American Economic Journal: Applied Economics 2019, 11(4): 1–35
https://doi.org/10.1257/app.20170616

Trade and Income—Exploiting Time Series in Geography[†]

By James Feyrer*

Establishing a robust causal relationship between trade and income has been difficult. Frankel and Romer (1999) uses a geographic instrument to identify a positive effect of trade on income. Rodriguez and Rodrik (2001) shows 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. (*JEL* F14, F43, L93)

Does increased trade lead to higher income? The economics profession has historically tended to assume that the answer is yes. In the 1990s, 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. 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 violates exclusion restrictions because it is correlated with geographic differences in outcomes that are not

*Dartmouth College Department of Economics, 6106 Rockefeller, Hanover, NH 03755-3514 (email: james.feyrer@dartmouth.edu). Dave Donaldson was coeditor for this article. Many thanks to Alan Taylor and Reuven Glick for sharing their bilateral trade data. Thanks to Jay Shambaugh, Nina Pavcnik, Doug Staiger, Doug Irwin, Matias Berthelon, Simon Johnson, Bruce Sacerdote, and participants at BREAD, NBER EFG, and NBER ITI conferences for helpful comments. All errors are my own.

[†]Go to https://doi.org/10.1257/app.20170616 to visit the article page for additional materials and author disclosure statement(s) or to comment in the online discussion forum.

[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 (2001) critiques this group. See Estevadeordal and Taylor (2008) for a more thorough summary of the debate.

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 (2001) and others have shown that Frankel and Romer's (1999) 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 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 that 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 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 of the "deep determinants" of income differences and generate identification purely through time-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.

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 large 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 routes cross land masses. This will result in differential impacts on trade for each country.

[2] See Acemoglu, Johnson, and Robinson (2001); Rodrik, Subramanian, and Trebbi (2004); Glaeser et al. (2004); McArthur and Sachs (2001); and Gallup, Sachs, and Mellinger (1999) on the relative importance of geography and institutions.

[3] See also Rodrik, Subramanian, and Trebbi (2004) and Irwin and Terviö (2002). Using a larger trade sample, Noguer and Siscart (2005) finds that geographic controls reduce the estimated effect of trade on income, but does not eliminate it. 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.

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

Gravity regressions on panels of bilateral trade have relied on point to point great circle differences even though the majority of long distance trade has historically travelled by sea. This paper is the first to use sea distances in a comprehensive panel of world trade.[6] Gravity regressions that include both air and sea distance and allow for time-varying coefficients on distance show that the influence of air distance on bilateral trade has grown relative to sea distance over time.

The insights from the gravity regressions can be used to create time-series predictions for bilateral trade that are based on geography and are exogenous with regards to income growth. 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 over time. 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 and initial industrial structure.

Compared to Frankel and Romer (1999), the results are much less susceptible to missing variable bias. Due to the construction of the instrument, any potential causes for GDP growth other than trade must be related to bilateral distances by air and sea. Enhanced movement of people is the main alternative to trade in goods as an explanation for how distance relates to trade growth over time. These results can therefore be seen as an estimate of the impact of economic integration more broadly defined.

Feyrer (2009) uses a similar methodology to estimate the impact of trade on GDP by using the temporary closure of the Suez to construct an instrument that is entirely about trade by sea. The Suez estimates are roughly half what this paper finds, suggesting that about half the impact of tighter global integration is directly from trade.

I. Overall Framework

The goal of this paper is to estimate the impact of trade on GDP. The basic estimating equation is

$$\ln(y_{it}) = \gamma_i + \gamma_t + \beta \times \ln(trade_{it}) + \epsilon_{it}, \tag{1}$$

where y_{it} is real GDP per capita, γ_i and γ_t are country and time effects, $trade_{it}$ is the sum of imports and exports for country i at time t, and ϵ_{it} is a disturbance term. Given the time and country effects, all identification will come from changes in

[6] While sea distance occasionally appears in gravity models, it has tended to be in the context of single country or regional studies. Disdier and Head (2008) conducts a meta study of gravity model results and cites 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 or small sets of countries. Bergstrand (1985, 1989) uses sea distance for 15 OECD countries. Coulibalya and Fontagné (2005) considers sea distance in an examination of African trade. Pascali (2017) uses both direct sea and sailing distances in work that postdates working versions of this paper.

GDP and trade over time. An OLS regression of equation (1) will not be identified because of reverse causality from GDP to trade. An IV strategy will be employed to deal with this endogeneity.

A. *Instrument Exogeneity*

Following Frankel and Romer (1999), instruments will be built on a foundation of bilateral trade relationships and aggregated to obtain an instrument for aggregate trade for each country in each year. Predictions for bilateral trade will take the form

$$\ln(trade_{ijt}) = f_t(\mathbf{X}_{ij}, \mathbf{X}_i, \mathbf{X}_j), \tag{2}$$

where $\mathbf{X}_{ij}$ represents time-invariant characteristics of the pair (such as distance between them) and $\mathbf{X}_i$ and $\mathbf{X}_j$ represent time-invariant characteristics of the individual countries in the pair (such as initial population or land area).

The time-invariant characteristics of country i will be controlled for by the country-level controls in equation (1). Since no country-specific time series information appears in equation (2), there is no channel for GDP *growth* to feed back into these predictions for trade. In order to make this more clear, we can drop the $\mathbf{X}_i$ term and completely exclude information from country i:

$$\ln(predicted\ trade_{ijt}) = f_t(\mathbf{X}_{ij}, \mathbf{X}_j). \tag{3}$$

The bilateral predictions can be summed to make a prediction for aggregate trade for country i at time t:

$$predicted\ trade_{it} = \sum_{i \neq j} \exp(f_t(\mathbf{X}_{ij}, \mathbf{X}_j)). \tag{4}$$

The bilateral predictions will change over time based on the changing relationship between trade, the time-invariant characteristics of the pair, and the time-invariant characteristics of each trading partner. For the purposes of identification, the key assumption is that $f_t(\cdot)$ is independent of any particular country and therefore embeds no information about the GDP growth rates of specific countries.

The time-varying nature of this function is motivated by the gravity model and developments in the technology of transport by air and by sea over time. A natural functional form for $f_t(\cdot)$ is therefore

$$\ln(trade_{ijt}) = \mathbf{X}_j + \beta_{sea,t} \times \ln(seadist_{ij}) + \beta_{air,t} \times \ln(airdist_{ij}). \tag{5}$$

The key parameters driving the time-series variation are $\beta_{air,t}$ and $\beta_{sea,t}$. One can think of these time-changing βs as weights on the two distance measures that vary over time as technology changes. Consider a pair of countries without no land route between them so that all trade travels by sea or by air. Before air travel was possible, the weight on air distance should be zero and the weight on sea distance positive in predicting bilateral trade. After the advent of air travel, the weight on air distance should become nonzero. Conceptually, we could consider adding measures for other modes such as roads or railways.[7]

The most obvious method for determining the βs is through the estimation of a gravity model. Estimating in this way necessitates using country-specific information about trade. Since there are many countries, each individual country's influence on the βs is small and the result is a function that is not country specific.

The use of the gravity model to determine the βs is not strictly necessary but has the advantage of predictive power. Ad hoc βs based on the hypothesis that air distances have become more important over time can also be used. For example, we can use $\beta_{sea,t} = -1$ and $\beta_{air,t} = 0$ in 1960 and $\beta_{sea,t} = 0$ and $\beta_{air,t} = -1$ in 1995. The predictions resulting from this contain no information from trade data.

The $\mathbf{X}_j$ scales the time-changing distance relationship with time-invariant information about each partner in the trading pair. The propensity of each partner to trade measured by their average aggregate trade is the most obvious scaling and comes directly from the gravity model. Other scalings such as population at the beginning of the sample period and the log of country land area will also be used. In this latter case, the instrument will be built with no information other than geography.

B. *Exclusion Restrictions*

In the previous section, I argue that the proposed instrument has no potential channels from country-level growth rates to the instrument. This leaves open the question of whether the instrument influences output exclusively through the channel of trade.

This is the key problem facing Frankel and Romer (1999). Their instrument is exogenous because it is constructed from geography, but may have an impact on output through channels other than trade. Countries that are geographically closer to the rest of the world may have developed better institutions over time. Remoteness also correlates with being nearer to the equator, which is associated with worse health conditions and institutions. Rodrik, Subramanian, and Trebbi (2004) shows that the Frankel and Romer (1999) results are not robust to controlling for geography and modern institutions.

By exploiting the time series, the instruments in this paper can solve this set of problems. Because the predicted values are from a panel, one can include country effects, deriving all identification from changes over time. Country effects will remove any of these deep determinants of income differences.

Any non-trade channels for the instrument to act on income are limited to time-varying bilateral relationships. One needs to tell a story about how countries see changes in income over time for reasons other than trade that are correlated with these bilateral distance differences. This dramatically limits the scope of omitted variable bias, particularly compared to previous studies of trade and income.

The most obvious potential violation of the exclusion restriction is an increase in the movement of people generating increases in GDP. This could come from increases in technology transfer or foreign direct investment that lead to income

[7] For example, Donaldson (2018), Allen and Arkolakis (2014), and Asher and Novosad (2018).

increases for reasons other than trade.[8] Campante and Yanagizawa-Drott (2018) finds that business links and capital flows increase with lower costs of air travel.

All the potential channels that rely on improvements in air travel can easily be categorized as increases in integration between countries. In this light, the reduced-form regressions can be seen as describing the general effects of globalization. The trade estimates therefore represent an upper bound on the direct causal impact of trade on income with the estimates being inflated by other globalization related activities.

Feyrer (2009) uses the temporary closure of the Suez Canal between 1967 and 1975 to construct an instrument for trade. Since this instrument is focused entirely on trade by sea, the estimates do not include other spillover effects from globalization. The Suez estimates are roughly half what this paper finds, suggesting that about half the impact of globalization is directly from trade and half from other factors.

C. *Local Average Treatment Effects*

Improvements in air travel were potentially beneficial to all countries in the world. Any country that can build an airstrip can potentially use air freight. The ability to fly from JFK airport to almost any country around the globe within 24 hours suggests that this possibility is more than theoretical. This is why an instrument built from air and sea distances can make strong predictions of trade growth.

This does not mean that the instrument becomes invalid if some countries are more effective at building airstrips than others. This concern might matter for the magnitude of the results if the countries that take advantage of air travel have more to gain from trade than countries that do not. If there are heterogeneous treatment effects, the IV will be picking up the local average treatment effect of the countries that embrace air freight. The local average treatment effect may be larger than the average impact of trade on income.[9]

For several reasons this is unlikely to be a significant problem. First, the patterns of trade by air that I will document in the following section suggest that the use of air freight is wide spread across types of countries and goods. Second, I will run regressions with controls for region and industry that show that countries with particular manufacturing competencies are not driving the results. Finally, the comparison with Feyrer (2009) is again useful. The identification comes from a very different source and therefore provides some bounds on how much the estimates are being driven by local average treatment effects.

II. The Changing Shape of the Globe

Transport between countries has developed rapidly 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 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.[10] These decreases were

[8] Keller (2002) and Buera and Oberfield (2016).
[9] Angrist, Imbens, and Rubin (1996).
[10] Hummels (2007, 137–38).

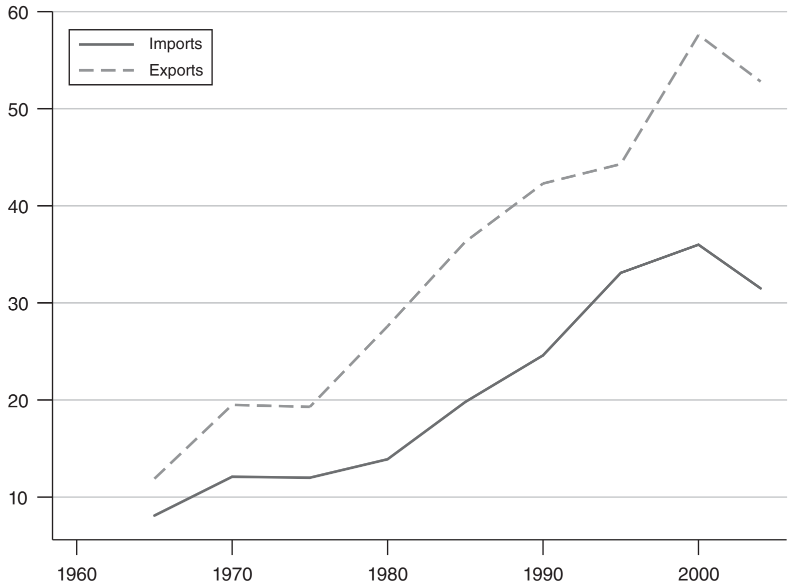

Figure 1. Air Freight Share of US Trade Value (Excluding North America)

Source: Hummels (2007, 133)

relatively uniform across the globe and affected all regions. Ocean freight prices did not fall as rapidly as air freight.[11] 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.

A. *What Goods Travel by Air?*

US import data is available disaggregated by type of good and mode of transport.[12] While this is limited to the United States, it is useful to give a more detailed picture of what goods are transported by air. Table 1 lists the top 20 Harmonized System (HS) trade categories imported to the United States 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 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

[11] Hummels (2007, 152) finds that despite significant technological change in ocean shipping (i.e., containerization) ocean freight rates were flat between 1952 and 1972 and rising with oil prices through the mid 1980s.

[12] US Census Bureau—US Imports of Merchandise (2001).

Table 1—Top 20 HS2 Trade Categories by Air

HS code	Description	Air import value (billion dollars)	Percent by air
85	Electrical machinery and equip. and 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 and accessories	20.63	59.2%
29	Organic chemicals	20.28	63.9%
98	Agric., construction, trans., electric/gas/sanitary, eng. and mgmt. and 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, and parts thereof	3.45	16.3%
95	Toys, games, and sports equip., parts & acces.	2.22	11.0%
91	Clocks and watches and 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, mollusks, aquatic invertebrates	0.93	11.8%

Source: US Census Bureau—US Imports of Merchandise (2001)

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 United States 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. Singapore, Malaysia, and the Philippines shipped the majority of their exports to the United States by air. It is not the case that the historically wealthy countries are more concentrated in goods shipped by air. Figure 2 is a scatter plot showing the percentage of exports sent to the United States by air versus the log of GDP per worker in 1960. There is no significant relationship between income per worker in 1960 (before the fall in price of air freight) and the percentage of trade by air in 2001.

Table A1 (in the Appendix) lists the top overall importers to the United States, their share of imports to the United States by air, and the HS4 category with the highest value of goods transported by air to the United States. The primary air export varies quite a bit from country to country. Many of the Asian countries export computers and parts to the United States by air. European countries export chemicals and pharmaceuticals to the United States by air. Many developing countries export precious metals and jewelry to the United States by air. 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 United States. From Spain, 54 percent of leather shoes arrive in the United States by air. For a few countries such as Bangladesh and Guatemala, the largest air category to the United States is clothing.

TABLE 2—TOP 20 COUNTRIES FOR US IMPORTS BY AIR

Country	Air import value (billion dollars)	Percent by air
Japan	34.1	26.9%
United Kingdom	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)

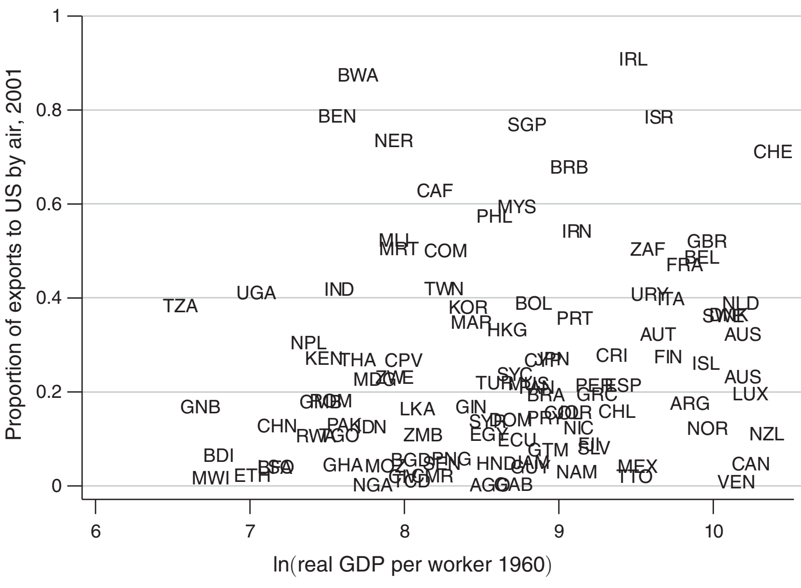

FIGURE 2. 2001 AIR IMPORTS TO THE UNITED STATES VERSUS 1960 GDP PER CAPITA

Source: US Census Bureau—US Imports of Merchandise (2001); Penn World Table 6.2

Air transport is important for a variety of goods exported by countries at different levels of development. With the exception of a few small islands, all countries in the world exported goods to the United States by air in 2001. The overall importance of air transport (at least with regards to exports to the United States) is uncorrelated with development before the sample period. The rise of air transport therefore has the potential to affect the quantity of trade for all countries in the world.

B. *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 of 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 regard 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.

III. Gravity Model Estimation

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. The distance measures 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.

Anderson and van Wincoop (2003) develops a theoretical model to derive the gravity model. The basic gravity relationship is

$$trade_{ijt} = \frac{y_{it}y_{jt}}{y_{wt}}\left(\frac{\tau_{ijt}}{P_{it}P_{jt}}\right)^{1-\sigma}, \tag{6}$$

where $trade_{ijt}$ 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; τ_{ijt} is a bilateral resistance term; and P_{it} and P_{jt} are country-specific multilateral resistance terms. Taking logs,

$$\ln(trade_{ijt}) = \ln(y_{it}) + \ln(y_{jt}) - \ln(y_{wt}) + (1-\sigma)\big(\ln(\tau_{ijt}) + \ln(P_{it}) + \ln(P_{jt})\big). \tag{7}$$

I will assume that the bilateral resistance term, τ_{ijt}, in equation (7) is a function of air and sea distance with coefficients that can change over time. The key assumption is that all country pairs share the same bilateral resistance function for each time period,

$$\begin{aligned} \ln(\tau_{ijt}) &= f_t(airdist_{ij}, seadist_{ij}) \\ &= \beta_{sea,t} \times \ln(seadist_{ij}) + \beta_{air,t} \times \ln(airdist_{ij}) + \beta \mathbf{X}_{ij}. \end{aligned} \tag{8}$$

The change in this function over time is assumed to be driven by changes in transportation technology. 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 βs. The absolute value of the βs is less important than the relative moves. One can think of this as changing weights on the two distances as technology drives a shift from one mode to the other. The vector $\mathbf{X}_{ij}$ 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.[13] 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

$$\begin{aligned} \ln(trade_{ijt}) = {} & \alpha + \gamma_i + \gamma_j + \gamma_t + \beta_{sea,t} \times \ln(seadist_{ij}) \\ & + \beta_{air,t} \times \ln(airdist_{ij}) + \beta \mathbf{X}_{ij} + \epsilon_{ijt}, \end{aligned} \tag{9}$$

$$\begin{aligned} \ln(trade_{ijt}) = {} & \alpha + \gamma_{ij} + \gamma_t + \beta_{sea,t} \times \ln(seadist_{ij}) \\ & + \beta_{air,t} \times \ln(airdist_{ij}) + \epsilon_{ijt}, \end{aligned} \tag{10}$$

[13] 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.

where equation (9) includes country effects and equation (10) 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. Estimates of equations (9) and (10) 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.

IV. An Exogenous Instrument for Trade

Predictions for bilateral trade can be produced by estimating equations (9) and (10) 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.[14]

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.

$$\begin{aligned}
(11)\qquad \textit{predicted trade}_{it} &= \sum_{i\neq j} e^{\hat{\gamma}_t+\hat{\gamma}_i+\hat{\gamma}_j+\hat{\beta}_{air,t}\times\ln(airdist_{ij})+\hat{\beta}_{sea,t}\times\ln(seadist_{ij})} \\
&= e^{\hat{\gamma}_t} e^{\hat{\gamma}_i} \sum_{i\neq j} e^{\hat{\gamma}_j}\, e^{\hat{\beta}_{air,t}\times\ln(airdist_{ij})+\hat{\beta}_{sea,t}\times\ln(seadist_{ij})},
\end{aligned}$$

$$\begin{aligned}
(12)\qquad \textit{predicted trade}_{it} &= \sum_{i\neq j} e^{\hat{\gamma}_t+\hat{\gamma}_{ij}+\hat{\beta}_{air,t}\times\ln(airdist_{ij})+\hat{\beta}_{sea,t}\times\ln(seadist_{ij})} \\
&= e^{\hat{\gamma}_t} \sum_{i\neq j} e^{\hat{\gamma}_{ij}}\, e^{\hat{\beta}_{air,t}\times\ln(airdist_{ij})+\hat{\beta}_{sea,\,t}\times\ln(seadist_{ij})}.
\end{aligned}$$

Equation (11) 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

[14] 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. Restricting the sample to country pairs with a full panel of observations from 1950–1997 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. Results from these restricted regressions will be reported in the Appendix.

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.

These predictions are free of reverse causality from income. The time and country-level dummies in the second stage will control for the terms outside the summation.[15] Within the summation, the bilateral distance measures are time invariant and exogenous. These are weighted by the shared βs and the dummy values for each trading partner, which reflects each countries average propensity to trade. The time variation is provided by the changing $\hat{\beta}$s, which represent the changing relationship between distance and trade frictions. 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.[16]

By using weights generated from the estimation of a gravity equation, I am attempting to maximize the predictive power of the instrument. Because the aggregate instrument set is going to be built from averages of bilateral distances with weights that are equal across all countries, in theory, any arbitrary weights could be used in the creation of a valid instrument. One obvious candidate is the population of each trading partner at the beginning of the sample:

$$(13) \qquad \textit{predicted trade}_{it} = \sum_{i \neq j} POP_{1950,j} \times e^{\hat{\beta}_{air,t} \times \ln(\textit{airdist}_{ij}) + \hat{\beta}_{sea,t} \times \ln(\textit{seadist}_{ij})}.$$

This version of the trade predictions contains no information about individual countries that was not available at the beginning of the sample period.

A. *Simple Instrument for Long Differences*

The gravity-model-based instrument described above provides a full panel of trade predictions. Before performing the panel analysis, I will present long difference results examining average trade and income growth over time from 1960 to 1995. Examining long differences allows me to show the results graphically. It also becomes possible to dispense with the formal gravity model entirely and generate an instrument based directly on geography.

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 geographic instrument for trade growth is therefore the average of the log difference between air and sea trade distances to all trading partners. Because all trading partners are not created equal it makes sense to weight each observation by some characteristic of the trading partner that might influence trade volumes:[17]

$$(14) \qquad \textit{simple inst}_i = \ln\left(\sum_{i \neq j} \textit{weight}_j \times \textit{seadist}_{ij}\right) - \ln\left(\sum_{i \neq j} \textit{weight}_j \times \textit{airdist}_{ij}\right).$$

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

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

[17] Strictly speaking, a weighted average should be divided through by the sum of the weights. Because the sums are logged and differenced, this term drops out.

The most obvious choice of weights is total trade of each potential trading partner in 1960, the beginning of the sample for the long difference analysis, $weight_j = trade_{j,1960}$. Using these weights, the two terms are proportional to the log of the average distance to a unit of world trade in 1960 by air and by sea.

In terms of the gravity estimation, this removes potential objections to the validity of the instrument in two ways. First, I am using only beginning-of-sample trade. Second, I am not using any information from the gravity model other than the distances. This instrument is equivalent to equation (13) where I arbitrarily set $\beta_{sea} = -1, \beta_{air} = 0$ at the beginning of the sample and $\beta_{sea} = 0, \beta_{air} = -1$ at the end.

These two changes mean that no country-specific time-series data is used in the construction of the instrument and all country-specific information is either clearly exogenous and fixed (the distances) or predetermined. An alternative version of this instrument can avoid the use of trade data altogether and use the population in 1960 as weights, $weight_j = POP_{j,1960}$. An instrument can also be constructed that relies on the land mass of each country, $weight_j = \ln(land\ area_j)$. This final instrument is entirely based on geography.

These instrument sets are confined to predicting the growth in trade over the sample period and are therefore not useful for the full panel estimation. They are, however, useful instruments for examining growth rate differences over the entire sample period.

V. Data

Trade data were provided by Glick and Taylor (2010), 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 a balanced panel with no missing values.

Bilateral great circle distances (the measure of air distance) are from the CEPII.[18] The CEPII provide several different variations for measuring the great circle distance between countries.[19] 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 1×1 degree squares. The points representing

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

[19] 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) develops the methodology for the weighted measures.

points on land were identified using gridded geographic data from CIESIN.[20] 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.[21] 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.[22] 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 an almost mechanical relationship between the value of trade and income. None of the results are sensitive to the inclusion of the oil exporters.

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 United States 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 United States and Canada can be seen as an outcome), the trade of the United States 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 US east-west population distribution for 1975, the middle of the sample. In effect, the United States 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 United States 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 United States 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. While the main specification will use the unbalanced panel to maximize sample size, regressions will also be run limiting the sample to 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 160,000 observations to just above 50,000 and does not significantly alter the results.

[20] http://sedac.ciesin.columbia.edu/povmap/ds global.jsp.
[21] Meehl (1980), http://dss.ucar.edu/datasets/ds280.0/.
[22] Specifically, Djikstra's algorithm.

VI. Trade Regression Results

Figures 3 and 4 plot the sequence of coefficients on air distance and sea distance found by estimating equations (9) and (10). Each point represents the elasticity of trade with regards to sea or air distance over a particular time period.[23] 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 3 shows that the elasticity of trade with regard to sea distance between 1950 and 1955 was roughly −0.9. This elasticity falls in absolute value until the 1985–1990 period where it levels off near zero. In the same figure, the elasticity with regards to air distance starts out insignificantly different from 0 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 relative 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 seeing larger increases in trade.

Table A2 (in the Appendix) presents the results of estimating equations (9) and (10) using various methods of gravity model estimation and include estimations where the sample is limited to trade pairs with a balanced panel of observations.[24] These variations all tell a similar story. The elasticity of trade with regard to sea distance becomes less negative between 1950 and 1995. The elasticity of trade with regard to air distance becomes more negative over the same period.

One potential complication with the conceptual splitting of air and sea distance is ground travel. This is clearly as issue for the European countries 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) surveys estimates of gravity models and finds an increase in coefficients on distance over time.[25] However, none

[23] Table A2 (in the Appendix) presents the results underlying Figures 3 and 4.

[24] The reported regressions include country dummies with and without a standard set of bilateral controls from the CEPII dataset and pair dummies. Each of these variation is run on both a balanced and unbalanced bilateral trade panel.

[25] Brun et al. (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 an increasing effect of distance over time for standard gravity

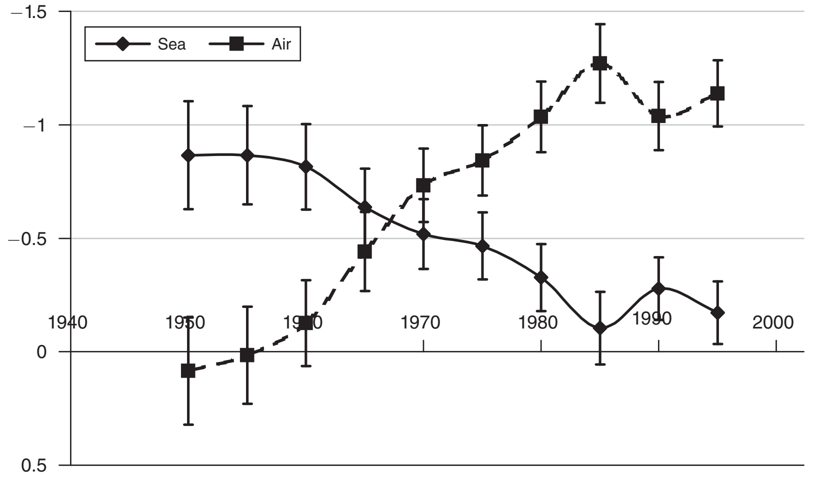

Figure 3. The Change in Elasticity of Trade with Respect to Sea and Air Distance over Time from a Gravity Regression with Country-Fixed Effects

Source: Coefficients are from regression Table A2, column 2. Each point represents the coefficient on (sea or air) distance over a five-year interval. Error bars represent plus or minus two standard errors for each coefficient.

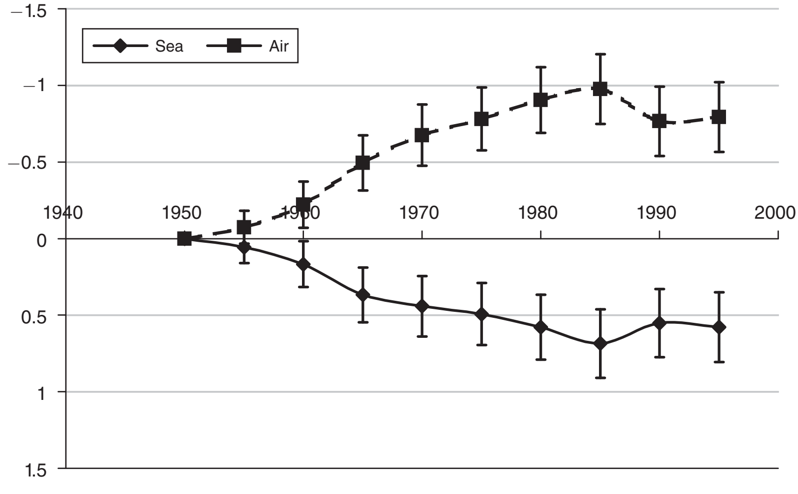

Figure 4. The Change in Elasticity of Trade with Respect to Sea and Air Distance over Time from a Gravity Regression with Pair-Fixed Effects

Source: Coefficients are from regression Table A2, column 5. Each point represents the coefficient on (sea or air) distance over a five-year interval. Error bars represent plus or minus two standard errors for each coefficient.

of these studies included sea distances along with the standard great circle bilateral distances. Table A3 shows the results of regressions including only the standard great circle distances. These results are consistent with the earlier studies in finding

model estimations. Berthelon and Freund (2008) finds similar effects in disaggregated trade. See Disdier and Head (2008) for a full survey of papers on the "Death of Distance."

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.

VII. Regressions of Income on Trade

A. *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.[26] While less precise than the panel regressions, this exercise can show the basic relationships visually and also allow for using the most basic instrument described earlier. The estimating equation in this section is

$$\Delta \ln(y_i) = \beta \times \Delta \ln(trade_i) + \gamma + \epsilon, \tag{15}$$

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 trade share 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.[27] 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 uninstrumented relationship between the growth of trade and the growth of per capita GDP. Table 3 shows the results of estimating equation (15)

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

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

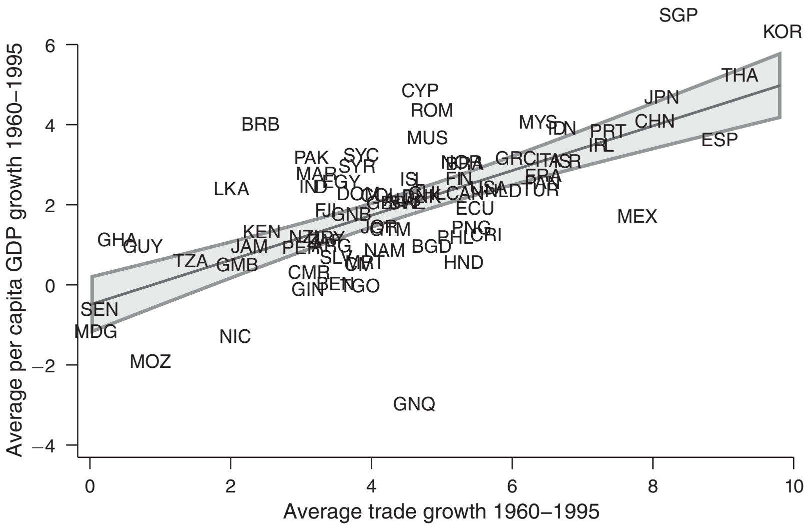

FIGURE 5. AVERAGE PER CAPITA GDP GROWTH VERSUS TRADE GROWTH 1960–1995

Source: Penn World Table 6.2, IMF Direction of Trade database

TABLE 3—THE EFFECT OF TRADE ON GDP IN LONG DIFFERENCES

	Annual per capita real GDP growth 1960–1995				
		IV			
			Simple instrument		
	OLS (1)	Gravity instrument (2)	Trade weight (3)	Pop. weight (4)	Area weight (5)
Average trade growth	0.558	0.688	0.732	0.668	0.596
	(0.067)	(0.111)	(0.146)	(0.165)	(0.247)
R^2	0.464				
Observations	76	76	76	76	76
First stage					
		Annual trade growth 1960–1995			
Trade instrument		1.275	1.062	0.821	5.429
		(0.235)	(0.266)	(0.235)	(2.170)
Instrument F-statistic		29.45	15.95	12.22	6.26
First-stage R^2		0.242	0.151	0.097	0.071
Reduced form					
		Annual per capita real GDP growth 1960–1995			
Trade instrument		0.877	0.778	0.548	3.236
		(0.189)	(0.210)	(0.191)	(1.856)
Reduced-form R^2		0.170	0.121	0.064	0.038

Notes: The gravity instrument is based on predictions of trade from a gravity model estimated with country-fixed effects. The simple instruments are based on the air and sea distance for each pair of countries weighted by trading partners population in 1960, overall trade in 1960, and the log of surface area.

using OLS and IV. The instrument in column (2) is the log change in predicted trade between 1995 and 1960 from the gravity model described in equation (11).

Columns (3) through (5) use the instrument based on simple distances weighted by trade in 1960, population in 1960, and the log of surface area as described in equation (14). The first instrument uses gravity-model estimates to maximize the predictive power of the first stage. The three simple instruments have the advantage of simplicity and do not require any estimation to construct at the cost of lower power in the first stage.

For all but the surface area weighted regression, the *F*-statistics are all safely above the standard weak instrument threshold of ten suggested by Staiger and Stock (1997). First-stage power clearly drops as less information is used in the creation of the instruments. Figure 6 shows the first-stage relationships between trade growth and the predicted change in trade for the first three instruments. Figure 7 shows the reduced-form relationship between the growth in per capita GDP and the instruments.

The IV estimates are all significant and very similar in magnitude. The area-weighted estimates are the weakest, as we should expect given the limited information used to construct the instrument. They are included to show that the results change very little when different weights are used, suggesting that the underlying distance measures are providing the identifying variation.

The point estimates on the effect of trade on income are slightly larger than the OLS estimates but not significantly so. Looking at the reduced form, trade predictions from the gravity model can explain 17 percent of the variation in income growth between 1960 and 1995.

B. *Panel Regressions*

This section will repeat the exercise of the previous section with panel regressions. Using the coefficients estimated earlier, equations (11), (12), and (13) are used to calculate country-level predictions for trade 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 for 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

$$\ln(y_{it}) = \gamma_i + \gamma_t + \beta \times \ln(trade_{it}) + \epsilon_{it}, \tag{16}$$

where y_{it} is real GDP per capita from the Penn World Table,[28] γ_i and γ_t are country and time effects, and ϵ_{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.

[28] Heston et al. (1950–2004). Specifically, the rgdpc series in the Penn World Table version 6.2 is used.

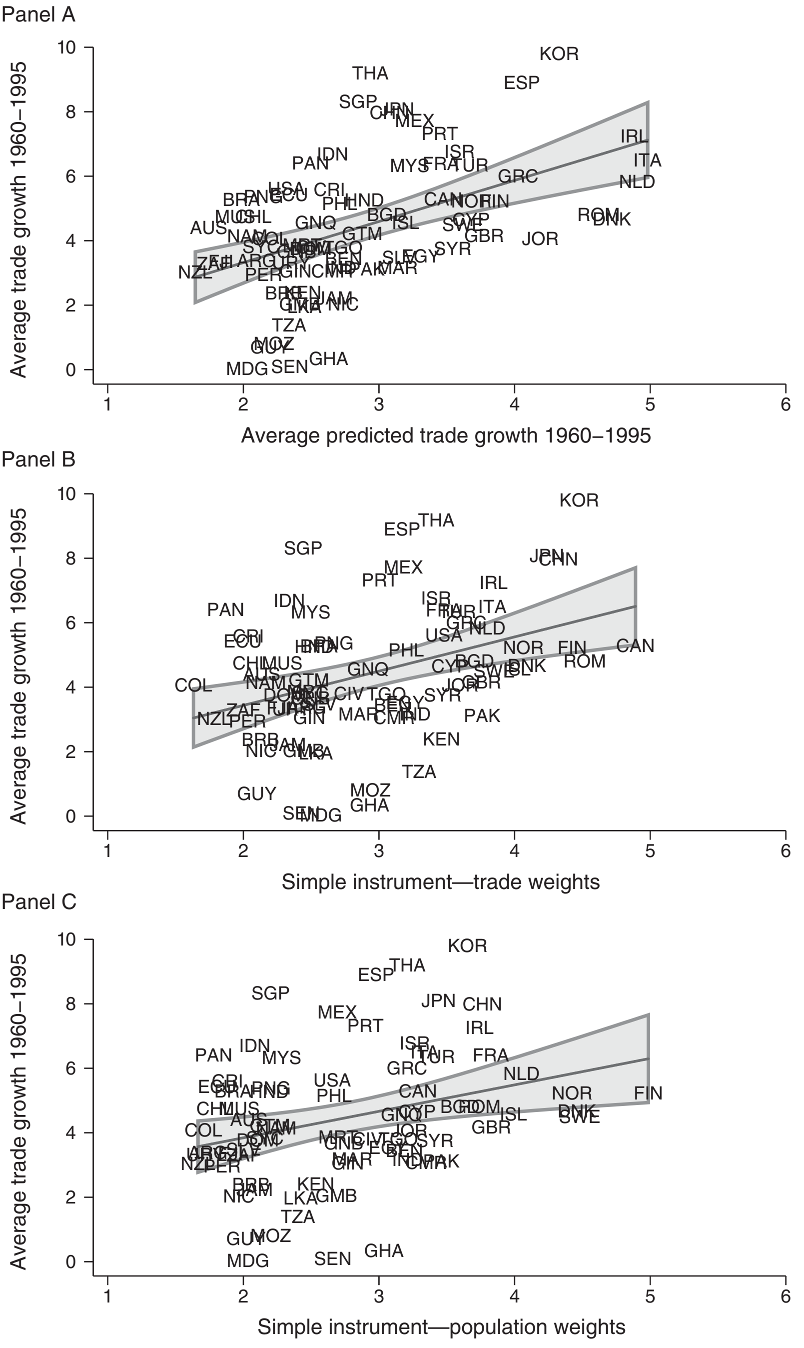

Figure 6. First Stage: Trade Growth 1960–1995 versus Instruments

Source: IMF Direction of Trade database; author's calculations

Table 4 shows the first-stage, reduced-form, and IV results from estimating the full panel in levels. The differences between the columns in Table 4 are driven by differences in the construction of the instrument. Columns 3 and 4 use instruments

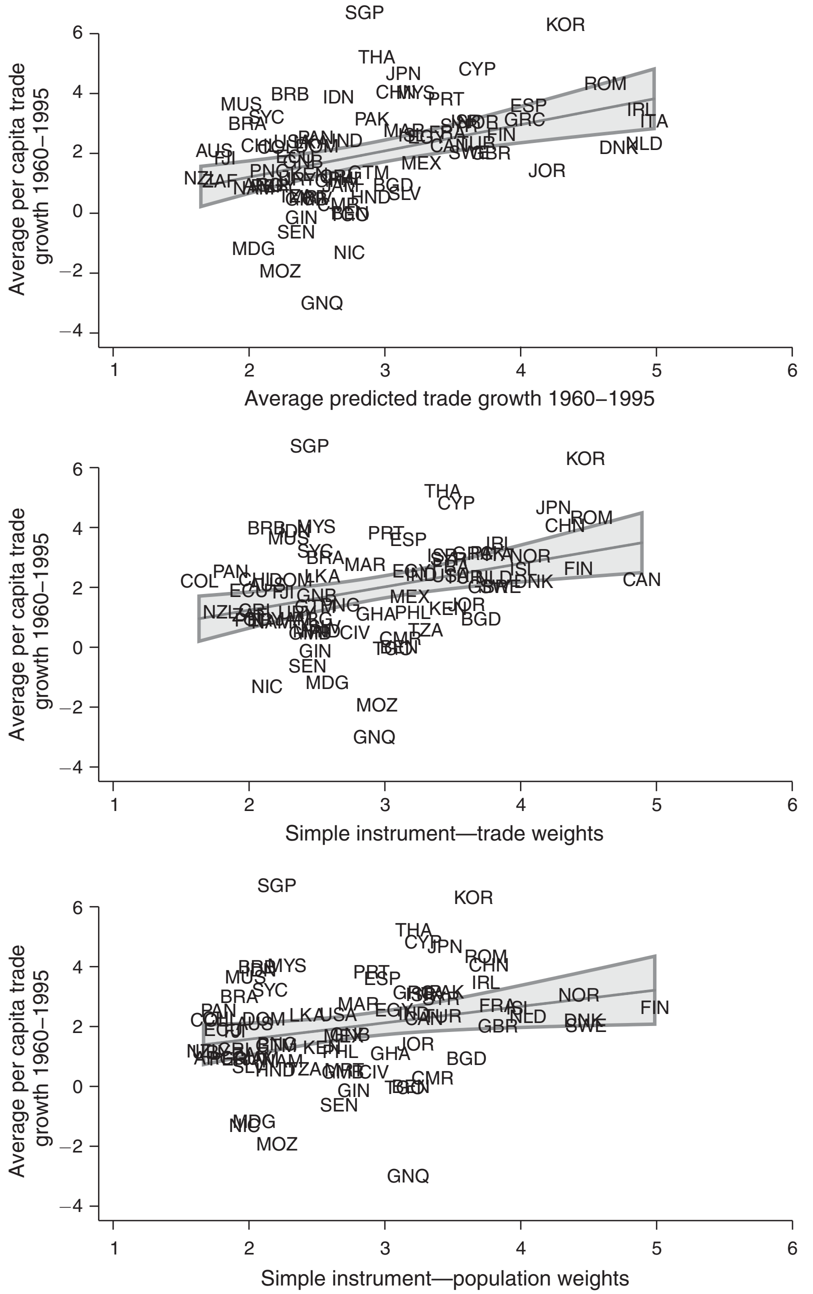

Figure 7. Reduced Form: Average Per Capita Real GDP Growth 1960–1995 versus Instruments

Source: Penn World Table 6.2, author's calculations

calculated using βs estimated from a gravity model with country-fixed effects. Columns 4 and 5 use instruments calculated from βs from a gravity model estimated with pair-fixed effects. The instruments for columns 2 and 4 are direct predictions from the gravity model (equations (11) and (12)). The instruments for columns 3

TABLE 4—PANEL ESTIMATES OF TRADE ON PER CAPITA GDP

	ln(real GDP per capita)				
		IV—Gravity instruments			
		Country dummies		Pair dummies	
	OLS	Trade weight	Pop weight	Trade weight	Pop weight
	(1)	(2)	(3)	(4)	(5)
ln(trade)	0.446	0.578	0.611	0.459	0.716
	(0.041)	(0.082)	(0.131)	(0.097)	(0.128)
R^2	0.965				
		ln(trade)			
First stage					
ln(predicted trade)		0.993	0.731	1.385	1.353
		(0.144)	(0.187)	(0.251)	(0.296)
Instrument F-statistic		47.22	15.29	30.47	20.92
First-stage R^2		0.975	0.972	0.973	0.972
Instrument-partial R^2		0.170	0.067	0.100	0.080
		ln(real GDP per capita)			
Reduced form					
ln(predicted trade)		0.573	0.446	0.636	0.968
		(0.116)	(0.130)	(0.185)	(0.195)
Reduced-form R^2		0.947	0.943	0.943	0.945
Instrument-partial R^2		0.118	0.052	0.044	0.085
Observations	774	774	774	774	774
Countries	101	101	101	101	101
Years	10	10	10	10	10

Notes: Standard errors are clustered by country. Regressions are on data at 5-year intervals from 1950 to 1995. Regressions include country and time dummies.

and 5 are based on equation (13) and use the βs from the gravity regression with the population of each country in 1950 as weights.

The IV estimates of the impact of trade on GDP are modestly larger than the OLS.[29] The first-stage relationship between predicted trade and actual trade is very strong with F-statistics over 15 in all cases. Moving from the full gravity specification to population weighting weakens the first stages, but they remain within the acceptable range. The first-stage R^2 values in Table 4 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 full gravity instruments can predict 17 percent of trade in the panel.

C. *Estimation in First Differences*

The model can also be estimated in differences.[30] Table 5 shows results for a set of differenced regressions that correspond to the regressions in levels in Table 4.

[29] The differences between OLS and IV are not significant for columns 1 through 3 and significant at the 5 percent level for column 4.

[30] Differencing changes the error structure to eliminate first-order serial correlation, and country-level clustering can now be used to control for second-order serial correlation.

Table 5—IV Estimates of Trade on Per Capita GDP

	Δln(real GDP per capita)				
		IV—Gravity instruments			
		Country dummies		Pair dummies	
	OLS (1)	Trade weight (2)	Pop weight (3)	Trade weight (4)	Pop weight (5)
Δln(trade)	0.229	0.739	0.698	0.540	1.201
	(0.030)	(0.149)	(0.234)	(0.152)	(0.722)
R^2	0.186				
		Δln(trade)			
First stage					
Δln(predicted trade)		0.548	0.342	0.640	0.361
		(0.118)	(0.150)	(0.201)	(0.278)
Instrument F-statistic		21.68	5.182	10.15	1.686
First-stage R^2		0.470	0.463	0.465	0.461
Instrument-partial R^2		0.020	0.0057	0.011	0.002
		Δln(real GDP per capita)			
Reduced form					
Δln(predicted trade)		0.404	0.238	0.345	0.434
		(0.096)	(0.104)	(0.133)	(0.139)
R^2		0.080	0.060	0.060	0.061
Instrument-partial R^2		0.029	0.008	0.008	0.010
Observations	673	673	673	673	673
Countries	93	93	93	93	93
Years	9	9	9	9	9

Notes: Standard errors are clustered by country. Regressions are on data at 5-year intervals from 1950 to 1995. Regressions include country and time dummies.

The point estimates for the effect of trade on GDP are the same as for the panel with the curious exception of OLS. The first stages for the full gravity instruments are strong with F-statistics above 10. The population-weighted instruments have weak first stages in this case and are included for completeness.

D. *Additional Controls*

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 that geography is correlated with trend growth for reasons that have nothing to do with improvements in air travel but that happen to correspond to longer air routes. 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.

For Frankel and Romer (1999), geography had a direct impact on output through colonial history, disease environment, etc. Their instrument therefore violated exclusion restrictions and was not operating exclusively through the channel of trade. In the time series, the case for violation of exclusion restrictions is much more difficult to make. Is there reason to believe that the particular geography of East Asia

Table 6—IV Regressions Controlling for Industrial Structure and Region

	Annual real per capita GDP growth 1960–1995		
	No controls (1)	Region-by-year dummies (2)	Industry-by-year controls (3)
Average trade growth	0.578	0.318	0.435
	(0.082)	(0.138)	(0.097)
Instrument F-statistic	47.22	17.72	9.150
Observations	774	774	511
Countries	101	101	57

Notes: Standard errors clustered by country. Regressions include country and year dummies. Column 1 is identical to column 2 in Table 4. Column 2 adds a full set of region-by-year dummies. Column 3 adds a full set of industrial structure-by-year controls. See Table 7 for a list of regions and industrial categories.

led to rapid growth rates over the period 1950–1995 other than through the channel of trade and integration? If not, adding additional controls removes legitimate identifying variation. The following regressions are therefore not intended as evidence that these controls are needed, but to illustrate that the results are not entirely a story about the difference between East Asia and Africa.

Column 2 of Table 6 adds a full set of region-by-time dummies to the main specification.[31] This allows each region to have different growth patterns throughout the sample and is identified from differences in growth rates within each region. The coefficient falls but is still significant and positive. Table 7 performs a similar estimation in differences with a full set of region dummies. The point estimate is significant and similar in magnitude to the base regression. This regression should be approached with some caution as the first stage is weak (F-statistic below 5).

Another potential confounding factor might be 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. Column 3 of Table 6 includes a set of controls for industrial structure in 1970 (the first year that data are relatively complete) interacted with a full set of time dummies.[32] The use of UNIDO data limits the sample to 57 countries. The point estimate is relatively unchanged from column 1 with a weaker first stage.[33] Table 7 performs a similar estimation in differences with industrial composition dummies. Again, the point estimate is similar to the base regression with a weak first stage.

VIII. Discussion of 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

[31] Table 4, column 2.

[32] The data are from the UNIDO database on manufacturing, which provides information on value added in manufacturing industries. This was combined with 1970 data from the United Nations on broad industrial structure. The resulting controls are the proportion of GDP in each broad industry with disaggregated manufacturing at the two-digit ISIC rev2 level. For ISIC 38, the category most likely to contain high value to weight manufactures, the data are further disaggregated to the three-digit level. Table 7 contains the full list of categories.

[33] The F-statistic on the instrument falls to just below the threshold of 9.

Table 7—IV Regressions Controlling for Industrial Structure and Region

	Δ ln(real GDP per capita)					
	(1)		(2)		(3)	
Δln(trade)	0.739	(0.149)	0.685	(0.283)	0.669	(0.224)
East Asia			0.0229	(0.0586)		
East Central Asia			−0.0402	(0.0810)		
Middle East and N. Africa			0.0500	(0.0400)		
South Asia			0.0667	(0.0326)		
Western Europe			0.0254	(0.0484)		
North America			−0.0042	(0.0425)		
Latin America and Caribbean			0.0269	(0.0268)		
Industrial classification—UN 1970						
Mining					0.592	(0.299)
Construction					−0.701	(0.406)
Services					0.055	(0.169)
Transport					−0.173	(0.314)
Other					−0.049	(0.102)
Manufacturing breakdown – UNIDO (ISIC rev2)						
Food, beverages, and tobacco (31)					−1.021	(0.354)
Textile, apparel, and leather (32)					−0.654	(0.569)
Wood, including furniture (33)					−3.437	(2.275)
Paper, printing, and publishing (34)					0.047	(0.890)
Chemical, petro, coal, rubber, and plastic (35)					−2.176	(0.798)
Nonmetallic mineral products, excluding petro and coal (36)					5.990	(2.069)
Basic metal industries (37)					−1.487	(1.122)
Other manufacturing (39)					0.759	(4.618)
Fabricated metal products (381)					−5.166	(1.945)
Machinery except electrical (382)					0.780	(1.660)
Electrical machinery, appliances (383)					1.160	(1.813)
Transport equipment (384)					0.830	(1.531)
Prof. and sci. equip., photo and optical (385)					−7.525	(4.290)
F-statistic on instrument	21.68		4.45		4.62	
Observations	673		673		455	
Countries	93		93		57	

Notes: Standard errors are clustered by country. Column 1 is identical to column 2 in Table 5. Regressions are on data at 5-year intervals from 1950 to 1995. Regressions include time dummies. The excluded region is sub-Saharan Africa. The excluded industry is agriculture.

to trade is between 0.5 and 0.75 compared to OLS estimates of 0.23 to 0.56. The point estimates are larger than OLS, though the differences are typically not statistically significant. An increase in the volume of trade of 10 percent will therefore raise per capita income by over 5 percent.

These point estimates are smaller than those found in Frankel and Romer (1999), but as discussed earlier, this paper is estimating the impact of trade on GDP in a log-log specification, while Frankel and Romer (1999) were estimating log GDP against the level of the trade share. In order to compare the two estimates, I use a transformation suggested by Donaldson (2015). Starting from estimation in differences:

$$\Delta \ln(GDP) = \beta \times \Delta \ln(trade) + \epsilon. \tag{17}$$

Plugging in trade as a function of trade share and solving for GDP:

$$\ln(trade) = \ln(tradeshare) + \ln(GDP), \tag{18}$$

$$\Delta \ln(GDP) = \frac{\beta}{(1-\beta)} \times \Delta \ln(tradeshare) + \epsilon. \tag{19}$$

Plugging in an approximation for the change in log trade share:

$$\Delta \ln(tradeshare) \approx \Delta tradeshare / tradeshare, \tag{20}$$

$$\Delta \ln(GDP) = \gamma \times \Delta tradeshare + \epsilon, \tag{21}$$

$$\gamma = \frac{\beta}{(1-\beta) \times tradeshare}. \tag{22}$$

Evaluating equation (22) allows me to transform the coefficients from the log-log specification in the paper to an approximation of Frankel and Romer (1999)-style coefficients. In order to do so, I will assume a trade share equal to the average trade share from the world development indicators over the sample period, approximately 55 percent. Coefficients from 0.5 to 0.75 in this paper can be transformed to an equivalent range of 1.8 to 5.5, overlapping Frankel and Romer's preferred estimate of approximately 2. Beyond the functional form, this paper is identified off very different variation from Frankel and Romer (1999). Their paper was focused on the level of trade, while the identification in this paper comes from changes in trade over time.

There may be some concern that the instrument in this paper is picking up significant other influences on output that are associated with the instrument and the estimates are therefore inflated. As discussed earlier, given the construction of the instrument, any omitted variables must be related to geography and have time-series variation that is in some way related to bilateral air and sea distances. Most potential omitted variables that fit this description can broadly be thought of as globalization.

In Feyrer (2009), I use a similar approach to this paper, but the identifying variation comes from the temporary closure of the Suez Canal between 1967 and 1975. This shock to distance is used to construct instruments for trade that are entirely based on geography and that vary over time. The elasticity of income to changes in trade are found to be approximately half those found in this paper with a range of roughly 0.16 to 0.25. This range corresponds to trade share coefficients of 0.35 to 0.61, well below those found in Frankel and Romer (1999).

Since it is entirely based on shipping distances, the identification in Feyrer (2009) eliminates most potential non-trade channels for geography to influence income. In particular, the channels of globalization that do not involve moving actual goods should not be influencing the Suez estimates. If the estimates from this paper can be taken as the overall influence of globalization on output, this suggests that a substantial portion can be attributed to the movement of goods, not people.

The estimates from both this paper and Feyrer (2009) are quite large compared to expectations from standard trade theory with as much as an order of magnitude difference.[34] There have been a number of recent papers on the gains implied by theoretical models of trade including Arkolakis, Costinot, and Rodríguez-Clare (2012), and Costinot and Rodríguez-Clare (2014). When evaluating the magnitude of gains from trade from theory, we need to remember that these models rest on a very restrictive set of assumptions and cut off many important channels through which trade might influence output such as industry efficiency and innovation. Goldberg and Pavcnik (2016) point to numerous studies showing that trade liberalization leads to higher industry-level productivity.

One potential source of upward bias in the results comes from the IV literature. This paper is estimating local average treatment effects and therefore the estimates may be inflated by countries that had the most to gain from increased trade. The results using additional controls provide some assurance that these impacts are not large. Controlling for countries that specialized in higher value manufactures does not change the results substantially. Nor does controlling for region. It is also the case that a wide variety of goods travel by air so the gains to individual countries are not obviously linked to any particular country characteristics. The similarity of the Suez results also argue against an inflated local average treatment effect. Variation in the Suez estimations is from a different source (the disruption of sea routes) and impacts a very different set of countries.

IX. Conclusion

Geography looms large in recent discussions of aggregate economic outcomes. Rodriguez and Rodrik (2001), Acemoglu, Johnson, and Robinson (2001), Rodrik, Subramanian, and Trebbi (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 results suggest that Frankel and Romer's (1999) 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

[34] Donaldson (2015) discusses this at length.

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. Considered together with the Suez closure results found in Feyrer (2009), these non-trade effects of integration represent at most about half the gains found here.

Appendix

Table A1—Top 50 Overall Importers to United States—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 and 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 and other office machines, computer accessories	8473	50%
5	Germany	30.2%	Medicaments, therapeutic, prophylactic use, in dosage	3004	90%
6	United Kingdom	52.0%	Turbojets, turbopropellers, and 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, and other gas turbines, pts.	8411	92%
10	Italy	39.7%	Articles of jewelry and 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 and 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 and 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, and zirconium ore and 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, and 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 and parts, of prec. metal or clad	7113	78%
35	Austria	32.1%	Glass beads, etc., and 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 and 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 and 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 A2—Gravity Model Estimation—The Changing Elasticity of Sea and Air Distance over Time

	ln(trade) (1)	ln(trade) (2)	ln(trade) (3)	ln(trade) (4)	ln(trade) (5)	ln(trade) (6)
ln(seadist) × $\mathbf{1}(1950 \leq \text{year} < 1955)$	−0.848 (0.130)	−0.885 (0.119)	−0.367 (0.102)	−0.429 (0.100)		
ln(seadist) × $\mathbf{1}(1955 \leq \text{year} < 1960)$	−0.858 (0.117)	−0.883 (0.108)	−0.321 (0.099)	−0.382 (0.096)	0.056 (0.052)	0.046 (0.047)
ln(seadist) × $\mathbf{1}(1960 \leq \text{year} < 1965)$	−0.8 (0.104)	−0.832 (0.094)	−0.194 (0.090)	−0.256 (0.084)	0.167 (0.075)	0.173 (0.070)
ln(seadist) × $\mathbf{1}(1965 \leq \text{year} < 1970)$	−0.616 (0.095)	−0.653 (0.086)	−0.09 (0.090)	−0.151 (0.084)	0.368 (0.089)	0.277 (0.087)
ln(seadist) × $\mathbf{1}(1970 \leq \text{year} < 1975)$	−0.496 (0.085)	−0.533 (0.078)	−0.117 (0.087)	−0.178 (0.081)	0.442 (0.099)	0.25 (0.094)
ln(seadist) × $\mathbf{1}(1975 \leq \text{year} < 1980)$	−0.437 (0.080)	−0.481 (0.074)	−0.152 (0.082)	−0.214 (0.078)	0.493 (0.101)	0.215 (0.097)
ln(seadist) × $\mathbf{1}(1980 \leq \text{year} < 1985)$	−0.29 (0.079)	−0.343 (0.075)	−0.159 (0.077)	−0.221 (0.073)	0.578 (0.106)	0.208 (0.097)
ln(seadist) × $\mathbf{1}(1985 \leq \text{year} < 1990)$	−0.065 (0.084)	−0.12 (0.080)	−0.024 (0.077)	−0.086 (0.074)	0.685 (0.112)	0.343 (0.109)
ln(seadist) × $\mathbf{1}(1990 \leq \text{year} < 1995)$	−0.268 (0.077)	−0.302 (0.071)	−0.018 (0.076)	−0.079 (0.073)	0.561 (0.112)	0.35 (0.109)
ln(seadist) × $\mathbf{1}(1995 \leq \text{year} < 1997)$	−0.263 (0.076)	−0.277 (0.070)	−0.086 (0.079)	−0.147 (0.075)	0.563 (0.114)	0.281 (0.109)
ln(airdist) × $\mathbf{1}(1950 \leq \text{year} < 1955)$	−0.071 (0.131)	0.102 (0.118)	−0.475 (0.101)	−0.302 (0.102)		
ln(airdist) × $\mathbf{1}(1955 \leq \text{year} < 1960)$	−0.132 (0.118)	0.031 (0.107)	−0.534 (0.098)	−0.36 (0.098)	−0.074 (0.054)	−0.059 (0.050)
ln(airdist) × $\mathbf{1}(1960 \leq \text{year} < 1965)$	−0.274 (0.107)	−0.111 (0.095)	−0.683 (0.091)	−0.51 (0.089)	−0.221 (0.075)	−0.208 (0.072)
ln(airdist) × $\mathbf{1}(1965 \leq \text{year} < 1970)$	−0.59 (0.098)	−0.426 (0.087)	−0.859 (0.093)	−0.686 (0.090)	−0.494 (0.090)	−0.384 (0.090)
ln(airdist) × $\mathbf{1}(1970 \leq \text{year} < 1975)$	−0.879 (0.088)	−0.718 (0.081)	−0.897 (0.090)	−0.724 (0.088)	−0.675 (0.100)	−0.422 (0.097)
ln(airdist) × $\mathbf{1}(1975 \leq \text{year} < 1980)$	−1.001 (0.083)	−0.829 (0.077)	−0.944 (0.084)	−0.771 (0.083)	−0.781 (0.102)	−0.469 (0.099)
ln(airdist) × $\mathbf{1}(1980 \leq \text{year} < 1985)$	−1.193 (0.082)	−1.021 (0.078)	−0.966 (0.080)	−0.792 (0.079)	−0.904 (0.107)	−0.49 (0.100)
ln(airdist) × $\mathbf{1}(1985 \leq \text{year} < 1990)$	−1.431 (0.089)	−1.256 (0.087)	−1.082 (0.079)	−0.908 (0.081)	−0.975 (0.114)	−0.607 (0.111)
ln(airdist) × $\mathbf{1}(1990 \leq \text{year} < 1995)$	−1.177 (0.082)	−1.014 (0.078)	−1.175 (0.079)	−1.001 (0.081)	−0.775 (0.113)	−0.699 (0.109)
ln(airdist) × $\mathbf{1}(1995 \leq \text{year} < 1997)$	−1.186 (0.079)	−1.039 (0.074)	−1.101 (0.081)	−0.927 (0.082)	−0.78 (0.114)	−0.626 (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^2	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

Notes: All regressions are on yearly data (1950–1997) and include a full set of time dummies. Standard errors are clustered at the country-pair level.

Table A3—Gravity Model Estimation—The Changing Elasticity of Great Circle Distance over Time

	ln(trade) (1)	ln(trade) (2)	ln(trade) (3)	ln(trade) (4)	ln(trade) (5)	ln(trade) (6)
ln(airdist) × $\mathbf{1}$(1950 ≤ year < 1955)	−0.857	−0.722	−0.819	−0.711		
	(0.045)	(0.047)	(0.046)	(0.048)		
ln(airdist) × $\mathbf{1}$(1955 ≤ year < 1960)	−0.929	−0.795	−0.835	−0.727	−0.024	−0.016
	(0.040)	(0.042)	(0.043)	(0.045)	(0.024)	(0.020)
ln(airdist) × $\mathbf{1}$(1960 ≤ year < 1965)	−1.032	−0.903	−0.867	−0.758	−0.076	−0.048
	(0.037)	(0.038)	(0.040)	(0.042)	(0.034)	(0.029)
ln(airdist) × $\mathbf{1}$(1965 ≤ year < 1970)	−1.177	−1.051	−0.947	−0.838	−0.160	−0.127
	(0.035)	(0.035)	(0.041)	(0.042)	(0.039)	(0.038)
ln(airdist) × $\mathbf{1}$(1970 ≤ year < 1975)	−1.353	−1.232	−1.009	−0.901	−0.271	−0.190
	(0.033)	(0.034)	(0.038)	(0.040)	(0.042)	(0.042)
ln(airdist) × $\mathbf{1}$(1975 ≤ year < 1980)	−1.42	−1.295	−1.089	−0.980	−0.329	−0.270
	(0.031)	(0.032)	(0.037)	(0.040)	(0.042)	(0.044)
ln(airdist) × $\mathbf{1}$(1980 ≤ year < 1985)	−1.472	−1.353	−1.117	−1.008	−0.370	−0.298
	(0.032)	(0.033)	(0.036)	(0.040)	(0.044)	(0.044)
ln(airdist) × $\mathbf{1}$(1985 ≤ year < 1990)	−1.494	−1.375	−1.108	−1.000	−0.339	−0.289
	(0.035)	(0.037)	(0.035)	(0.039)	(0.045)	(0.048)
ln(airdist) × $\mathbf{1}$(1990 ≤ year < 1995)	−1.434	−1.308	−1.195	−1.086	−0.258	−0.375
	(0.033)	(0.034)	(0.035)	(0.038)	(0.046)	(0.047)
ln(airdist) × $\mathbf{1}$(1995 ≤ year < 1997)	−1.437	−1.308	−1.184	−1.076	−0.262	−0.365
	(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^2	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

Notes: All regressions are on yearly data (1950–1997) and include a full set of time dummies. Standard errors are clustered at the country-pair level.

Table A4—Panel Estimates of Trade on Per Capita GDP—Balanced Panel

	ln(real GDP per capita)				
		IV—Gravity instruments			
		Country dummies		Pair dummies	
	OLS (1)	Trade weight (2)	Pop weight (3)	Trade weight (4)	Pop weight (5)
ln(trade)	0.398	0.427	0.615	0.417	0.699
	(0.038)	(0.076)	(0.100)	(0.092)	(0.124)
R^2	0.978				
		ln(trade)			
First stage					
ln(predicted trade)		2.055	2.049	1.696	2.304
		(0.418)	(0.474)	(0.365)	(0.531)
Instrument F-statistic		24.21	18.71	21.58	18.79
First-stage R^2		0.958	0.954	0.954	0.954
Instrument-partial R^2		0.216	0.146	0.145	0.132
		ln(real GDP per capita)			
Reduced form					
ln(predicted trade)		0.877	1.261	0.708	1.611
		(0.242)	(0.268)	(0.226)	(0.289)
Reduced-form R^2		0.958	0.961	0.956	0.962
Observations	560	560	560	560	560
Countries	62	62	62	62	62
Years	10	10	10	10	10

Notes: Standard errors are clustered by country. Regressions are on data at 5-year intervals from 1950 to 1995. Regressions include country and time dummies.

Table A5—IV Estimates of Trade on Per Capita GDP—Balanced Panel

	Δ ln(real GDP per capita)				
		IV—Gravity instruments			
		Country dummies		Pair dummies	
	OLS (1)	Trade weight (2)	Pop weight (3)	Trade weight (4)	Pop weight (5)
Δ ln(trade)	0.267	0.470	0.513	0.460	0.571
	(0.024)	(0.129)	(0.080)	(0.135)	(0.088)
R^2	0.305				
		Δ ln(trade)			
First stage					
Δ ln(predicted trade)		1.508	1.750	1.321	2.238
		(0.292)	(0.339)	(0.274)	(0.420)
Instrument F-statistic		26.73	26.72	23.18	28.46
First-stage R^2		0.466	0.460	0.457	0.463
Instrument-partial R^2		0.055	0.044	0.040	0.050
		Δ ln(real GDP per capita)			
Reduced form					
Δ ln(predicted trade)		0.708	0.898	0.608	1.278
		(0.183)	(0.168)	(0.176)	(0.193)
R^2		0.106	0.104	0.0933	0.120
Observations	498	498	498	498	498
Countries	61	61	61	61	61
Years	9	9	9	9	9

Notes: Standard errors are clustered by country. Regressions are on data at 5-year intervals from 1950 to 1995. Regressions include country and time dummies.

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