Equation (8). The former instrument uses gravity model estimates to maximize the predictive power of the first stage. The latter instrument, which is just the difference in average distance to trading partners by air and by sea, has the advantage of simplicity. It does not require any estimation to construct and it has a simple interpretation.

Figure 6 shows the first stage relationships between trade growth and the predicted change in trade from the gravity model estimations and the difference in air and sea distance described in Equation (8). The relationship between the instruments and actual trade growth is very strong. The F-statistic on the first stage is 29 for the change in predicted trade and 15.5 for difference between air and sea distance. Figure 7 show the reduced form relationship between the growth in per capita GDP and the two instruments.

More formally, I run the IV regression of trade growth versus GDP growth instrumenting actual trade growth with predicted trade growth and with the trade weighted difference in air and sea distance. Table 3 shows the results of regressing the change in income from 1960 to 1995 against actual trade and the instruments. Column (1) is the OLS regression on actual trade corresponding to Figure 5. Columns (2) and (3) are the reduced form regression on the instrument corresponding to Figure 7. Columns (4) and (5) are IV estimates.[21] Column (4) uses the change in

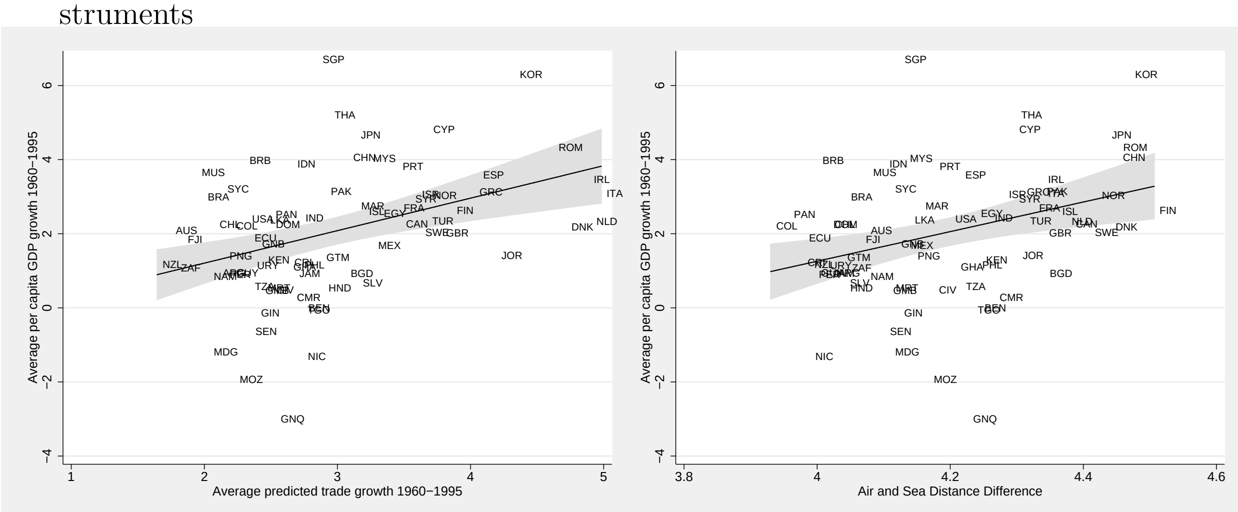
[21] Because the gravity model based instrument used in the IV regressions is not from raw data, but is instead constructed from data and regressors, conventional IV standard errors are understated. Unless otherwise noted, the standard errors in the paper are adjusted following footnote 15 in

Figure 6: First Stage: Actual Trade Growth 1960-1995 versus Instruments




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

Figure 7: Reduced Form: Average Per Capita GDP Growth 1960-1995 versus Instruments




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

Table 3: The Effect of Trade Growth on per capita GDP growth 1960-1995

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| | Annual per capita GDP growth 1960-1995 | | | | |
| | OLS | Reduced Form | | IV | IV |
| Trade growth | 0.558 | | | 0.688 | 0.754 |
| | (0.070)** | | | (0.111)** | (0.157)** |
| Predicted trade growth | | 0.877 | | | |
| | | (0.189)** | | | |
| Air Sea Distance Difference | | | 3.995 | | |
| | | | (1.043)** | | |
| First Stage F-stat | | | | 29.4 | 15.5 |
| First State $R^2$ | | | | 0.242 | 0.142 |
| Observations | 76 | 76 | 76 | 76 | 76 |
| $R^2$ | 0.464 | 0.17 | 0.12 | 0.439 | 0.407 |

In column (4) trade growth is instrumented with predicted trade growth.
In column (5) trade growth is instrumented with the average difference between air and sea distance.
$*$ significant at 5%; $**$ significant at 1%

log predicted trade between 1995 and 1960 as an instrument. Column (5) uses the trade weighted average difference in air and sea in distance as an instrument. Both instrument produce similar results. In each case the first stage is strong, with F-statistics of well over 10. As expected, the instrument created using the full gravity model has substantially more power than the ad hoc distance difference measure with $R^2$'s in the first stage of 0.24 and 0.14, respectively. This can also be seen in the reduced form results. Trade predictions from the gravity model can explain 17 percent of the variation in income growth between 1960 and 1995 versus 12 percent for the simple instrument.

## 5.2 Fixed Effects Regressions

This section will repeat the exercise 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 an instrument in a panel regression of per capita GDP on trade. With an exogenous instrument and the inclusion of country fixed effects, the regression specification can be kept extremely simple. Country effects control

Frankel and Romer (1999). In most cases the correction is extremely minor and never exceeds 15 percent.

Table 4: 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 1%

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

$$ln(y_{it}) = \gamma_i + \gamma_t + \beta\ ln(trade_{it}) + \epsilon_{it} \tag{10}$$

where $y_{it}$ is real GDP per capita from the Penn World Tables,[22] $\gamma_i$ and $\gamma_t$ are country and time effects and $\epsilon_{it}$ is a disturbance term. In order to deal with endogeneity in the volume of trade, $ln(trade)$ will be instrumented with the predicted trade described earlier. All estimation is done on a panel with observations every 5 years.

Table 4 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. The relationship between trade and income is very strong, but causality is indeterminate.

Table 5 shows the first stage, reduced form, and IV results from estimating the full panel in levels. The differences between the columns in Table 5 are driven by differences in the construction of the instrument corresponding to column in Table 9. Columns (3), (4), and (6) have a smaller sample size driven by the 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

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

Table 5: Panel Estimates of Trade on per capita GDP

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| IV RESULTS | | | | | | |
| | ln(Real GDP per Capita) | | | | | |
| ln(trade) | 0.578 | 0.589 | 0.427 | 0.429 | 0.459 | 0.417 |
| | (0.082)** | (0.090)** | (0.078)** | (0.075)** | (0.097)** | (0.092)** |
| FIRST STAGE | | | | | | |
| | ln(trade) | | | | | |
| 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)** |
| $R^2$ | 0.975 | 0.975 | 0.958 | 0.958 | 0.973 | 0.954 |
| F-stat on Instrument | 47.6 | 42.2 | 24.2 | 24.6 | 30.4 | 21.6 |
| Instrument Partial $R^2$ | 0.170 | 0.163 | 0.216 | 0.223 | 0.100 | 0.145 |
| REDUCED FORM | | | | | | |
| | 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)** |
| $R^2$ | 0.947 | 0.947 | 0.958 | 0.959 | 0.943 | 0.956 |
| 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 9

Standard errors clustered by country

IV standard errors in columns (1) - (4) corrected for constructed instruments.

** significant at 1%

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.

The first stage relationship between predicted trade and actual trade is very strong with F-statistics over 21 in all cases, well above the standard threshold of 10 for a strong instrument suggested by Staiger and Stock (1997). The coefficients vary between one and two. The first stage is a regression of $\ln(\sum_{i\neq j} e^{y_{ijt}})$ against $ln(\sum_{i\neq j} e^{\hat{y}_{ijt}})$ where $y_{ijt}$ is the log of bilateral trade for each pair at time t and $\hat{y}_{ijt}$ is the prediction for the log of bilateral trade obtained through regressions described in equations 4 and 5. Since this is a regression of a transformation of $y$ against the same transformation of $\hat{y}$ the expected coefficient is one. However, the process of transforming and aggregating $\hat{y}$ may cause the coefficient to be different than one. This makes the interpretation of the reduced form coefficients difficult, but the IV coefficients will be properly scaled to the actual movements in trade.

The first stage $R^2$'s in Table 5 include the contributions of time and country dummies and they are therefore quite high. Of more interest is the marginal contribution of the instrument in predicting trade. The instrument partial $R^2$'s are the values taken from regressions of the residuals of log trade against the residuals of log predicted trade after each has been regressed against the country and year dummies. Depending on the specific formulation, the instrument can generate from 10 to 22 percent of the residual movement in trade once country and time dummies are accounted for. The variation accounted for is somewhat stronger for predictions based on trade regressions using country dummies. Using a data set restricted to complete panels of bilateral trade tends to increase the proportion explained. Regardless of the estimation method or sample used for the gravity regressions, the first stage is strong. The proportion of trade predicted is consistent with the visual evidence of Figure 6 which clearly shows an upward sloping relationship between trade growth and predicted trade growth over a 35 year period.

Table 5 presents the IV results with actual trade instrumented with predicted trade.[23] The elasticity of income with respect to trade is in the vicinity of one half

[23] As mentioned earlier, the conventional IV standard errors need to be corrected to account for the use of a constructed instrument. Columns (1) through (4) have corrected standard errors. For columns (5) and (6), the use of almost 7000 country pair fixed effects in the bilateral trade regression makes the calculation of the correction impractical and conventional IV standard errors

in all specifications. It matters very little what instrument set or sample is used. The IV results are nearly identical to the OLS results.

### 5.3 Estimation in First DIfferences

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 6 shows results for a set of differenced regressions that correspond to the regressions in levels in Table 5.[24] The first stage is strong with F-statistics above 10 in all cases. The change in estimation method makes no difference for the results.

Compared to Frankel and Romer (1999), controlling for country fixed effects eliminates omitted 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 7 shows that this is not the case by adding a set of regional dummies. This allows each region to have different trend growth throughout the sample and is identified from differences within each region.[25] Differences in trend growth by region are not driving the basic relationship between trade growth and income growth.

Another potential source of concern is industrial structure. Suppose that the set of countries producing high value/low weight manufactures before the advent of air travel were relatively far away by air and also had high growth during the sample period. The instrument may be picking up these differences in industrial structure. Column (5) adds the average proportion of value added during the 1960's in ISIC codes 383 and 385, the two codes which most closely represent the computers and precision equipment that tend to travel by air in 2000.[26] Column (6) adds

are reported. Given that the maximum correction is less than 5 percent for columns (1) through (4) this omission is unlikely to be significant.

[24]Columns (1) through (4) have standard errors corrected for constructed instruments (the maximum correction for this table is about 15 percent). For columns (5) and (6), the use of almost 7000 country pair fixed effects in the bilateral trade regression makes the calculation of the correction impractical and conventional IV standard errors are reported.

[25]The excluded region is Sub Saharan Africa.

[26]The data are from the UNIDO database on manufacturing which provides information on

Table 6: IV Estimates of Trade on per capita GDP

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| IV RESULTS | | | | | | |
| | Δ ln(Real GDP per Capita) | | | | | |
| Δ ln(trade) | 0.739 | 0.782 | 0.470 | 0.478 | 0.540 | 0.460 |
| | (0.164)** | (0.202)** | (0.138)** | (0.134)** | (0.152)** | (0.135)** |
| FIRST STAGE | | | | | | |
| | Δln(trade) | | | | | |
| Δ ln(predicted trade) | 0.548 | 0.488 | 1.508 | 1.487 | 0.640 | 1.321 |
| | (0.118)** | (0.115)** | (0.292)** | (0.284)** | (0.201)** | (0.274)** |
| $R^2$ | 0.47 | 0.469 | 0.466 | 0.466 | 0.465 | 0.457 |
| F-stat on Instrument | 21.6 | 18.0 | 26.7 | 27.4 | 10.1 | 23.2 |
| Instrument Partial $R^2$ | 0.020 | 0.017 | 0.055 | 0.055 | 0.011 | 0.04 |
| REDUCED FORM | | | | | | |
| | ln(Real GDP per Capita) | | | | | |
| Δ ln(predicted trade) | 0.404 | 0.381 | 0.708 | 0.711 | 0.345 | 0.608 |
| | (0.095)** | (0.090)** | (0.183)** | (0.176)** | (0.133)* | (0.176)** |
| $R^2$ | 0.080 | 0.079 | 0.106 | 0.107 | 0.060 | 0.093 |
| 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 9

Standard errors clustered by country

IV standard errors in columns (1) - (4) corrected for constructed instruments.

∗ significant at 5%; ∗∗ significant at 1%

Table 7: 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 | 0.675 | 0.685 | 0.639 | 0.652 | 0.700 |
| | (0.164)** | (0.205)** | (0.315)* | (0.127)** | (0.151)** | (0.190)** |
| Tropical | | -0.015 | | | | |
| | | (0.018) | | | | |
| East Asia | | | 0.023 | | | |
| | | | (0.064) | | | |
| East Central Asia | | | -0.040 | | | |
| | | | (0.084) | | | |
| Middle East & N. Afr. | | | 0.050 | | | |
| | | | (0.043) | | | |
| South Asia | | | 0.067 | | | |
| | | | (0.033)* | | | |
| W. Europe | | | 0.025 | | | |
| | | | (0.053) | | | |
| North America | | | -0.004 | | | |
| | | | (0.047) | | | |
| Latin America | | | 0.027 | | | |
| | | | (0.028) | | | |
| High Tech (1960s) | | | | | -0.083 | 0.094 |
| | | | | | (0.249) | (0.347) |
| Mining | | | | | | 0.33 |
| | | | | | | (0.204) |
| Manufacturing | | | | | | -0.445 |
| | | | | | | (0.247)+ |
| Countruct | | | | | | -0.387 |
| | | | | | | (0.245) |
| Services | | | | | | 0.044 |
| | | | | | | (0.193) |
| Transport | | | | | | 0.152 |
| | | | | | | (0.263) |
| Other | | | | | | -0.01 |
| | | | | | | (0.097) |
| Observations | 673 | 672 | 673 | 470 | 470 | 470 |
| Countries | 93 | 93 | 93 | 57 | 57 | 57 |

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
Standard errors clustered by country.
+ significant at 10%; * significant at 5%; ** significant at 1%

additional data on overall industrial structure in 1970 from the National income and Product Accounts compiled by the UN. The regressors are the proportion of output attributable to broad output categories such as Manufacturing and Mining. Since the categories are inclusive, one must be omitted, in this case agriculture. The use of UNIDO data limits the sample to 57 countries. Column (4) runs the base regression on the smaller sample. The coefficient drops slightly but it is not significantly different than in the full sample. The use of additional controls in columns (5) and (6) does not significantly change the results.

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 omitted 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 omitted variables using a single cross section. The advantage of the panel approach is the complete removal of time invariant omitted variables.

# 6 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

manufacturing industries. This was combined with 1970 data from the UN on the proportion of total output in manufacturing to calculate the proportion of these codes in overall output. The full descriptions from ISIC codes Rev 2: 383 - Manufacture of electrical machinery apparatus, appliances and supplies; 385 - Manufacture of professional and scientific, and measuring and controlling equipment not elsewhere classified, and of photographic and optical goods.

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 results suggest that Frankel and Romer (1999)'s basic results hold (though the magnitudes may have been overstated). Trade has a positive impact on output. The elasticity of income with regards to trade is between one half and three quarters and is precisely estimated compared to earlier work. Changes in trade can explain 17 percent of the variation in growth rates across countries between 1960 and 1995.

As with Frankel and Romer (1999) there is the possibility that the instrument is acting through channels other than trade. However, 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.

A broad interpretation of the results would be to think of trade as a proxy for a number of bilateral interactions that could be affected by changes in the relative distances between countries. Some possibilities include direct foreign investment, multinational involvement, and simple information exchange facilitated through easier movement of people. In short, trade may be providing a proxy for many different elements of economic integration. In this view, the results should be seen as showing a positive causal effect of increasing integration between countries.

Table 8: Top 50 Overall Importers to US - Largest HS4 category by air

| | Country | Overall by Air | Trade Category with Largest Value Shipped by Air | HS4 code | Percent by Air |
|---|---|---|---|---|---|
| 1 | Canada | 4.5% | parts etc for typewriters & other office machines computer accessories | 8473 | 67% |
| 2 | Mexico | 4.0% | automatic data process machines, magn reader, etc. computer hardware | 8471 | 23% |
| 3 | Japan | 26.9% | automatic data process machines, magn reader, etc. computer hardware | 8471 | 49% |
| 4 | China | 12.7% | parts etc for typewriters & other office machines computer accessories | 8473 | 50% |
| 5 | Germany | 30.2% | medicaments, therapeutic, prophylactic use, in dosage | 3004 | 90% |
| 6 | UK | 52.0% | turbojets, turbopropellers & other gas turbines, pts | 8411 | 97% |
| 7 | South Korea | 37.9% | automatic data process machines, magn reader, etc. computer hardware | 8471 | 48% |
| 8 | Taiwan | 41.9% | automatic data process machines, magn reader, etc. computer hardware | 8471 | 78% |
| 9 | France | 47.0% | turbojets, turbopropellers & other gas turbines, pts | 8411 | 92% |
| 10 | Italy | 39.7% | articles of jewelry & parts, of prec metal or clad | 7113 | 96% |
| 11 | Malaysia | 59.3% | automatic data process machines, magn reader, etc. computer hardware | 8471 | 73% |
| 12 | Ireland | 90.7% | heterocyclics, nitrogen hetero atom only, nucleic aci | 2933 | 100% |
| 13 | Venezuela | 0.7% | crustaceans, live, fresh etc, and cooked etc. | 306 | 19% |
| 14 | Singapore | 76.8% | automatic data process machines, magn reader, etc. computer hardware | 8471 | 87% |
| 15 | Thailand | 26.7% | automatic data process machines, magn reader, etc. computer hardware | 8471 | 52% |
| 16 | Brazil | 19.2% | gold (incl put plated), unwr, semimfr or powder | 7108 | 100% |
| 17 | Saudi Arabia | 0.5% | womens, girls suits, jacket, dress, skirt, etc, wove | 6204 | 15% |
| 18 | Israel | 78.3% | diamonds, worked or not, not mounted or set | 7102 | 92% |
| 19 | Philippines | 57.2% | automatic data process machines, magn reader, etc. computer hardware | 8471 | 84% |
| 20 | Belgium | 48.6% | diamonds, worked or not, not mounted or set | 7102 | 98% |
| 21 | Indonesia | 12.4% | parts etc for typewriters & other office machines computer accessories | 8473 | 80% |
| 22 | India | 41.7% | diamonds, worked or not, not mounted or set | 7102 | 100% |
| 23 | Hong Kong | 33.1% | articles of jewelry & parts, of prec metal or clad | 7113 | 95% |
| 24 | Switzerland | 71.1% | medicaments, therapeutic, prophylactic use, in dosage | 3004 | 91% |
| 25 | Netherlands | 38.8% | medicaments, therapeutic, prophylactic use, in dosage | 3004 | 96% |
| 26 | Sweden | 36.1% | medicaments, therapeutic, prophylactic use, in dosage | 3004 | 87% |
| 27 | Nigeria | 0.1% | niobium, tantalum, vanadium & zirconium ore & conc | 2615 | 5% |
| 28 | Australia | 23.1% | medicaments, therapeutic, prophylactic use, in dosage | 3004 | 99% |
| 29 | Russia | 29.7% | platinum, unwrought, semimfr forms or in powder fm | 7110 | 100% |
| 30 | Colombia | 15.4% | cut flowers, dried flowers for bouquets, etc, | 603 | 100% |
| 31 | Norway | 12.1% | turbojets, turbopropellers & other gas turbines, pts | 8411 | 100% |
| 32 | Spain | 21.3% | footwear with uppers of leather | 6403 | 54% |
| 33 | South Africa | 50.2% | platinum, unwrought, semimfr forms or in powder fm | 7110 | 100% |
| 34 | Dominican Republic | 14.0% | articles of jewelry & parts, of prec metal or clad | 7113 | 78% |
| 35 | Austria | 32.1% | glass beads etc & articles nesoi, lamp wrkd-glass orn | 7018 | 100% |
| 36 | Chile | 15.8% | fish fillets, fish meat, mince except liver, roe | 304 | 75% |
| 37 | Denmark | 36.3% | blood, antisera, vaccines, toxins and cultures | 3002 | 100% |
| 38 | Finland | 27.3% | medicaments, therapeutic, prophylactic use, in dosage | 3004 | 100% |
| 39 | Honduras | 4.7% | gold (incl put plated), unwr, semimfr or powder | 7108 | 100% |
| 40 | Angola | 0.1% | articles of natural or cut pearls, prec/semprc stones | 7116 | 100% |
| 41 | Turkey | 21.9% | articles of jewelry & parts, of prec metal or clad | 7113 | 94% |
| 42 | Argentina | 17.4% | bovine or equine leather, no hair, not chamois, paten | 4104 | 80% |
| 43 | Hungary | 58.7% | automatic data process machines, magn reader, etc. computer hardware | 8471 | 99% |
| 44 | Costa Rica | 27.6% | parts etc for typewriters & other office machines computer accessories | 8473 | 99% |
| 45 | Algeria | 0.6% | raw hides and skins except bovine, equine, sheep | 4103 | 100% |
| 46 | Guatemala | 7.5% | womens, girls suits, jacket, dress, skirt, etc, wove | 6204 | 12% |
| 47 | Trinidad and Tobago | 1.9% | fish, fresh or chilled (no fillets or other meat) | 302 | 100% |
| 48 | Bangladesh | 5.4% | hats & headgear, knit etc, lace, etc in pc, hr net | 6505 | 12% |
| 49 | Pakistan | 12.8% | carpets and other textile floor covering, knotted | 5701 | 55% |
| 50 | New Zealand | 11.0% | fish, fresh or chilled (no fillets or other meat) | 302 | 100% |

source: US Census Bureau – US Imports of Merchandise 2001.

Table 9: 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 10: 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%

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