14.581 MIT PhD International Trade
—Lecture 4: The Ricardian Model (Empirics)—

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Plan of Today's Lecture

1. Introduction to tests of the Ricardian model
2. Empirical work on 'non-theoretical' (multi-country, multi-sector) Ricardian models
   2.1 Early work: MacDougall (1951), Stern (1962), Balassa (1963)
   2.2 Golub and Hsieh (RIE 2000)
   2.3 Nunn (QJE 2007)
3. Empirical work on more theoretically-grounded (multi-country, multi-sector) Ricardian models:
   3.1 Eaton and Kortum (Ecta, 2002)
   3.2 Costinot, Donaldson and Komunjer (2010)
4. Conclusion

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Introduction to tests of the Ricardian model

- Given that Ricardo's model of trade is the first and simplest model of international trade it's surprising to learn that very little empirical work has been done on testing the insights of the Ricardian model.

- As Deardorff (1984 Handbook survey) points out, this is actually doubly puzzling:
  - As he puts it, a major challenge in empirical trade is to go from the Deardorff (1980) correlation ($p^A . T \leq 0$) based on unobservable autarky prices p^A to some relationship based on observables.
  - So the name of the game is modeling p^A as a function of primitives (technology and tastes).
  - Doing so is trivial in a Ricardian model: relative prices are equal to relative productivities (which are in principle observable), both in autarky and when trading.

What has inhibited empirical work on the Ricardian model?

A host of reasons, Part I

- Complete specialization: If the model is right then there are some goods that a trading country doesn't make at all.
  - Problem 1: this doesn't appear to be true in the data, at least at the level for which we usually have output or price data. (Though some frontier data sources offer exceptions.)
  - Problem 2: if you did find a good that a country didn't produce (as the theory predicts you should), you then have a 'latent variable' problem: if a good isn't produced then you can't know what that good's relative labor cost of production is.
- A fear that relative labor costs, as recorded in international data, are not really comparable across countries.
  - See Bernard and Jones (AER 1996) and later comment/reply.
- A fear that relative labor costs are endogenous (to trade flows).

What has inhibited empirical work on the Ricardian model?

A host of reasons, Part II

- Leamer and Levinsohn (1995 Handbook survey): "the one-factor model is a very poor setting in which to study the impacts of technologies on trade flows, because the one-factor model is jut too simple."
    - Put another way, we know that labor's share is not always and everywhere one, so why would you ignore the other factors of production? (Though as we shall see next week, for an interesting two-factor model to drive the pattern of trade we need sectors to utilize more than one factor, *and* for these sectors to *differ* in their factor intensities.)
    - One possible retort: perhaps the other factors of production are very tradable and labor is not.
- A sense that the Ricardian model is incomplete because it doesn't say where relative labor costs come from.

What has inhibited empirical work on the Ricardian model?

A host of reasons, Part III

- Probably the fundamental inhibition: Hard to know what is the right test or specification to estimate without being "ad-hoc":
  - As discussed last lecture, generalizing the theoretical insights of a 2-country Ricardian model to a realistic multi-country world is hard (and has only been done to limited success).
  - As we will see shortly, many researchers have run regressions that take the intuition of a 2-country Ricardian model and translate this into a multi-country regression.
  - But because these regressions didn't follow directly from any general Ricardian model they couldn't be considered as a true test of the Ricardian model.

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Early Tests of the Ricardian Model

- MacDougall (EJ, 1951) made use of newly available comparative productivity measures (for the UK and the USA in 1937) to 'test' the intuitive prediction of Ricardian (aka: "comparative costs") theory:
  - If there are 2 countries in the world (eg UK an USA) then each country will "export those goods for which the ratio of its output per worker to that of the other country exceeds the ratio of its money wage rate to that of the other country."
- This statement is not necessarily true in a Ricardian model with more than 2 countries (and even in 1937, 95% of US exports went to places other than the UK). But that didn't deter early testers of the Ricardian model.
- MacDougall (1951) plots relative labor productivities (US:UK) against relative exports to the entire world (US:UK).
  - 2×2 Ricardian intuition suggests (if we're prepared to be very charitable) that this should be upward-sloping.
  - But note that even this simple intuition says nothing about *how much* a country will export.

MacDougall (1951) Results

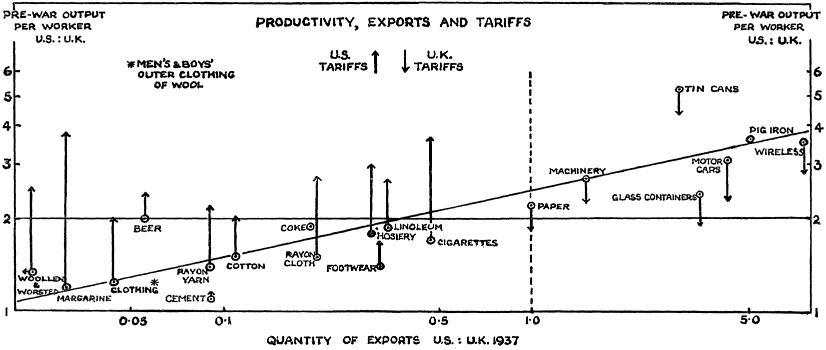

FIG. 1.

This plot was then replicated many times....

Stern (1962): 1950 data

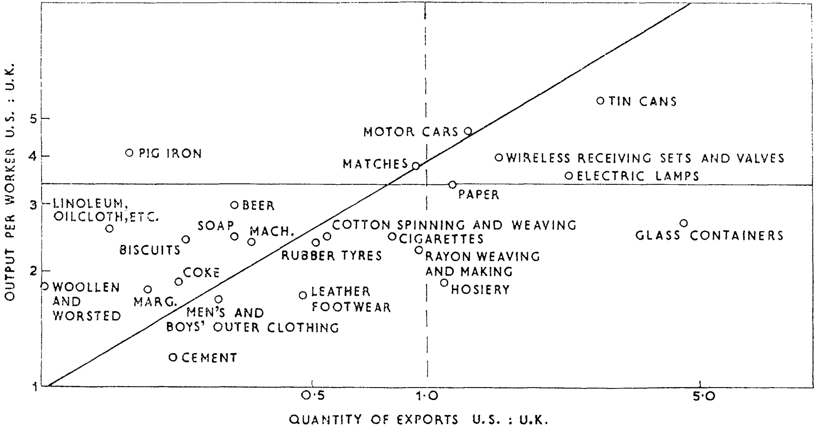

Fig. 1. Scatter diagram of American and British ratios of output per worker and quantity of exports, 1950.

This plot was then replicated many times....

MacDougall et al (EJ, 1962): 1950 data

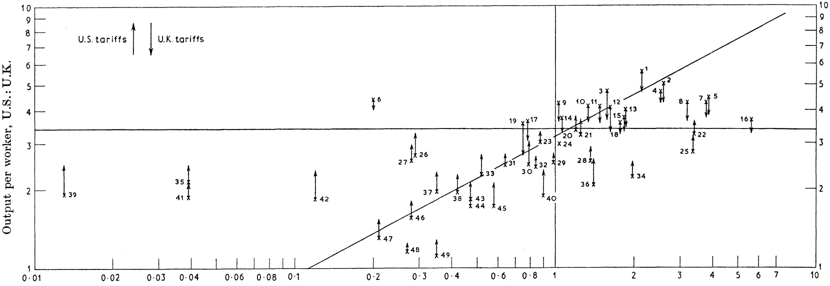

FIG. 1. Quantity of exports, U.S.: U.K. Productivity, exports, and tariffs, 1950.

For key to numbers,
see Table I.

This plot was then replicated many times....

Balassa (ReStat, 1963): 1950 data

CHART 2. — U.S./U.K. EXPORT AND PRODUCTIVITY RATIOS 1950 AND 1951 (LOGARITHMIC SCALE)

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Golub and Hsieh (RIE, 2000) I

- An update of MacDougall (1951)—or Stern (1962) or Balassa (1963)—to modern data.
- To fix ideas, suppose we are interested in testing the Ricardian model by comparing the US to the UK, as MacDougall did. (GH also compare the US to 6 other big OECD countries.)
- Suppose also (for now) that we only have one year of data (as MacDougall did).
- GH run regressions of the following form across industries k:

$$\begin{aligned}
\log\left(\frac{X_{US}^k}{X_{UK}^k}\right) &= \alpha_1 + \beta_1 \log(a_{US}^k / a_{UK}^k) + \varepsilon_1^k, \\
\log\left(\frac{X_{US \to UK}^k}{M_{US \leftarrow UK}^k}\right) &= \alpha_2 + \beta_2 \log(a_{US}^k / a_{UK}^k) + \varepsilon_2^k.
\end{aligned}$$

Golub and Hsieh (RIE, 2000) II

- GH run regressions of the following form across industries k:

$$\begin{aligned}
\log\left(\frac{X_{US}^{k}}{X_{UK}^{k}}\right) &= \alpha_1 + \beta_1 \log(a_{US}^{k}/a_{UK}^{k}) + \varepsilon_1^{k}, \\
\log\left(\frac{X_{US\to UK}^{k}}{M_{US\leftarrow UK}^{k}}\right) &= \alpha_2 + \beta_2 \log(a_{US}^{k}/a_{UK}^{k}) + \varepsilon_2^{k}.
\end{aligned}$$

- Here X_{US}^{k} is the US's total exports of good k, whereas $X_{US\to UK}^{k}$ is US exports to the UK in good k (and US imports from UK are $M_{US\leftarrow UK}^{k}$).
- The coefficient of interest is β.
  - The intuition of the Ricardian model suggests that $\beta_1 > 0$ and $\beta_2 > 0$.
  - But there is no explicit multi-country Ricardian model that would generate this estimating equation. So it is hard to know how to interpret this test.

Golub and Hsieh (RIE, 2000)—Comments

1. They also have a time series of this data for many years (from 1972-91):
   - So they run this regression separately for each year, restricting the coefficients α and β to be the same across each year's regression.
   - They also apply a SUR technique to improve efficiency.
2. Measuring a_{US}^k and a_{UK}^k is harder than it sounds:
   - One is in Dollars per hour and the other is in Sterling per hour.
   - Market exchange rates are likely to be misleading (failure of PPP in short-run).
   - So 'PPP exchange rates' are used instead. This is where international agencies collect price data for supposedly identical products (eg Big Macs) across countries and use these price observations to try to get things in real units (eg Big Macs per hour).
   - GH use three different PPP measures: 'Unadjusted' (same PPP in each sector) is surely wrong. 'ICP' (the Penn World Tables's PPP) is better, but has problem that these are *expenditure* PPPs. 'ICOP PPP' is probably best.

Golub and Hsieh (2000) Results: Regression 1

Table 2. Relative Exports[a] and Relative Productivity[b], for 39 Manufacturing Sectors

		Unadjusted		ICP PPP		ICOP PPP	
	Period	β_{jk}	R^2	β_{jk}	R^2	β_{jk}	R^2
US–Japan	84–90	0.33	0.22	0.31	0.20	0.30	0.18
		(3.03)[c]		(2.96)[c]		(2.80)[c]	
US–Germany	77–91	0.18	0.08	0.15	0.07	0.15	0.05
		(4.28)[c]		(3.55)[c]		(3.80)[c]	
US–UK	79–91	0.09	0.03	0.07	0.02	0.23	0.12
		(2.78)[c]		(2.45)[c]		(4.48)[c]	
US–France	78–91	–0.19	0.03	–0.24	0.06	0.09	0.03
		(–3.50)[d]		(–3.92)[d]		(1.96)[c]	
US–Italy	78–91	0.36	0.09	0.37	0.13	—	—
		(5.48)[c]		(6.25)[c]			
US–Canada	72–90	0.21	0.01	0.27	0.04	—	—
		(5.29)[c]		(6.26)[c]			
US–Australia	81–91	0.16	0.04	0.31	0.10	—	—
		(2.27)[c]		(3.52)[c]			

Note: $\log(X_{ij}/X_{ik}) = \alpha_{jk_1} + \beta_{jk_1}\log(a_{ik}/a_{ij})_{-1} + \varepsilon_{ijk_1}$ estimated by seemingly unrelated regressions. *t*-statistics in parentheses, calculated from heteroskedasticity-consistent (White) standard errors.

[a] Log of US divided by other country exports.

[b] Log of US relative to other productivity.

[c] The coefficient is significant at 1% level with the correct sign.

[d] The coefficient is significant at 1% level with incorrect sign.

Golub and Hsieh (2000) Results: Regression 2

Table 4. Bilateral Trade Balances[a] *and Relative Productivity*[b]*, for 21 Manufacturing Sectors*

	Period	Unadjusted		ICP PPP		ICOP PPP	
		b_{jk}	R^2	b_{jk}	R^2	b_{jk}	R^2
US–Japan	84–91	0.14	0.09	0.20	0.10	0.43	0.25
		(2.07)[c]		(2.68)[c]		(2.99)[c]	
US–Germany	77–90	0.46	0.06	0.83	0.11	0.07	0.05
		(8.71)[c]		(17.03)[c]		(1.32)	
US–UK	79–90	–0.08	0.03	–0.02	0.02	–0.01	0.02
		(–2.93)[d]		(–1.41)		(–.06)	
US–France	78–90	–0.21	0.02	0.02	0.02	0.05	0.02
		(–7.97)[d]		(0.52)		(2.70)[c]	
US–Italy	79–89	0.26	0.11	0.25	0.01	—	—
		(7.11)[c]		(7.55)[c]			
US–Canada	72–89	0.41	0.02	0.73	0.01	—	—
		(37.44)[c]		(77.15)[c]			
US–Australia	81–91	0.72	0.05	0.89	0.10	—	—
		(5.75)[c]		(7.13)[c]			
US–Korea	72–90	–0.64	0.02	–0.12	0.02	0.93	0.18
		(–11.17)[d]		(–6.71)[d]		(36.88)[c]	
US–Mexico	80–90	0.46	0.14	0.31	0.10	0.56	0.18
		(6.12)[c]		(4.21)[c]		(7.50)[c]	

Note: $\log(X_{ijk}/M_{ijk}) = \alpha_{jk_3} + \beta_{jk_3}\log(a_{ik}/a_{ij})_{-1} + \varepsilon_{ijk_3}$ estimated by seemingly unrelated regressions. *t*-statistics in parentheses, based on heteroskedasticity-consistent (White) standard errors.

[a] Log of the ratio of bilateral exports to bilateral imports.

[b] Log of US relative to other productivity.

[c] The coefficient is significant at 1% level with the correct sign.

[d] The coefficient is significant at 1% level with the incorrect sign.

Discussion of GH (2000) and MacDougall (1951)

- Results in MacDougall (1951) and GH (2000) broadly supportive of Ricardian model. But problems remain:
  1. Bhagwati (1963, EJ survey): Ricardian theory doesn't necessarily predict relationships like these.
  2. Deardorff (1984, Handbook survey): HO model (without FPE) would predict a relationship like this too.
  3. Harrigan (2003, Handbook survey): Simple partial equilibrium supply-and-demand models predict this relationship too. "A truly GE prediction of Ricardian models is that a productivity advantage in one sector can actually *hurt* export success in another sector, but GH do not investigate this prediction [and nor has anyone since.]"
  4. Harrigan (2003, Handbook survey): A test of a trade model needs to have a plausible alternative hypothesis built in which can be explicitly tested (and perhaps rejected).
- Subsequent work (which we will discuss shortly) has tackled 'Problem 1', but not 'Problems 2-4.'

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Nunn (QJE, 2007): Introduction I

- Open question in Ricardian model: where do labor cost (ie productivity) differences come from?
  - Relatedly, in an empirical setting: are we prepared to assume that productivity differences are exogenous with respect to trade flows?

- Nunn (2007) took an innovative take on this problem.
  - But he does not tackle the fundamental 'Problems 1-4' of Ricardian model-based empirical work highlighted above.

Nunn (QJE, 2007): Introduction II

- Nunn (2007) is an influential paper in the 'Trade and Institutions' literature (really: How Institutions $\Rightarrow$ Trade; a separate literature considers the reverse—see lectures 17 and 18).

  - As we saw in the previous lecture, this literature argues that institutional differences across countries do not just have aggregate productivity consequences (as in, eg, AJR 2001), but may also have *differential* productivity differences across industries within countries (industries may differ in their 'institutional intensity').

  - If that is true, institutional differences should generate scope for comparative advantage, and hence trade.

  - This general idea goes back (at least) to a series of papers by Ronald Findlay (eg Findlay and Wilson (1987)) which make this point with respect to infrastructure.

Nunn (2007): The set-up

- The key intuition was seen in the previous lecture:
  - With imperfect contract enforcement ('bad courts') input suppliers who make relationship-specific inputs will under-invest ex ante in fear of ex post hold-up.
  - This harms productivity. And it is worse in industries that are particularly-dependent on relationship-specific inputs, and in countries with bad courts.
  - Suppose further that productivity (in country i and industry k) is the simple product of the 'relationship-specific input intensity' of the industry, z^k, and the quality of the country's legal system, Q_i.
  - Then we have an institutional microfoundation for each country and industry's productivity level: $a_i^k = z^k \times Q_i$.

Nunn (2007): Empirical Specification

- Based on this logic, Nunn (2007) estimates the following regression, which is similar to Golub and Hseih (2000)'s regression 1:

$$\ln x_i^k = \alpha^k + \alpha_i + \beta_1 z^k Q_i + \beta_2 h^k H_i + \beta_3 k^k K_i + \varepsilon_i^k$$

- Here, x is total exports, and α^k and α_i are industry and country fixed effects.
  - The inclusion of α_k is the same thing as taking differences across countries (like the US-UK comparison that GH did) and pooling all of these pairwise comparisons.

- While the regressor of interest is $z^k Q_i$, Nunn controls for Heckscher-Ohlin-style effects by including an interaction between industry-level skill-intensity (h^k) and country-level skill endowments (H_i), and similarly for capital.

Nunn (2007): Is this regression justified by theory?

- Nunn appeals to Romalis (AER, 2004) which derived an expression like this from theory.
  - Romalis (2004) is a Heckscher-Ohlin model with monopolistic competition and trade costs, so FPE is broken.
  - One problem with that is that Romalis doesn't explicitly have 'technology' terms (like $z^k Q_i$) in his regression, though Morrow (2008) derives a version with these included.
  - A second problem with this appeal to Romalis (2004) is that the model is effectively a two-country model, so it's not clear whether an expression like this holds in a multi-country (and zero trade costs) world.
- Costinot (2009) provides a justification for the regression if the human and physical capital terms are left out.
  - Note that by assumption, $a_i^k = z^k Q_i$. So a_i^k is log supermodular and everything in Costinot (2009) applies.

Nunn (2007): Where is the data on z^k and Q_i?

- z^k (industry-level 'relationship-specific input intensity'):
  - Nunn follows Rajan and Zingales (AER, 1998) and assumes that the US is a 'model technology' country. So data from the US can shed light on the innate nature of the technology of making good k, which works (by assumption) in all countries.
  - Nunn uses $z^k = \sum_j \theta_j^k R^k_{neither}$, where the sum is over all upstream supplying industries j to industry k
  - θ_j^k is the share of industry k's total input choices sourced from industry j (according to US 1997 Input-Ouptut Table)
  - $R^k_{neither}$ is a classification created by Rauch (1999) of whether good k is a good that is neither 'sold on an organized exchange' nor 'reference priced in industry journals' (ie it is more likely to be relationship-specific.)

- Q_i (country-level 'quality of legal system'):
  - Nunn uses standard measures from the World Bank (based on investors' perceptions of judicial predictability and enforcement of contracts).

Nunn (2007): Examples of z^k

NB: Nunn's z_i^{rs1} is what we're calling z^k here.

TABLE II
THE TWENTY LEAST AND TWENTY MOST CONTRACT INTENSIVE INDUSTRIES

Least contract intensive: lowest z_i^{rs1}		Most contract intensive: highest z_i^{rs1}	
z_i^{rs1}	Industry description	z_i^{rs1}	Industry description
.024	Poultry processing	.810	Photographic & photocopying equip. manuf.
.024	Flour milling	.819	Air & gas compressor manuf.
.036	Petroleum refineries	.822	Analytical laboratory instr. manuf.
.036	Wet corn milling	.824	Other engine equipment manuf.
.053	Aluminum sheet, plate & foil manuf.	.826	Other electronic component manuf.
.058	Primary aluminum production	.831	Packaging machinery manuf.
.087	Nitrogenous fertilizer manufacturing	.840	Book publishers
.099	Rice milling	.851	Breweries
.111	Prim. nonferrous metal, excl. copper & alum.	.854	Musical instrument manufacturing
.132	Tobacco stemming & redrying	.872	Aircraft engine & engine parts manuf.
.144	Other oilseed processing	.873	Electricity & signal testing instr. manuf.
.171	Oil gas extraction	.880	Telephone apparatus manufacturing
.173	Coffee & tea manufacturing	.888	Search, detection, & navig. instr. manuf.
.180	Fiber, yarn, & thread mills	.891	Broadcast & wireless comm. equip. manuf.
.184	Synthetic dye & pigment manufacturing	.893	Aircraft manufacturing
.190	Synthetic rubber manufacturing	.901	Other computer peripheral equip. manuf.
.195	Plastics material & resin manuf.	.904	Audio & video equipment manuf.
.196	Phosphatic fertilizer manufacturing	.956	Electronic computer manufacturing
.200	Ferroalloy & related products manuf.	.977	Heavy duty truck manufacturing
.200	Frozen food manufacturing	.980	Automobile & light truck manuf.

The contract intensity measures reported are rounded from seven digits to three digits.

Nunn (2007): Main results

$\ln x_i^k = \alpha^k + \alpha_i + \beta_1 z^k Q_i + \beta_2 h^k H_i + \beta_3 k^k K_i + \varepsilon_i^k$

TABLE IV
THE DETERMINANTS OF COMPARATIVE ADVANTAGE

	(1)	(2)	(3)	(4)	(5)
Judicial quality interaction: $z_i Q_c$	.289**	.318**	.326**	.235**	.296**
	(.013)	(.020)	(.023)	(.017)	(.024)
Skill interaction: $h_i H_c$			.085**		.063**
			(.017)		(.017)
Capital interaction: $k_i K_c$			.105**		.074
			(.031)		(.041)
Log income × value added: $va_i \ln y_c$				−.117*	−.137*
				(.047)	(.067)
Log income × intra-industry trade: $iit_i \ln y_c$				.576**	.546**
				(.041)	(.056)
Log income × TFP growth: $\Delta tfp_i \ln y_c$				.024	−.010
				(.033)	(.049)
Log credit/GDP × capital: $k_i CR_c$				.020	.021
				(.012)	(.018)
Log income × input variety: $(1 - hi_i) \ln y_c$				.446**	.522**
				(.075)	(.103)
Country fixed effects	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes
R^2	.72	.76	.76	.77	.76
Number of observations	22,598	10,976	10,976	15,737	10,816

Dependent variable is $\ln x_{ic}$. The regressions are estimates of (1). The dependent variable is the natural log of exports in industry i by country c to all other countries. In all regressions the measure of contract intensity used is z_i^{rs1}. Standardized beta coefficients are reported, with robust standard errors in brackets. * and ** indicate significance at the 5 and 1 percent levels.

Nunn (2007): Comments

- Interpreting the results:
  - Regression coefficients are standardized, so they can be compared directly with one another. Hence institution-driven comparative advantage appears to explain more of the world than Heckscher-Ohiln CA.
  - But the partial R^2 in these regressions is very low (3 % of the non-fixed effects variation can be explained by all regressors combined). So there is lots more to do on explaining export specialization! (Or the specification was wrong and/or there is big time measurement error.)
- Nunn (2007) pursues a number of extensions:
  - Worry about endogeneity of Q_i so IV for it with legal origin (La Porta et al, 1997/1998).
  - Propensity score matching: restrict attention to British and French legal origin countries only. Then do matching on them (to control non-parametrically for observed confounders...but note that matching never helps to obviate concerns about omitted variable bias due to unobserved confounders).

Nunn (2007): IV results

TABLE VII
IV ESTIMATES USING LEGAL ORIGINS AS INSTRUMENTS

	OLS (1)	IV (2)	OLS (3)	IV (4)	OLS (5)	IV (6)
OLS and second stage IV estimates: Dependent variable is ln x_{ic}.						
Judicial quality interaction: z_iQ_c	.289** (.013)	.385** (.022)	.326** (.023)	.539** (.044)	.296** (.024)	.520** (.046)
Skill interaction: h_iH_c			.085** (.017)	.042* (.019)	.063** (.017)	.023 (.019)
Capital interaction: k_iK_c			.105** (.031)	.183** (.035)	.074 (.041)	.114** (.043)
Full set of control variables	No	No	No	No	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R^2	.72	.72	.76	.76	.76	.76
Number of observations	22,598	22,598	10,976	10,976	10,816	10,816
First stage IV estimates: Dependent variable is z_iQ_c.						
British legal origin: z_iB_c		−.295** (.033)		−.210** (.038)		−.215** (.036)
French legal origin: z_iF_c		−.405** (.025)		−.304** (.030)		−.298** (.028)
German legal origin: z_iG_c		−.072 (.045)		−.072 (.051)		−.088 (.049)
Socialist legal origin: z_iS_c		−.477** (.035)				
F-test		113.1		74.6		60.4
Hausman test (p-value)		.00		.00		.00
Over-id test (p-value)		.00		.00		.00

In the second stage standardized beta coefficients are reported, with robust standard errors in brackets. The dependent variable is the natural log of exports in industry i by country c to all other countries. In the first stage I report regular coefficients, with robust standard errors clustered at the country level reported in brackets. The dependent variable is the judicial quality interaction z_iQ_c. The measure of contract intensity used is z_i^{rs1}. Although all explanatory variables in the second stage are also included in the first stage, to conserve space I do not report the first stage coefficients for these variables. The omitted legal origin category is Scandinavian. Because there are no Socialist legal origin countries in the smaller samples of columns (3)–(5), the Socialist interaction term does not appear as an instrument in these specifications. The reported F-test is for the null hypothesis that the coefficients for the interaction terms are jointly equal to zero. * and ** indicate significance at the 5 and 1 percent levels.

Similar Ricardian-style Exercises

- A number of other papers pursue similar empirical set-ups to that in Nunn (2007):
  - Cunat-Melitz: industry-level volatility $\times$ country-level labor market institutions.
  - Costinot (JIE, 2009): industry-level job complexity $\times$ country-level human capital.
  - Levchenko (ReStud, 2007): industry-level complexity $\times$ country-level contracting institutions.
  - Manova (2008): industry-level financial dependence $\times$ country-level financial depth.
  - Chor (2009): (roughly) all of the above in one regression, plus H-O variables ("The Determinants of Comparative Advantage").

Plan of Today's Lecture

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2. Empirical work on 'non-theoretical' (multi-country, multi-sector) Ricardian models
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   2.2 Golub and Hsieh (RIE 2000)
   2.3 Nunn (QJE 2007)
3. **Empirical work on more theoretically-grounded (multi-country, multi-sector) Ricardian models:**
   3.1 **Eaton and Kortum (Ecta, 2002)**
   3.2 Costinot, Donaldson and Komunjer (2010)
4. Conclusion

Eaton and Kortum (Ecta, 2002)

- As described in previous lecture, EK (2002) is a Dornbusch, Fischer and Samuelson (AER, 1977)-style Ricardian model (continuum of goods with technological differences and trade costs).
  - But, by exploiting an ingenious choice for the distribution of technology within each country, EK 2002 works with more than 2 countries, unlike DFS (1977).
- It would be natural to discuss the empirical side of EK (2002) here. However:
  - While the model makes clear, elegant, and (in some senses) closed-form predictions about the total volume of trade, the model makes no (closed-form) predictions about the core Ricardian question: Who produces/exports what to whom, or What is the pattern of trade?
- We will discuss the empirical side of EK (2002) in Week 8 (when we cover gravity equations).

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Costinot, Donaldson and Komunjer (2010)

- CDK (ReStud, forthcoming) extend EK (2002) in a number of empirically-relevant dimensions in order to bring the Ricardian model closer to the data:
  - Multiple industries:
    - Now the model says nothing about which varieties within an industry get traded (ie the fundamental EK-style indeterminacy moves 'down' a level).
    - But the model does predict *aggregate* industry trade flows.
    - These industry-level aggregate trade flow predictions have a very Ricardian feel. These predictions are the core of the paper.
  - Also, an extension that weakens the assumption behind EK 2002's clever choice of within-industry productivity distribution.

Costinot, Donaldson and Komunjer (2010)

- The result goes beyond the preceding Ricardian literature we've seen (eg MacDougall (1951), Golub and Hseih (2000), and Nunn (2007)):
    - Provides theoretical justification for the regression being run. This not only relaxes the minds of the critics, but also adds clarity: it turns out that no one was running the right regression before.
    - Model helps us to discuss what might be in the error term and hence whether orthogonality restrictions sound plausible.
    - Empirical approach explicitly allows (and attempts to correct) for Deardorff (1984)'s selection problem of unobserved productivities.
    - Explicit GE model allows added quantification: How important is Ricardian CA for welfare (given the state of the productivity differences and trade costs in the world we live in)?

Ricardian Assumptions

- Essentially: a multi-industry Eaton and Kortum (2002) model.

- Many countries indexed by i.

- Many goods indexed by k.
  - Each comprised of infinite number of varieties, ω.

- One factor ('labor'):
  - Freely mobile across industries but not countries.
  - In fixed supply L_i.
  - Paid wage w_i.

Assumption 1 (Technology)

- Productivity $z_i^k(\omega)$ is a random variable drawn independently for each triplet (i, k, ω)
- Drawn from a Fréchet distribution $F_i^k(\cdot)$:

$$F_i^k(z) = \exp[-\left(z/z_i^k\right)^{-\theta}]$$

- Where:
  - $z_i^k > 0$ is location parameter we refer to as 'fundamental productivity'. Heterogeneity in z_i^k generates scope for cross-industry Ricardian comparative advantage. This 'level' of CA is the focus of CDK (2010).
  - $\theta > 1$ is intra-industry heteroegeneity. Generates scope for intra-industry Ricardian comparative advantage. This 'level' of CA is the focus of EK (2002).

Assumption 2 (Trade Costs)

- Standard iceberg formulation:
  - For each unit of good k shipped from country i to country j, only $1/d_{ij}^k \leq 1$ units arrive.
  - Normalize $d_{ii}^k = 1$
  - Assume: $d_{il}^k \leq d_{ij}^k \cdot d_{jl}^k$

Assumption 3 (Market Structure)

- Perfect competition:
  - In any country j the price $p_j^k(\omega)$ paid by buyers of variety ω of good k is:
$$p_j^k(\omega) = \min_i \left[c_{ij}^k(\omega)\right]$$
  - Where $c_{ij}^k(\omega) = \frac{d_{ij}^k w_i}{z_i^k(\omega)}$ is the cost of producing and delivering one unit of this variety from country i to country j.
- Extension: paper also develops case or Bertrand competition.
  - This builds on the work of Bernard, Eaton, Jensen and Kortum (AER, 2003)
  - Here, the price paid is the *second*-lowest price (but the identity of the seller is the seller with the lowest price).
  - This alteration doesn't change any of the results that follow, because the distribution of markups is fixed in BEJK (2003).

Assumption 4 (Preferences)

- Cobb-Douglas upper-tier (across goods), CES lower-tier (across varieties within goods):
  - Expenditure given by:

$$x_j^k(\omega) = \left[p_j^k(\omega) / \, p_j^k \right]^{1-\sigma_j^k} \cdot \alpha_j^k \mathrm{w}_j L_j$$

  - Where $0 \leq \alpha_j^k \leq 1$ is the Cobb-Douglas share and $\sigma_j^k < 1 + \theta$ is the CES parameter.
  - And $p_j^k \equiv \left[\sum_{\omega' \in \Omega} p_j^k(\omega')^{1-\sigma_j^k} \right]^{1/(1-\sigma_j^k)}$ is the typical CES price index.
- Comment: assumption on upper-tier is not necessary for main Ricardian prediction below (ie Theorem); can have <u>any</u> upper-tier utility function.

Assumption 5 (Trade Balance)

- For any country i, trade is balanced:

$$\sum_{j=1}^{I}\sum_{k=1}^{K}\pi_{ij}^{k}\alpha_{j}^{k}\gamma_{j}=\gamma_{i}$$

  - Where $\gamma_i \equiv \mathrm{w}_i L_i / \sum_{i'=1}^{I} \mathrm{w}_{i'} L_{i'}$ is the share of country i in world income.

- Comments:
  1. For the main Ricardian prediction below (ie Theorem 3) no assumption on trade balance is necessary.
  2. As with most trade models, the key thing for all other results below is just that the TB is exogenous, not that it's fixed at zero.

Theoretical Predictions: 2 Types

1. Cross-sectional predictions:
   - How productivity (z_i^k) affects trade flows (x_{ij}^k) within any given equilibrium.
   - These relate to previous Ricardian literature (eg Golub and Hsieh, 2000).
   - Testable in any cross-section of data.

2. Counterfactual predictions:
   - How productivity changes affect trade flows and welfare across equilibria.
   - Used to inform GE response of economy to a counterfactual scenario.
   - Our scenario of interest: a world without cross-industry Ricardian trade, which we explore in order to shed light on the 'importance' (eg for welfare) of Ricardian forces for trade.

Cross-Sectional Predictions: Lemma 1

Lemma 1

Suppose that Assumptions A1-A4 hold. Let x_{ij}^k be the value of trade from i to j in industry k. Then for any importer, j, any pair of exporters, i and i', and any pair of goods, k and k',

$$\ln\left(\frac{x_{ij}^k x_{i'j}^{k'}}{x_{ij}^{k'} x_{i'j}^k}\right) = \theta \ln\left(\frac{z_i^k z_{i'}^{k'}}{z_i^{k'} z_{i'}^k}\right) - \theta \ln\left(\frac{d_{ij}^k d_{i'j}^{k'}}{d_{ij}^{k'} d_{i'j}^k}\right).$$

where $\theta > 0$.

- Proof: Model readily delivers a 'gravity equation' for trade flows among any pair of countries (i and j) in each industry k. (Then just take logs and difference twice.)

$$x_{ij}^k = \frac{(\mathrm{w}_i d_{ij}^k / z_i^k)^{-\theta}}{\sum_{i'} (\mathrm{w}_{i'} d_{i'j}^k / z_{i'}^k)^{-\theta}} \cdot \alpha_j^k \mathrm{w}_j L_j$$

Cross-Sectional Predictions: Theorem 3

- Difficulty of taking Lemma 1 to data:
  - 'Fundamental Productivity' (z_i^k) is not observed (except in autarky). This is $z_i^k = E\left[z_i^k(\omega)\right]$.
  - Instead we can only hope to observe 'Observed Productivity', $\widetilde{z}_i^k \equiv E\left[z_i^k(\omega)\middle|\,\Omega_i^k\right]$, where Ω_i^k is set of varieties of k that i actually produces.
  - This is Deardorff's (1984) selection problem working at the level of varieties, ω.
- CDK show that:

$$\frac{\widetilde{z}_i^k}{\widetilde{z}_{i'}^k} = \left(\frac{z_i^k}{z_{i'}^k}\right) \cdot \left(\frac{\pi_{ii}^k}{\pi_{i'i'}^k}\right)^{-1/\theta}$$

  - Intuition: more open economies (lower π_{ii}^k's) are able to avoid using their low productivity draws by importing these varieties.
  - Note that this solves the selection problem, but only by extrapolation due to a functional form assumption.

Cross-Sectional Predictions: Theorem 3

Theorem 3

Suppose that Assumptions A1-A4 hold. Then for any importer, j, any pair of exporters, i and i', and any pair of goods, k and k',

$$\ln\left(\frac{\widetilde{x}_{ij}^{k}\widetilde{x}_{i'j}^{k'}}{\widetilde{x}_{ij}^{k'}\widetilde{x}_{i'j}^{k}}\right) = \theta\ln\left(\frac{\widetilde{z}_{i}^{k}\widetilde{z}_{i'}^{k'}}{\widetilde{z}_{i}^{k'}\widetilde{z}_{i'}^{k}}\right) - \theta\ln\left(\frac{d_{ij}^{k}d_{i'j}^{k'}}{d_{ij}^{k'}d_{i'j}^{k}}\right),$$

where $\widetilde{x}_{ij}^{k} \equiv x_{ij}^{k} \Big/ \pi_{ii}^{k}$.

- Note that (if trade costs take the form $d_{ij}^{k} = d_{ij}d_{j}^{k}$ so that the last term is zero) then this has a very similar feel to the standard 2×2 Ricardian intuition.
  - But standard 2×2 Ricardian model doesn't usually specify trade quantities like Theorem 3 does.
  - And the Ricardian model here makes this same 2×2 prediction for any i, k pair, and for each export destination j.

Cross-Sectional Predictions: Theorem 3

- Can also write this in 'gravity equation' form:

$$\ln \widetilde{x}_{ij}^{k} = \gamma_{ij} + \gamma_{j}^{k} + \theta \ln \widetilde{z}_{i}^{k} - \theta \ln d_{ij}^{k}$$

- This derivation answers a lot of questions implicitly left unanswered in the previous Ricardian literature:
  - Should the dependent variable be x_i^k or something else?
  - How do we average/aggregate over multiple country-pair comparisons (ie what to do with the j's)?
  - How do we interpret the regression structurally (ie, What parameter is being estimated)?
  - What fixed effects should be included?
  - Should we estimate the relationship in levels, logs, semi-log?
  - What is in the error term? (Answer here: Non-differenced part of $\ln d_{ij}^k$ and measurement error in trade flows.)
- However, this specification is effectively a gravity equation (which we will see many variants of throughout this course) so this cannot be seen as a test of Ricardo vs some other gravity model.

Cross-Sectional Predictions: Theorem 3

$\ln \widetilde{x}_{ij}^k = \delta_{ij} + \delta_j^k + \theta \ln \widetilde{z}_i^k - \theta \ln d_{ij}^k$

- In the above specification, note that δ_{ij} and δ_j^k are fixed-effects. Comments about these:
  - These absorb a bunch of economic variables that are important to the model (eg e_j^k is in δ_j^k) but which are unknown to us. This is good and bad.
  - The good: we don't have to collect data on the e_j^k variables—they are perfectly controlled for by δ_j^k. (And similarly for other variables like wages and the price indices.) And even if we did have data on these variables such that we could control for them, they would be endogenous and their presence in the regression would bias the results. The fixed effects correct for this endogeneity as well.
  - The bad: The usual problem with fixed-effect regressions is that the types of counterfactual statements you can make are much more limited. However, in this instance, because of the particular structure of this model, there are a surprising number of counterfactual statements that *can* be made with fixed effects estimates only.

Finally, an Extension

- A1 (Fréchet distributed technologies) is restrictive. However, consider the following alternative environment:
  (i) Productivites are drawn from any distribution that has a single location parameter (z_i^k).
  (ii) Production and trade cost differences are small: $c_{1j}^k \simeq \ldots \simeq c_{Ij}^k$.
  (iii) CES parameters are identical: $\sigma_j^k = \sigma$.

- In this environment, Theorems 3 and 5 hold approximately (ie locally).
  - Furthermore: Fréchet is the only such distribution in which Theorems 3 and 5 hold exactly, and in which the CES parameter can vary across countries and industries.
  - See paper for intuition—assumptions A1(ii) and A1(iii) are homogenizing the intensive margins of adjustment.

Data: Productivity

- Well-known challenge of finding productivity data that is comparable across countries and industries
  - Problem lies in converting nominal revenues into measures of physical output.
  - Need internationally comparable producer price deflators, across countries and sectors (Bernard and Jones, 2001).
- CDK use what they see to be the best available data for this purpose:
  - 'International Comparisions of Output and Productivity (ICOP) Industry Database' from GGDC (Groningen).

Data: Productivity

- ICOP data:
  - Single cross-section in 1997.
  - Data are available from 1970-2007, but only fit for CDK's purposes in 1997, the one year in which ICOP collected comparable producer price data.
  - Careful attention to matching producer prices in thousands of product lines.
  - 21 OECD countries: 17 Europe plus Japan, Korea, USA.
  - 13 (2-digit) manufacturing industries.

Data: Productivity

- As BEJK (2003) point out, in Ricardian world relative productivity is entirely reflected in relative (inverse) producer prices.
  - That is, $\frac{\widetilde{z}_i^k \widetilde{z}_{i'}^{k'}}{\widetilde{z}_{i'}^k \widetilde{z}_i^{k'}} = \left[\frac{E\left[p_i^k(\omega)|\Omega_i^k\right] E\left[p_{i'}^{k'}(\omega)|\Omega_{i'}^{k'}\right]}{E\left[p_{i'}^k(\omega)|\Omega_{i'}^k\right] E\left[p_i^{k'}(\omega)|\Omega_i^{k'}\right]} \right]^{-1}$.
  - This is always true in a Ricardian model (since wages cancel).
- But further impetus here:
  - It might be tempting to use measures of 'real output per worker' instead as a measure of productivity.
  - But statistical agencies rarely observe physical output. Instead they observe revenues ($R_i^k \equiv Q_i^k P_i^k$) and deflate them by some price index (P_i^k) to try to construct 'real output' ($\equiv \frac{R_i^k}{P_i^k}$).
  - In a Ricardian world, then, 'real output per worker' $= \frac{R_i^k / P_i^k}{L_i^k} = \frac{w_i L_i^k}{P_i^k L_i^k} = \frac{w_i}{P_i^k}$.
  - So again wages cancel (in ratio across k's). In a Ricardian world, statistical agencies' measures of relative 'real output per worker' <u>are</u> just relative inverse producer prices.

Final Specification

- With all of the above comments included the final specification used by CDK (2010) is:

$$\ln x_{ij}^k - \ln \pi_{ii}^k = \delta_{ij} + \delta_j^k - \theta \ln p_i^k + \varepsilon_{ij}^k$$

- OLS requires the orthogonality restriction that $E[\ln P_i^k | d_{ij}^k, \delta_{ij}, \delta_j^k] = 0$.
    - CDK can't just control for trade costs, because the full measure of trade costs d_{ij}^k is not observable (trade costs are hard to observe, as we'll discuss in Week 8).
    - Recall that ε_{ij}^k includes the component of trade costs that is not country-pair or importer-industry specific.
- This orthogonality restriction is probably not believable. So CDK also present IV specifications in which $\ln P_i^k$ is instrumented with log R&D expenditure (in i and k in 1997).

Table 3: OLS Results

$\ln(\frac{x_{ij}^k}{\pi_{ii}^k}) = \delta_{ij} + \delta_j^k + \theta \ln \widetilde{z}_i^k + \varepsilon_{ij}^k$. 'Corrected exports' $\equiv \frac{x_{ij}^k}{\pi_{ii}^k}$.

Dependent variable:	log(corrected exports)	log(exports)
	(1)	(2)
log (productivity, based on producer prices)	1.123 (0.099)***	1.361 (0.103)***
Observations	5,652	5,652
R-squared	0.856	0.844

Notes: Regressions include exporter-times-importer fixed effects and importer-times-industry fixed effects. Robust standard errors in parentheses.

Endogeneity Concerns

- Concerns about OLS results:
  1. Measurement error in relative observed productivity levels: attenuation bias.
  2. Simultaneity: act of exporting raises fundamental productivity.
  3. OVB: eg endogenous protection (relative trade costs are a function of relative productivity)
- Move to IV analysis:
  - Use 1997 R&D expenditure as instrument for productivity (inverse producer prices).
  - This follows Eaton and Kortum (2002), and Griffith, Redding and van Reenen (2004).
- Also cut sample: pairs for which $d_{ij}^k = d_{ij} \cdot d_j^k$ (which, recall, is sufficient to difference out endogeneity concerns) is more likely.

Table 3: IV Results

$\ln(\frac{x_{ij}^k}{\pi_{ii}^k}) = \delta_{ij} + \delta_j^k + \theta \ln \widetilde{z}_i^k + \varepsilon_{ij}^k$. 'Corrected exports' $\equiv \frac{x_{ij}^k}{\pi_{ii}^k}$.

Dependent variable:	log(corrected exports)	log(exports)	log(corrected exports)
	(1)	(2)	(3)
log (productivity, based on producer prices)	6.534 (0.708)***	11.10 (0.981)***	4.621 (0.585)***
Sample	Entire	Entire	EU only
Observations	5,576	5,576	2,162
R-squared	0.747	0.460	0.808

Notes: Regressions include exporter-times-importer fixed effects and importer-times-industry fixed effects. Robust standard errors in parentheses.

Counterfactual Predictions

- Remainder of paper does something different: exploring the model's response to counterfactual scenarios.
- CDK scenarios aim to answer: How 'important' is (cross-industry) Ricardian comparative advantage for driving trade flows and gains from trade?
- CDK answer a closely related question:
    - Suppose that, for any pair of exporters, there were no fundamental relative productivity differences across industries. What would be the consequences of this for aggregate trade flows and welfare?

Counterfactual Predictions

- More formally:
  1. Fix a reference country i_0.
  2. For all other countries $i \neq i_0$, assign a new fundamental productivity $(z_i^k)' \equiv Z_i \cdot z_{i_0}^k$.
  3. Choose Z_i such that terms-of-trade effects on i_0 are neutralized: $(w_i/w_{i_0})' = (w_i/w_{i_0})$.
  4. Let $Z_{i_0} = 1$ (normalization).
  5. Refer to all of this as 'removing country i_0's Ricardian comparative advantage.'
- Questions:
  - (a) How to compute Z_i? (Lemma 4)
  - (b) How to solve for endogenous GE responses under counterfactual scenario? (Theorem 5)
  - (c) What model parameters and ingredients (eg trade costs) are needed to answer (a) and (b)?

Counterfactual Predictions: Computing Z_i

Lemma 4

Suppose that Assumptions A1-A5 hold. For all countries $i \neq i_0$, adjustments in absolute productivity, Z_i, can be computed as the implicit solution of

$$\sum\nolimits_{j=1}^{I} \sum\nolimits_{k=1}^{K} \frac{\pi_{ij}^{k} \left(z_i^k / Z_i\right)^{-\theta} \alpha_j^k \gamma_j}{\sum_{i'=1}^{I} \pi_{i'j}^{k} \left(z_{i'}^{k} / Z_{i'}\right)^{-\theta}} = \gamma_i$$

Note: only need data (π_{ij}^k, z_i^k) and θ. This is a trick first spotted in Dekle, Eaton and Kortum (2007, IMF Staff Paper).

Counterfactual Predictions: Trade Flows

Theorem 5 (a)

Suppose that Assumptions A1-A5 hold. If we remove country i_0's Ricardian comparative advantage, then counterfactual (proportional) changes in bilateral trade flows, x_{ij}^k, satisfy

$$\widehat{x}_{ij}^k = \frac{\left(z_i^k / Z_i\right)^{-\theta}}{\sum_{i'=1}^{I} \pi_{i'j}^k \left(z_{i'}^k / Z_{i'}\right)^{-\theta}}$$

Note: Again, only need data (π_{ij}^k, z_i^k) and θ.

Counterfactual Predictions: Welfare

Theorem 5 (b)

And counterfactual (proportional) changes in country i_0's welfare, $W_{i_0} \equiv w_{i_0} \cdot \prod_k (p_{i_0}^k)^{-\alpha_{i_0}^k}$, satisfy

$$\widehat{W}_{i_0} = \prod_{k=1}^{K} \left[\sum_{i=1}^{I} \pi_{ii_0}^k \left(\frac{z_i^k}{z_{i_0}^k Z_i} \right)^{-\theta} \right]^{\alpha_{i_0}^k \big/ \theta}$$

We will usually normalize this by the total gains from trade ($\equiv$ welfare loss of going to autarky):

$$\mathrm{GFT}_{i_0} \equiv \prod_{k=1}^{K} (\pi_{i_0 i_0}^k)^{-\alpha_{i_0}^k / \theta}$$

Revealed Productivity Levels

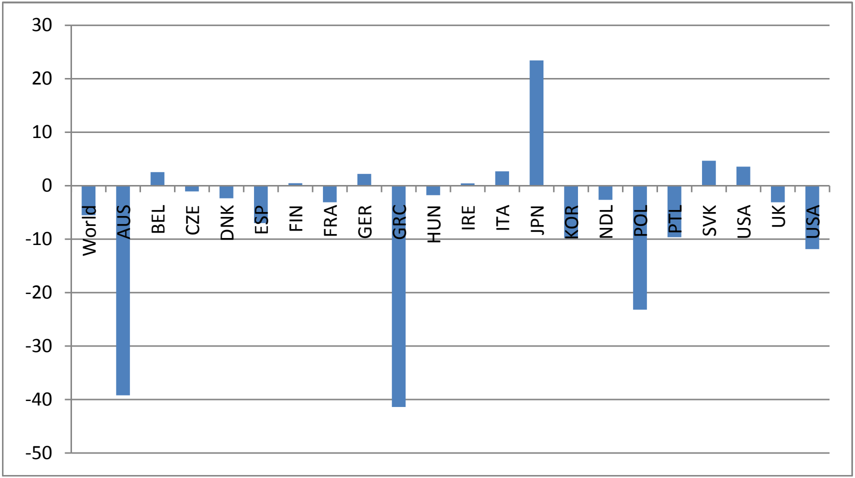
- Counterfactual method requires data on relative z_i^k.
  - Could use data on z_i^k from ICOP, but empirics suggest measurement error is a problem.
  - Instead use trade flows to obtain 'revealed' productivity:
  - Estimate fixed effect $\delta_i^k = \theta \ln z_i^k$ from:

$$\ln x_{ij}^k = \delta_{ij} + \delta_j^k + \delta_i^k + \varepsilon_{ij}^k$$

- This is a theoretically-justified analogue of Balassa's (1965) 'revealed comparative advantage' measure.

Results: Gains from Trade (Baseline)

Welfare change as fraction of total gains from trade, for each reference country



Gains from Removing Ricardian CA? (eg Japan?)

- How is this possible?
- In both model and in calibration, nothing restricts CA from coming about as purely a supply-side (ie conventional Ricardian) phenomenon.
  - Upper-tier utility function's Cobb-Douglas shares could vary by country and industry (demand-driven CA). Recall that CDK didn't need to estimate these, so didn't restrict them in any way. If these vary across countries and industries then there is demand-side scope for CA.
  - And trade costs were unrestricted (so they can in principle vary in such a way as to create CA). Again, reall that these were not estimated and hence not restricted (eg a common approach would be restrict TCs to be a function of distance that is the same function across industries; this restriction would prevent TCs from generating CA).

Gains from Removing Ricardian CA?

- With this much generality, it is possible that when you remove a country's supply-side (ie Ricardian) CA then it is actually better off.
  - Put loosely, this requires that, prior to this change, supply-side and demand/TC-driven CA were offsetting one another. That is, countries prefer (ceteris paribus) the goods that they're better at producing.
  - These 'offsetting' sources of CA will mean that autarky prices are actually similar to realized trading equilibrium prices.
- The paper discusses some calibation exercises that confirm this intuition:
  - If tastes are restricted to be homogeneous across countries (taking the Cobb-Douglas weights of world expenditure shares), or TCs not to create CA, then fewer countries lose from removing Ricardian CA.
  - If both restrictions are imposed then no countries lose from removing Ricardian CA.

Plan of Today's Lecture

1. Introduction to tests of the Ricardian model
2. Empirical work on 'non-theoretical' (multi-country, multi-sector) Ricardian models
   2.1 Early work: MacDougall (1951), Stern (1962), Balassa (1963)
   2.2 Golub and Hsieh (RIE 2000)
   2.3 Nunn (QJE 2007)
3. Empirical work on more theoretically-grounded (multi-country, multi-sector) Ricardian models:
   3.1 Eaton and Kortum (Ecta, 2002)
   3.2 Costinot, Donaldson and Komunjer (2010)
4. **Conclusion**

Rough Ideas for Future Work

- Can one construct a true 'test' of the Ricardian model against other models (eg Heckscher-Ohlin, imperfect competition models)?
  - Recall Harrigan 1 (2003, Handbook survey): Simple partial equilibrium supply-and-demand models predict this relationship too. "A truly GE prediction of Ricardian models is that a productivity advantage in one sector can actually *hurt* export success in another sector." In CDK all the 'hurting' is there, but collapsed into fixed effects.
  - And Harrigan 2 (2003, Handbook survey): A test of a trade model needs to have a plausible alternative hypothesis built in which can be explicitly tested (and perhaps rejected).