Lecture Note 13 – The Gains from International Trade: Empirical Evidence Using the Method of Instrumental Variables

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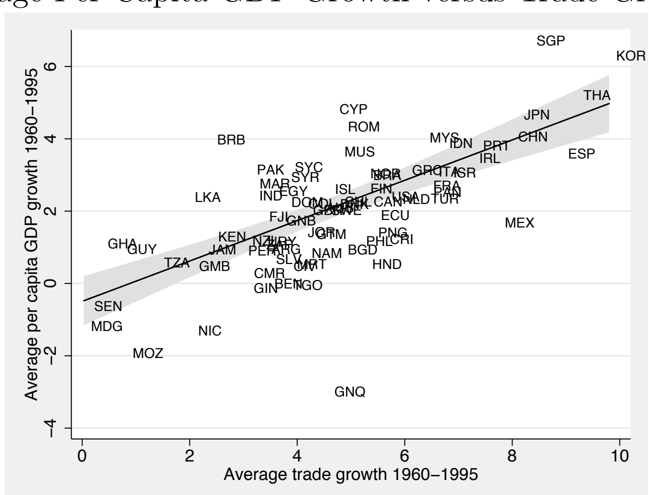
1 Introduction: Measuring the Causal Effect of Trade on GDP (James Feyrer, 2009)

Using data from the Penn World Tables, Figure 5 of James Feyrer's 2009 paper, "Trade and Income—Exploiting Time Series in Geography" shows that countries that experienced rising trade volumes between 1960 and 1995 also experienced rising GDP. Is this relationship causal, or does it simply stem from rich countries trading more? As 14.03/003 students understand, economic theory clearly predicts that trade increases national income, since it expands the set of goods and services a country can consume. (Note that "income" in this discussion refers to *real* income – the purchasing power of residents in a country – rather than *nominal* income in terms of local currency.) But this theoretical prediction is difficult to test because it's hard to conduct a credible experiment. We cannot readily manipulate the trade flows of various countries to study the impact this has on their national incomes.

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



Courtesy of James Feyrer. Used with permission.

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

Let's formalize this point. Applying our familiar causal framework, we would like to measure the causal effect of trade on country j as follows:

$$\gamma_j = Y_j^T - Y_j^A,$$

where γ_j is the causal effect of trade on Y in country j (γ stands for "gain from trade") while Y^T and Y^A signify counterfactual national income according to some income measure (e.g., income per capita) under Autarky and Trade, respectively. Note that the T and A superscripts here denote counterfactuals, so they serve the role of the *0* and *1* subscripts which we used in the first few lectures of class. The Fundamental Problem of Causal Inference says that we can never directly observe γ_j: we cannot observe income per capita for country j under both Autarky and free trade *simultaneously*.

To uncover the true γ_j, one standard solution would be to contrast incomes of trading and non-trading countries. We could form

$$\hat{\gamma} = E\left[Y^T|T=1\right] - E\left[Y^A|T=0\right],$$

where $T \in \{0,1\}$ denotes whether or not a country is open to free trade and hats denote that we are using our data to estimate expectations (taking sample means).

As you all learned when you studied for the first midterm, $\hat{\gamma}$ is an unbiased estimate of γ only if the following holds:

$$\begin{aligned} E\left[Y^T|T=1\right] &= E\left[Y^T|T=0\right], \\ E\left[Y^A|T=1\right] &= E\left[Y^A|T=0\right]. \end{aligned}$$

That is, the autarkic economies would have the same income per capita as the trading countries if they opened to trade, and vice-versa for the trading countries if they became autarkic. (As we discussed earlier in the semester, a good shorthand term for this assumption is *exchangeability*: if the experimenter had exchanged the treatment and control groups prior to performing the experiment, she would have have obtained the same causal effect estimate.)

Are these assumptions plausible? Would countries that trade a lot be similar to countries that trade very little, absent these differences in trading? Probably not. The extent to which a country trades is an endogenous outcome that is very likely correlated with other factors that directly affect income per capita. A few possible factors:

1. Countries that are rich for other reasons might trade more because they can afford to import more goods from overseas.

2. Countries that pursue sound economic policies (that raise income) may also choose to pursue trade (another sound economic policy).

3. Countries that are rich in natural resources may trade because there is high world demand for their goods, but these countries might have been rich due to their copious endowments even in the absence of any trade.

One should therefore be very skeptical of any "causal inference" that naively compares the incomes of trading and non-trading countries. In point of fact, countries that trade more *are* on average wealthier, but this correlation need not be causal.

2 Using the method of Instrumental Variables (IV) to measure causal effects

2.1 Looking for experiments in strange places

What we need is an "experiment" that exogenously raises or lowers trade in some group of countries. In past class examples, we've used both "natural" or "quasi-" experiments (e.g. the NJ minimum wage change, the rollout of cell phones in Kerala, India) and randomized experiments (e.g. the Jensen-Miller rice subsidy) to isolate exogenous variation in the treatment variable of interest.

In the case of free trade, such experiments are difficult to find. Even policy changes that open or close a country to trade (for example, war, natural disaster, revolutionary overthrow) are potentially suspect: they are quite likely to induce *other* economic and policy shocks *in addition to trade shocks* that also directly raise or lower real income. This means that even a difference-in-differences design – the "gold standard" from our first few lectures – fails to meet the "parallel trends" assumption that we discussed, and therefore fails to give us a reliable estimate of γ_j. (Refresher: Recall that a DD identifies the effect of a policy under the assumption that the treatment and control groups' outcomes would have evolved in parallel absent the policy change. If a war closes off trade but also destroys the national economy of country j, then we suspect that country j would have evolved very differently from it's neighbors even absent the closure of trade).

We need a new – and even cooler – technique to uncover causal effects in this setting. This subtle and powerful approach to identify causal effects is the method of *Instrumental Variables* (IV). IV is frequently referred to by the name of the statistical procedure conventionally used to implement it, *Two Stage Least Squares* (2SLS), and in this class we will use these two terms synonymously.

Here's the idea: we are interested in measuring the effect of trade on income. Since trade is endogenous, we are reluctant to draw any causal inferences from the observed correlation between trade and income. And we haven't yet found a difference-in-differences design that passes the smell test for parallel trends.

- Assume now that there is some third, exogenously assigned variable, $Z \in \{0, 1\}$ that affects the extent to which countries trade.
- Assume further that we have reason to believe that Z has no effect on national income, *except* potentially through its effect on trade.
- Under these assumptions, Z may serve as an "instrument" that exogenously manipu-

lates trade, allowing us to study trade's effect on income. Economists would say that Z is a valid *instrumental variable* for analyzing the causal effect of trade on income.

2.2 The Feyrer strategy

James Feyrer's 2009 paper, "Trade and Income: Exploiting Time Series in Geography," proposes an ingenious IV approach for analyzing the causal effect of trade on national per capita income. His insight is that, historically, most trade between non-contiguous countries occurred by sea. As the cost of air freight fell over the last four decades, a substantially larger share of trade was transported by airplane rather than ship. The impact of this cost reduction was not uniform across different pairs of trading partners. For country pairs connected by a direct sea route (e.g., Spain and Brazil), the declining cost of air freight is not particularly important: it reduces transport time but not necessarily transport cost. For country pairs that are connected by a highly indirect sea route however (e.g., Japan and the Western Europe), the reduction in the cost of air freight means that traded goods will potentially have to travel a much shorter distance by air than sea. This makes trade much cheaper for these country pairs.

This insight underlies Feyrer's empirical approach: As air freight gets cheaper, countries that have a high value of their "Air-Sea Distance Difference" ($ASDD$)—that is, the air distance to their trading partners relative to their sea distance to their trading partners—will experience a large increase in trade volumes. By contrast, trade flows among countries that have small or zero $ASDDs$ will not be greatly affected.

Here's how $ASDD$ is defined. Let D^S_{jk} be the sea distance between countries j and k and D^A_{jk} be the air distance. Let $ASDD_{jk} = D^S_{jk} - D^A_{jk}$. If country j and k have nothing between them but water, then their sea and air distances will be the same, meaning that $ASDD_{jk} = 0$. If they are separated by land masses that a cargo ship must circumnavigate, then $ASDD_{jk} > 0$.

Now, define the average $ASDD$ for each country j as the trade-volume weighted $ASDD_{jk}$ for all of its trading partners k. Specifically,

$$\overline{ASDD}_j = \frac{\sum\limits_k \left(D^S_{jk} - D^A_{jk}\right) \times T_{jk}}{\sum\limits_k T_{jk}},$$

where T_{jk} is the trade volume between j and k (in dollars, for example) in 1960. Note that $\frac{T_{jk}}{\sum_k T_{jk}}$ captures the historical importance of country k relative to other countries in country j's historical trading patterns. So $\overline{ASDD}_j$ measures the overall change in trading costs for country j thanks to the advent of the airplane, assuming country j followed it's historical trading patterns.

If Feyrer's hypothesis is correct, then trade flows will rise differentially between countries with relatively high $ASDD_{jk}$ as air freight gets cheaper. Moreover, if $ASDD_{jk}$ *exclusively* affects a country's economy via its effect on trade, then cross-country variation in $\overline{ASDD}_j$ provides a kind of natural experiment for studying the causal effect of trade on income: as the cost of air freight falls, countries with high $\overline{ASDD}_j$ should begin to trade more than countries with low $\overline{ASDD}_j$, which will in turn allow us to study the effect of trade on national incomes.

You may object: $ASDD$ is not the *only* determinant of changing trading patterns. For example, the U.S. began trading extensively with China in the 1990s but was trading extensively with Japan decades earlier. Clearly, the $ASDD$ gap between the US-China and US-Japan $ASDD$ is trivial, so the falling cost of air freight cannot be the cause of rising China trade. That's correct! But that's not a problem for the IV approach. $ASDD$ need not be the *only* determinant of trade. What we need is:

1. $ASDD$ has a measurable, direct causal effect on trade. This is called the *first stage*. This is directly testable.

2. $ASDD$ does not plausibly affect national income through any other channel but trade. Restated, trade is the exclusive channel by which $ASDD$ affects national incomes (if at all). This is called the *exclusion restriction.* The exclusion restriction is not directly testable. Thus it deserves extra scrutiny whenever we are designing or evaluating an IV strategy.

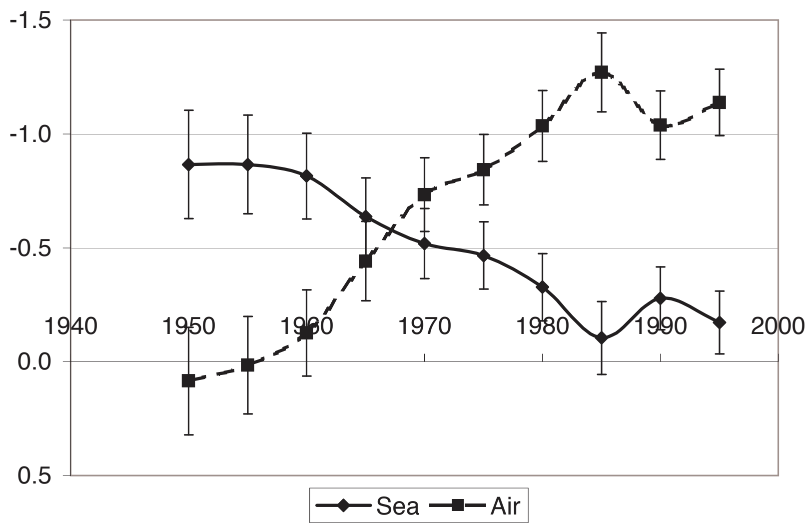
2.3 Setting the stage for IV

Figure 1 of Feyrer (2009) shows that air freight came to encompass a substantial share of U.S. trade between 1965 and 2005, while Figure 3 documents that countries' trading volumes became substantially more sensitive to air distance between 1960 and 1995 and, simultaneously, substantially *less* sensitive to sea distance.

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

Courtesy of James Feyrer. Used with permission.

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



Courtesy of James Feyrer. Used with permission.

How can we use this information about the changing relationship between $ASDD$ and trade volumes to find the causal effect of trade on income? That's where the subtlety comes in. The validity of our approach will rest on three pillars, which we will discuss in turn:

1. Balance of treatment and control groups: Observations with different values for the instrumental variable have similar counterfactual outcomes..

2. First stage relationship: There is a causal effect of the instrumental variable on the endogenous variable

3. Exclusion restriction: It is plausible that the instrumental variable affects the outcome variable *only* through its effect on the endogenous variable

Now, imagine that we have a set of potentially comparable countries that differ according to whether they have High $ASSD$ ($A = 1$) or Low $ASDD$ ($A = 0$). (Note that A take the place of Z on pages 4-5.) In our example: a) the endogenous variable of interest is a country's trading volume; b) the instrumental variable is the country's $ASDD$; and c) the outcome variable is the country's GDP.

2.3.1 Condition 1: Balance of treatment and control groups

As with our previous techniques for causal inference, our treatment and control groups be comparable—that is, they must have have balanced counterfactual outcomes.

- Let Y_{jt} equal the GDP of country j in time t.
- Imagine that there are two time periods, $t = \{0, 1\}$, and that in the early period ($t = 0$), traded goods travel exclusively by sea, whereas in the latter ($t = 1$), traded goods can travel by air or by sea.
- Let ΔY_j equal the change in GDP in country j between $t = 0$ and $t = 1$. Note that this paper focuses on how changes in trade affect changes in income, rather than how levels of trade affect levels of income. Theoretically, both designs could uncover the effect of trade on income.
- For each country, imagine two potential outcomes

$$\Delta Y_j \in \left\{ \Delta Y_j^1, \Delta Y_j^0 \right\},$$

  where ΔY_j^1 is the change in GDP in j if $A = 1$ and ΔY_j^0 is the change in GDP in j if $A = 0$.
- Of course, each country j is either one type or the other ($ASDD$ is either High or Low, $A = 1$ or $A = 0$). So, we will never observe both ΔY_j^1 and ΔY_j^0 (i.e., the fundamental problem of causal inference, FPCI). Thus ΔY_j^1 and ΔY_j^0 are counterfactuals of one another.
- Assuming balance of the treatment and control groups means that we believe in ex-

changeability:

$$
\begin{aligned}
E\left[\Delta Y_j^1 | A=1\right] &= E\left[\Delta Y_j^1 | A=0\right] \\
E\left[\Delta Y_j^0 | A=1\right] &= E\left[\Delta Y_j^0 | A=0\right].
\end{aligned}
$$

If the countries with high $ASDD$ were somehow assigned low $ASDD$, their GDP growth would be the same as the the countries that actually have low $ASDD$, and vice versa if the low $ASDD$ countries were somehow assigned to have high $ASDD$. We can't completely prove exchangeability by looking at data, but by comparing observable characteristics of countries with $A = 0$ and countries with $A = 1$ we can make a plausible case that exchangeability is reasonable.

2.3.2 Condition 2: There is a causal effect of the instrumental variable on the endogenous variable

For our proposed Instrumental Variables approach to be valid, it must be the case that $ASDD$ has a causal effect on the amount that countries trade. This is called the "first stage" relationship by econometricians. The existence of a first stage relationship is verifiable as a statistical matter. (Though as always, correlation does not imply causality. More on this below.)

- Write T_{jt} as the trade volume (in dollar terms, for example) of country j in year t.
- Again, imagine two counterfactual states for each country j, one in which it has Low $ASDD$ ($A = 0$) and the other if it has High $ASDD$ ($A = 1$).
- We know that between 1965 and 1995, air transport got considerably less expensive overall and simultaneously the air volume of U.S. trade increased considerably (Figure 1).
- Define the counterfactual change in trade volume between 1965 and 2005 in each country under $ASDD \in \{0, 1\}$ as

$$\Delta T_j \in \left\{\Delta T_j^1, \Delta T_j^0\right\}$$

- We require the following:

$$\Delta T_j^1 \geq \Delta T_j^0 \ \forall\ j,$$

In words, country $j's$ trade volume must increase by more between time 0 and 1 if $ASDD$ is High than if $ASDD$ is low.

- Due to FPCI, this assumption is also not testable. We only see countries in one state—$ASDD$ is High or Low—or another.

- However, we can test one *necessary but not sufficient* condition for the validity of this relationship, which is:

$$E\left[\Delta T_j | A = 1\right] > E\left[\Delta T_j | A = 0\right].$$

  That is, the average growth in trade in the $A = 1$ countries must be greater than in the $A = 0$ countries.

- We can check this empirically by verifying that:

$$\frac{1}{n_{A=1}} \times \sum_{j,A=1} \Delta T_j > \frac{1}{n_{A=0}} \times \sum_{j,A=0} \Delta T_j,$$

  where $n_{A=1}$ is the number of countries with $A = 1$ and similarly for $n_{A=0}$

- Figure 6 of Feyrer suggests that this relationship holds in the data.

2.3.3 Condition 3: Exclusion restriction

- A valid instrumental variable must also satisfy an "Exclusion Restriction." The exclusion restriction says that the instrumental variable (here $ASDD$) must *only* affect the outcome variable of interest (here GDP) *indirectly* through its effect on the intermediating endogenous variable of interest (here, Trade).

- If we do *not* find it plausible that $ASDD$ *only* affects national income through its impact on trade, we cannot rely on any measured relationship between distance and income to help us uncover the causal effect of trade on income.

- Conversely, if we find it plausible that $ASDD$ *only* affects national income through its impact on trade, we *can* interpret the measured relationship between distance and income as reflecting (though not identical to) the causal effect of trade on income.

- The exclusion restriction can be expressed formally as follows:

$$E\left[\Delta Y_j | \Delta T_j = k, A = 1\right] = E\left[\Delta Y_j | \Delta T_j = k, A = 0\right],$$

  where k is some constant.

- This equation says that if were were to hold trade in country j constant at a given level k, $ASDD$ would have no effect on GDP—since its entire effect operates through influencing trade. Holding country $j's$ trade constant at level k, GDP of j is independent of $ASDD$.

- The exclusion restriction must be plausible or the IV strategy is a non-starter. However, this postulate is not *testable*. We cannot directly manipulate $ASDD$ for a given country. Moreover, if we could, this manipulation would also affect T_j (under our hypothesis above). Thus, we cannot verify that $ASDD$ only affects a country's GDP through its effect on trade.

- If we believe that $ASDD$ affects GDP through some other mechanism (e.g., $ASDD$ increases a country's air traffic, and the smell of burning jet fuel makes citizens happier and more productive, raising GDP), then using $ASDD$ as an instrumental variable for trade will not allow us to isolate the causal effect of trade on GDP.

2.3.4 The smell test for our conditions

If we tentatively accept the conditions above, the empirical analysis proceeds as follows:

1. We check that trade grows by more in $ASDD = 1$ than $ASDD = 0$ countries between times $t = 0$ and $t = 1$:

$$\hat{E}\left[\Delta T_j | A = 1\right] > \hat{E}\left[\Delta T_j | A = 0\right]$$

or, the same expression written differently:

$$\frac{1}{n_{A=1}} \times \sum_{j,A=1} \Delta T_j > \frac{1}{n_{A=0}} \times \sum_{j,A=0} \Delta T_j$$

If this inequality is satisfied, then A is a candidate instrument for T. If this inequality is not satisfied, then our assumption that $[\Delta T_j | A = 1] > [\Delta T_j | A = 0] \ \ \forall \ j$ is false. Verifying the inequality above does not prove that the assumption is true. But rejecting it would demonstrate that the assumption is false, and therefore we will not want to use our proposed IV strategy.

2. If we pass this test, we can next test whether GDP rises by more over time (between time $t = 0$ and $t = 1$) in $ASDD = 1$ versus $ASDD = 0$ countries. The hypothesis that trade raises income implies that

$$E\left[\Delta Y_j | A = 1\right] > E\left[\Delta Y_j | A = 0\right].$$

If trade raises GDP, then the fact that trade rises by more in $A = 1$ than $A = 0$ countries implies that GDP also rises by more in $A = 1$ than $A = 0$ countries.

If both of these relationships are verified in the data, we may be correct to conclude that trade has a positive causal effect on national income. But we would not *yet* have an estimate of the size of this effect. Instead, we would have an estimate of the causal effect of $ASDD$ on trade, and another estimate of the causal effect of $ASDD$ on income. That's close, but not quite what we're after. We need to take one more step.

2.4 Estimating the causal relationship using the method of Instrumental Variables

2.4.1 The parameters we can grab from the data

- Our goal is to estimate the causal effect of trade volumes on GDP. Let's write this as:

$$E[\Delta Y|\Delta T] = \alpha + \gamma \Delta T, \tag{1}$$

  where γ denotes the causal effect of trade on GDP. This is the parameter we'd like to estimate.

- We found that $ASDD$ is correlated with the change between 1960 and 1995 in the extent that a country trades, and given our balance assumptions above, we view this correlation as causal:

$$\pi_1 = E[\Delta T|A = 1] - E[\Delta T|A = 0] > 0$$

- We compare the change in the incomes of $ASDD$ High and Low countries.

$$\pi_2 = E[\Delta Y|A = 1] - E[\Delta Y|A = 0].$$

  Here, π_2 is the causal effect of $ASDD$ (not trade) on GDP.

- That's a start, but we have not yet estimated γ, *the causal effect of trade on GDP*. If we had exogenous (as good as randomly assigned) variation in the change in trade that countries experienced, we could simply estimate equation (1) above, and $\hat{\gamma}$ would be our causal effect estimate.

- We cannot do that because the variation in trade that we observe is endogenous. Naively regressing ΔGDP on ΔT will tell us about the correlation between trade and GDP, but it will not provide an unbiased estimate of γ.

- It turns out that we *can* infer this causal relationship using the observed *causal* relationships between (1) $ASDD$ and ΔT, and (2) $ASDD$ and ΔY.

2.4.2 Using those parameters to construct a causal estimate

Putting the pieces together:

- Causal effect of $ASDD$ on Trade:

$$\begin{aligned} E\left[\Delta T|A=1\right] &= \alpha_1+\pi_1 \\ E\left[\Delta T|A=0\right] &= \alpha_1 \\ E\left[\Delta T|A=1\right]-E\left[\Delta T|A=0\right] &= \pi_1 \end{aligned} \tag{2}$$

- Causal effect of $ASDD$ on GDP growth:

$$\begin{aligned} E\left[\Delta Y|A=1\right] &= \alpha_2+\pi_2 \\ E\left[\Delta Y|A=0\right] &= \alpha_2 \\ E\left[\Delta Y|A=1\right]-E\left[\Delta Y|A=0\right] &= \pi_2 \end{aligned} \tag{3}$$

- Substituting (2) and (3) into (1) gives us the expression for the causal effect of $ASDD$ on GDP growth:

$$\begin{aligned} E\left[\Delta Y|A=1\right]-E\left[\Delta Y|A=0\right] &= \pi_2 \\ &= \gamma\left(E\left[\Delta T|A=1\right]-E\left[\Delta T|A=0\right]\right) \\ &= \gamma\times\pi_1 \end{aligned}$$

  By implication

$$\pi_2=\gamma\times\pi_1.$$

- Thus, our estimate of π_2 is closely related to the causal effect of trade on GDP (γ) in equation (1) above. They only differ by a scalar: $\pi_2=\gamma\times\pi_1$.

- Combining our two causal effects , π_1 and π_2, we can estimate the causal effect of trade on income:

$$\frac{E\left[\Delta Y|A=1\right]-E\left[\Delta Y|A=0\right]}{E\left[\Delta T|A=1\right]-E\left[\Delta T|A=0\right]}=\frac{\pi_2}{\pi_1}=\frac{\pi_1\times\gamma}{\pi_1}=\gamma$$

- We thus estimate the causal effect of trade on income by taking the ratio of the two causal effects: the causal effect of $ASDD$ on GDP growth ($\hat{\pi}_2$) and the causal effect of

$ASDD$ on trade growth $(\hat{\pi}_1)$. This ratio gives us $\hat{\gamma}$, our Instrumental Variables (IV) estimate of the causal effect of trade on GDP.

- Intuitively, we are comparing incomes among potentially similar countries that have different $ASDD'$s. This comparison gives us the causal effect of $ASDD$ on income growth ($\hat{\pi}_2 = \gamma \times \pi_1$). We convert this relationship into an estimate of the causal effect of trade on income by re-scaling the GDP growth difference between high and low $ASDD$ countries by the causal effect of $ASDD$ on trade growth.

- [A bit of history: The IV method was developed in 1928 by the economist, P.G. Wright, who wanted to measure the causal effect of supply changes on the price of flaxseed. He used weather shocks as an exogenous source of variation in supply of flaxseed. Instrumental Variables has become central to causal empirical analysis in economics within the last two decades.]

3 Findings

The main figures in the Feyrer paper tell the story. You should understand how each of these figures contribute to the empirical case. See figures *in the following order*:

1. Figure 1: Air freight shares to the U.S.

2. Figure 3: Change in elasticity of trade with respect to Sea and Air distance over time

3. Figure 2: Air imports to the US versus 1960 GDP per capita

4. Figure 6 panel B (right-hand side): Air and Sea Distance Differential ($ASDD$) versus Average Trade Growth 1960-1995

5. Figure 7 panel B (right-hand side): $ASDD$ and per capita GDP growth, 1960-1995

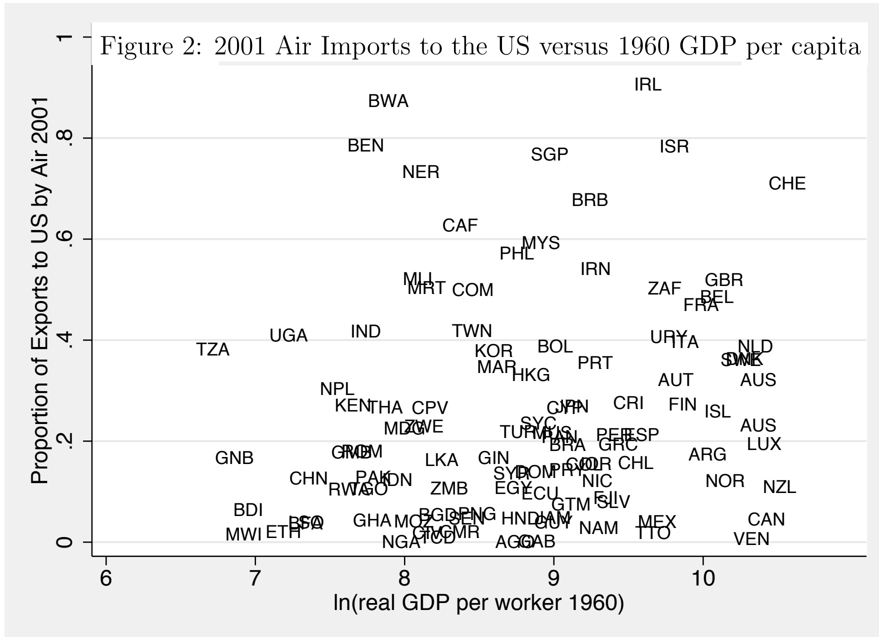


Figure 2: 2001 Air Imports to the US versus 1960 GDP per capita

Courtesy of James Feyrer. Used with permission.

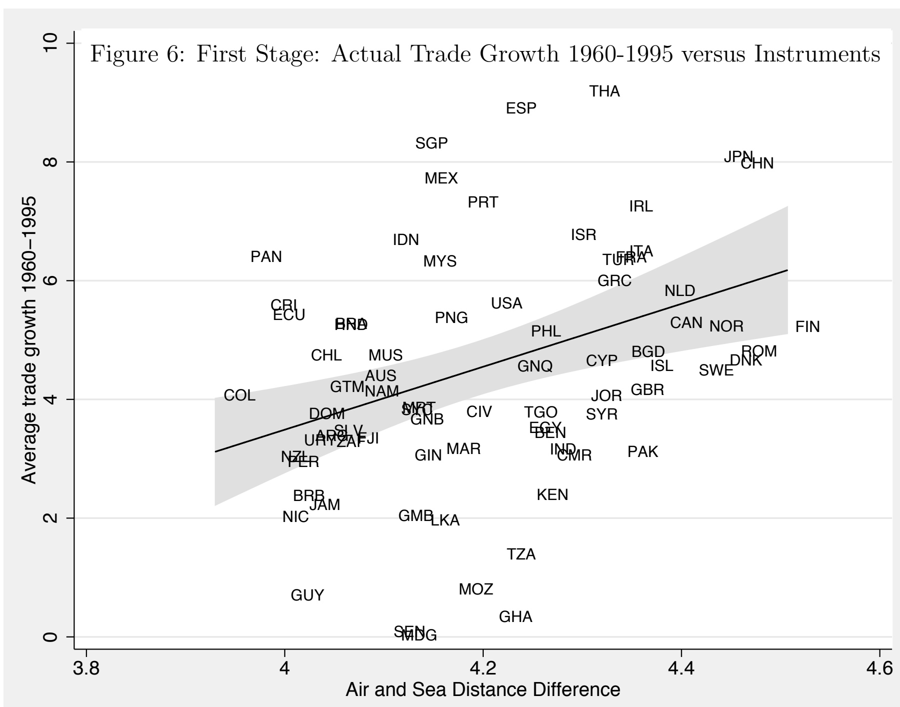


Figure 6: First Stage: Actual Trade Growth 1960-1995 versus Instruments

Courtesy of James Feyrer. Used with permission.

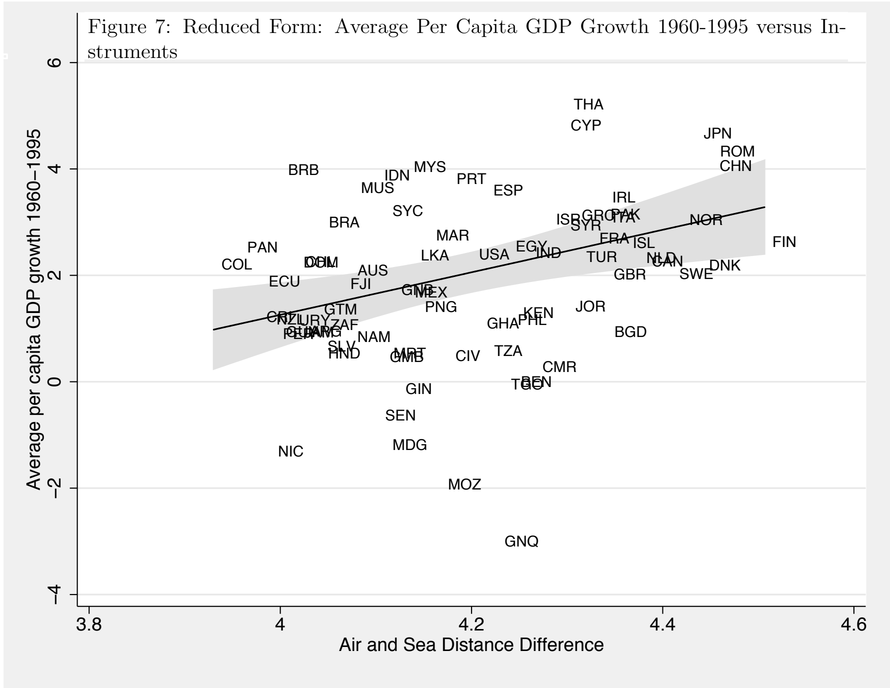


Figure 7: Reduced Form: Average Per Capita GDP Growth 1960-1995 versus Instruments

Courtesy of James Feyrer. Used with permission.

Jim Feyrer was kind enough to make a special table *exclusively for 14.03/14.003* that shows the key results in a format that complements the analytic tools presented above.

The Effect of Trade Growth on Per Capita GDP Growth, 1960 - 1995

	OLS (1)	First Stage (2)	Reduced Form (3)	Instrumental Variables (4)
Dependent Variable	**GDP Growth**	**Trade Growth**	**GDP Growth**	**GDP Growth**
Trade Growth	0.55 [0.070]**			0.75 [0.16]**
Air Sea Distance Difference		5.30 [1.35]**	4.00 [1.04]**	
Constant	-0.50 [0.35]	-17.71 [5.65]**	-14.72 [4.37]**	-1.37 [0.74]~
Observations	76	76	76	76
R-squared	0.464	0.142	0.12	0.407

Robust standard errors in brackets
+ significant at 10%; * significant at 5%; ** significant at 1%

Courtesy of James Feyrer. Used with permission.

- The first column shows the Ordinary Least Squares (OLS) relationship between the change in GDP and the change in trade at the country level during 1960 - 1995 for 76 countries:

$$\text{Column (1)}:\ \Delta \ln GDP_{j,60-95} = \alpha + \beta_1 \Delta \ln Trade_{j,60-95} + e_j.$$

The point estimate of 0.55 implies that a 1% rise in trade is *associated with* a 0.55% rise in GDP (an elasticity of 0.55). You should not view this relationship as causal.

- The second and third column show the relationship between $ASDD$ and trade growth (column 2) and GDP growth (column 3).

$$\text{Column (2)}:\ \Delta \ln Trade_{j,60-95} = \alpha' + \pi_1 ASDD_j + e'_j,$$

where Feyrer estimates that $\hat{\pi}_1 = 5.30$

- And

$$\text{Column (3)}:\ \Delta \ln GDP_{j,60-95} = \alpha'' + \pi_2 ASDD_j + e''_j,$$

where $\hat{\pi}_2 = 4.00$.

- Recall that $\hat{\pi}_2 = \gamma \times \pi_1$. Hence, we can calculate the causal effect of trade on GDP as:

$$\hat{\gamma} = \frac{\pi_1 \times \gamma}{\pi_1} = \frac{\hat{\pi}_2}{\hat{\pi}_1} = \frac{4.00}{5.30} = 0.75$$

- This is exactly what Feyrer obtains in Column 4:

$$\text{Column (4)}:\ \Delta \ln GDP_{j,60-95} = \alpha''' + \gamma \Delta T^*_j + e'''_j,$$

where $\hat{\gamma} = 0.75$. I've denoted the change in trade in this equation with an asterisk (ΔT^*_j) because this is *not* the endogenous trade variable available in the data. Rather, it is the exogenous component due to $ASDD$, which is found in column 2 of the Feyrer table.

- Thus, our causal estimate of the effect of trade on GDP is that a one percent rise in trade raises GDP per capita by three-quarters of a percentage point.

- We'll talk further about this evidence (both its strengths and limitations) in class.