14.581: International Trade
— Lecture 11 —
Heckscher-Ohlin Model and Inequality (Empirics I)

Plan of Today's Lecture (HO Empirics, Part I)

1. Introduction
2. Tests concerning the 'goods content' of trade
3. Factor content of trade tests
4. Empirical work on the Specific Factors model
5. Brief Discussion of Other Tests
6. Areas for future research

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Introduction to HO Empirics

- The H-O model is probably the most influential model in all of Trade. So how do we assess how useful a description of the real world it is?
- One immediate obstacle is that the theory's predictions aren't that precise.
  - The 2×2 model makes precise predictions, but (without putting more structure on the problem) not much of this generalizes to higher dimensional settings (Ethier, 1984 *Handbook* chapter).
  - As we have seen, this is a familiar problem from wider Comparative Advantage settings (including the Ricardian model)

What predictions does HO make in general cases?

- Recall that assumption on the number of goods (G) and factors (F) is key:
    - If $G \leq F$, production (and hence trade) is determinate. Hence the '*Goods* Content of Trade' (GCT) (or pattern of trade) is determinate. We will first discuss empirical work that pursues this approach. However, to get empirical traction, this approach usually needs to assume that $G = F$.
    - If $G > F$, production (and hence trade) is indeterminate. But the (Net) *Factor* Content of Trade (NFCT) is determinate—the HO-Vanek (HOV) prediction. We will mainly discuss empirical work that pursues this approach.

Aside: How many goods and factors are there?

- Clearly, as we map from this model to the real world, the $G \geq\leq F$ question really hangs on our level of aggregation (every worker is different in some dimension!)
    - And of course "aggregation" is really just a question of the level at which we assume goods/factors are perfect substitutes so that they can be trivially aggregated.
- A different approach is pursued by Bernstein and Weinstein (JIE, 2002), who examine whether $G \geq F$ seems more plausible by testing the indeterminacy of production (conditional on endowments) in a $G > F$ world (i.e. can we predict what is made where?).
    - That is a very clever idea, but clearly also extremely challenging.

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Introduction to '*Goods* Content' of Trade Tests

- Now we focus on the case of $G \leq F$, and ask whether the H-O model's predictions for trade (or output) of *goods* find support in the data.
- Also called 'Rybczinski regressions'.
- Brief chronology:
  - Baldwin (1971): not quite the right test
  - Leamer (1984, book): first pure test on trade flows
  - Harrigan (JIE, 1995): same as Leamer (1984) but on output
  - Harrigan (AER, 1997): adding technology differences
  - Schott (AER, 2001): multiple cones of specialization
  - Romalis (AER, 2004) (and Morrow (2009)): actually $G > F$, but production indeterminacy broken by trade costs (and hence lack of FPE).

H-O Theory with $G \leq F$, Part I

- Recall the revenue function (for country c):
  $Y^c = r^c(p^c, V^c) \equiv \max_{y^c}\{p^c.y^c : y^c \in T(V^c)\}$.
  - Here Y is total GDP, y is the vector of outputs (in each sector), p is the vector of prices, V are endowments and T is the technology set.
- Then we have (with $G \leq F$): $y^c = \nabla_p r^c(p^c, V^c)$, which is homogeneous of degree one in V^c by CRTS.
  - Recall that with $G > F$, this becomes a correspondence (i.e. production is indeterminate), not an equality.
- And hence: $y^c = \nabla_{pV} r^c(p^c, V^c).V^c \equiv R^c(p^c, V^c).V^c$ by Euler's Theorem.
  - $R^c(p^c, V^c)$ is often called the "Rybczinski matrix".

H-O Theory with $G \leq F$, Part II

- The prediction $y^c = R^c(p^c, V^c).V^c$ looks amenable to empirical work, at first glance.
  - Clearly, without any structure on the technology set T, i.e. on $R(.,.)$, this can't go anywhere.
  - Some work (e.g. Kohli (1978, 1990)) has applied further functional form assumptiosn (e.g. a translog or generalized Leontief revenue function) and gone from there, using data from one country.
  - But if you wanted to pool estimates across countries, or don't observe goods price data in all countries, the equation above offers no guidance on how to proceed.

H-O Theory with $G \leq F$, Part III

- The more influential "Trade" approach has been to further assume that $G = F$ (the "even case"). Then:
  - The factor market clearing conditions $V^c = A^c(w^c, V^c)y^c$ (where $A^c(w^c, V^c)$ are unit factor requirements) imply immediately that (assuming $A^c(w^c, V^c)$ is invertible): $y^c = [A^c(w^c, V^c)]^{-1}V^c$
  - So $R^c(p^c, V^c) = [A^c(w^c, V^c)]^{-1}$.
  - And if we confine attention to a FPE equilibrium (identical technologies (i.e. $A^c(.,.) = A(.,.)$), no trade costs, no factor intensity reversals, and endowments inside the FPE set) then "factor price insensitivity" holds: $A(w^c, V^c) = A(w)$. (i.e. techniques used are locally independent of V^c.)
  - Similarly: $R^c(p^c, V^c) = R(p)$—that is, all countries have the same Rybczinski (or A) matrix.

From Production to Trade

- Finally, we can apply the usual trick to convert predictions about output into predictions about trade flows: *Identical and Homothetic Preferences* (IHP).
- Which, when coupled with the assumption of no trade costs, implies that:

$$T^c(p, V^c) = R(p).V^c - \alpha(p)Y^c$$

- Where $\alpha(p)$ is the vector of consumption budget shares over prices p (common to the whole world since both $\alpha(\cdot)$ and p are common).
- This can be re-written as:

$$T^c(p, V^c) = R(p).(V^c - s^c V^w)$$

- Where s^c is country c's share of world GDP, and V^w is the world endowment vector (since $\alpha(p)Y^c = s^c \alpha(p)Y^w = s^c y^w = s^c R(p)V^w$).

Brief Overview of Chronology

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Baldwin (1971) I

- Theory: $T^c(p, V^c) = R(p).(V^c - s^c V^w)$
- Baldwin (1971) was the first to explore empirical implications.
- He could have either:
  1. Taken data on $T^c(p, V^c)$, $R(p) = [A(w)]^{-1}$, and $(V^c - s^c V^w)$, to check this prediction exactly. As we'll discuss next, one can obtain data on $A(w)$ from input-output accounts.
  2. Or, regressed $T^c(p, V^c)$ on $R(p) = [A(w)]^{-1}$ to check whether the estimated coefficients take the same signs/magnitudes as $(V^c - s^c V^w)$
  3. Or, regressed $T^c(p, V^c)$ on $(V^c - s^c V^w)$ to check whether estimated coefficients take same signs/magnitudes as $R(p) = [A(w)]^{-1}$
- Baldwin (1971) did 2. Found US exported more in industries with more scientists, craftsmen, foreman or farmers and less where more capital/worker.
- Leamer (1984) did a version of 3. Found exports of manufacturing rose with higher capital endowment.

Baldwin (1971) II

- Baldwin (1971) used data:
  - From the US, for 60 industries and 9 factors (K plus 8 types of labor), around 1960.
  - This seems to say that $G > F$ (not $G = F$) but since we're testing this equation-by-equation, it's OK if we just happen to be missing the other 41 factors (whatever they are!)
  - Data on T^c was net exports. (No role for intra-industry trade.)
- Results:
  - Unfortunately, Baldwin (1971) actually mistook $R(p) = [A(w)]$ instead of $R(p) = [A(w)]^{-1}$, so the results are wrong. But Leamer and Bowen (1981) show that the *sign* pattern of the estimated coefficients is only wrong if $\text{sign}\{(AA')^{-1}\} \neq \text{sign}\{A^{-1}\}$. And Bowen and Sveikauskas (1992) show that the actual A matrices suggest this isn't likely to be true.
  - Results were not really testable (without reliable data on V^w), but seemed reasonable except for one exception: the coefficient on physical capital was negative (and everyone thought the US was relatively capital abundant).

Leamer (1984 book): Set-up

- Leamer instead treats $(V^c - s^c V^w)$ as *data* and regresses $T^c(p, V^c)$ on $(V^c - s^c V^w)$.

- Really, this amounts to estimating the regression equation $T_i^c = \sum_{k=1}^{F} \beta_{ik}(V_k^c - s^c V_k^w) + \varepsilon_i^c$ across countries c, one commodity i at a time.
  - The coefficients β_{ik} are often called "Rybczinski effects".

Leamer (1984): Data

- Leamer (1984) did a huge amount of pioneering work in compiling data on trade flows and factor endowments.
- 60 countries, two different years (1958 and 1975)
- Goods classifications: Leamer organizes the data into 10 goods, deliberately aggregating over some finer-level data in order to find 'industries' in which exports appear to flow the same way (within industries), and capital-worker and professional worker-all worker ratios are similar within industries. (So industries look roughly similar along taste and technology dimensions.)
- Factors: K, 3 types of L, 4 types of land (distinguished by climate), and 3 types of natural resources.
- 11 Goods (10 plus non-traded goods) and 11 Factors ("even"!)

Leamer (1984): Results and Interpretation I

- Leamer (1984) stresses that point estimates shouldn't be taken too seriously. But that coefficient signs should be, especially when they're precisely estimated.

- But how do we interpret the signs here?
  - The signs should all be equal to the signs on $[A(w)]^{-1}$. But Leamer (1984) doesn't pursue this (I don't know why not).
  - HO theory says nothing (beyond 2×2) about the signs we should expect on $R(p) = [A(w)]^{-1}$.
  - With one exception: as you saw in Lecture #9, Jones and Scheinkman (1977) show that for each good i, one coefficient β_{ik} should be positive and one should be negative. ("Friends and Enemies"). Leamer (1984) indeed finds this to be true (though that is of course a weak test). Harrigan (2003, *Handbook* survey) argues that this is a nice example of evidence for GE forces in the data.

Leamer (1984): Results and Interpretation II

- Leamer (1984) has a great discussion of how we could interpret some of the precisely-estimated coefficients:
  - E.g.: in manufacturing, the coefficient on capital is positive (which perhaps seems sensible).
  - But in manufacturing, the coefficient on land is *negative*. (Note that this is the sort of surprising result you could never find in an industry-by-industry production function estimation approach.) Why? Perhaps because a country with lots of land specializes in agriculture, and this draws other resources out of manufacturing. However, this could of course just be sampling variation (i.e. *some* coefficient(s) may be negative simply by 'luck').
  - These are plausible interpretations, but there is nothing in general HO theory that says these need to be true.

Harrigan (JIE, 1995) I

- Harrigan (1995 and 2003) argues that the real intellectual content of HO theory concerns *production*, not *consumption*, and hence not trade at all!
    - The addition of the IHP assumption to convert a prediction about production into a prediction about trade, he argues, is at best a distraction, and at worse very misleading (since IHP isn't likely to be true.)
    - Of course, that isn't to imply that enriching the IHP assumption isn't worth doing if the goal is to explain trade flows.
    - A key reason for Leamer (1984) to use trade data rather than output data was not just his interest in trade—he lacked comparable output data across countries. (Trade data has been good and plentiful around the world for centuries longer than any other type of data.) By the early 1990s, however, the OECD had started to make comparable output data available to researchers, so Harrigan uses this.

Harrigan (JIE, 1995) II

- So Harrigan (1995) pursues the Leamer (1984) approach using output data instead of export data.
- The results are similar to Leamer's.
- But he highlights that an overall disappointment is that the R^2 is very low.
  - In other words, the production-side assumptions made in conventional HO theory are incapable of capturing much of the variation in output across countries and industries (and years).

Harrigan (AER, 1997)

- Harrigan (1997) starts from the premise that (what is probably) the most egregious assumption in conventional HO theory is that of identical technologies across countries.
  - But how to build non-identical technologies into the above framework?
  - That framework rested on the notion that since countries have identical technologies, and face identical goods prices due to free trade, and FPI and FPE hold, $R(.)$ is identical across countries. And we can therefore estimate $R(.)$ using variation in V^c across countries.
- Harrigan's solution was to add more structure to the set-up.
  - He assumed a particular (but flexible—"superlative", in the language of Diewert, 1976) functional form for the revenue function.

Harrigan (1997): Set-up I

- Harrigan assumes a translog revenue function.
- To this he adds Hicks-neutral productivity difference in each country and sector: θ_i^c.
- With the additional restriction that all countries face the same prices p and that the translog is CRTS (and fixed over time), he derives the following estimation equation:

$$s_{it}^c = \alpha_{it} + \sum_{k=2}^{F} a_{ki} \ln\left(\frac{\theta_{kt}^c}{\theta_{1t}^c}\right) + \sum_{j=2}^{G} r_{ij} \ln\left(\frac{V_{jt}^c}{V_{jt}^c}\right)$$

- Here, s_{it}^c is the share of output of sector i in country c's GDP in year t, α_{it} is a sector-year fixed effect, and the parameters a_{ki} and r_{ij} are the translog parameters.
- It turns out that this revenue function also has implications for factor shares which could be tested in principle.

Harrigan (1997): Set-up II

- A complication is the presence of non-traded goods:
  - That is, there are some elements of the price vector which are not equalized across countries and that will therefore not be absorbed into the α_{it} fixed effect.
  - In particular, there will now be terms involving non-traded goods prices and non-traded sectors' productivities.
  - Harrigan (1997) argues that these terms might be soaked up in a fixed effect at the country-good level, and if not, they might be orthogonal to the terms included above.

Harrigan (1997): Implementation

- Harrigan estimates the above equation using a panel of countries and industries.
- He estimates the equation one good at a time (with country and year fixed effects), but in a SUR sense (since the dependent variable is a share so all dependent variables sum to one).
- Note that the data requirements go beyond Harrigan (1995): Harrigan (1997) requires data on TFP by industry and country.
- He also instruments TFP (in fear of classical measurement error), using the average of other countries' TFPs as the instrument (sector by sector).

Harrigan (1997): Results

TABLE 5—ESTIMATES OF THE GDP SHARE EQUATIONS, EQUATION (5)

	Food	Apparel	Paper	Chemicals	Glass	Metals	Machinery
TFP Food	**−0.457**	0.672	0.144	−0.067	−0.327	0.381	0.005
	(−2.01)	(4.74)	(1.09)	(−0.48)	(−3.21)	(3.55)	(0.02)
TFP Apparel	0.672	**0.371**	0.360	−0.485	−0.057	−0.157	0.597
	(4.74)	**(2.40)**	(3.14)	(−4.25)	(−0.65)	(−1.92)	(3.39)
TFP Paper	0.144	0.360	**0.184**	−0.104	0.012	−0.003	0.387
	(1.09)	(3.14)	**(1.06)**	(−0.93)	(0.13)	(−0.04)	(2.34)
TFP Chemicals	−0.067	−0.485	−0.104	**2.025**	−0.060	−0.029	−1.198
	(−0.48)	(−4.25)	(−0.93)	**(11.9)**	(−0.72)	(−0.29)	(−5.32)
TFP Glass	−0.327	−0.057	0.012	−0.060	**0.369**	−0.107	−0.174
	(−3.21)	(−0.65)	(0.13)	(−0.72)	**(3.96)**	(−1.82)	(−1.26)
TFP Metals	0.381	−0.157	−0.003	−0.029	−0.107	**0.618**	−0.583
	(3.55)	(−1.92)	(−0.04)	(−0.29)	(−1.82)	**(4.88)**	(−3.00)
TFP Machinery	0.005	0.597	0.387	−1.198	−0.174	−0.583	**3.583**
	(0.02)	(3.39)	(2.34)	(−5.32)	(−1.26)	(−3.00)	**(6.06)**
Prod. durables	1.305	0.940	−0.016	1.186	0.358	0.193	0.913
	(6.90)	(6.57)	(−0.14)	(5.78)	(3.89)	(0.96)	(1.91)
Nonres. const.	−0.195	−0.353	0.157	−1.530	−0.244	−0.066	−1.754
	(−0.68)	(−1.68)	(0.90)	(−5.26)	(−1.70)	(−0.24)	(−2.44)
High-ed. workers	−0.170	−0.663	−0.219	−0.002	−0.190	−0.503	−2.114
	(−1.34)	(−7.16)	(−2.98)	(−0.02)	(−3.18)	(−3.93)	(−6.60)
Medium-ed. workers	0.682	0.688	−0.035	−0.889	0.378	−0.210	1.013
	(3.47)	(4.88)	(−0.31)	(−4.44)	(4.20)	(−1.10)	(2.11)
Low-ed. workers	−0.020	0.102	−0.148	−0.397	−0.103	−0.224	1.820
	(−0.14)	(0.99)	(−1.78)	(−2.68)	(−1.53)	(−1.55)	(5.22)
Arable land	−1.602	−0.714	−0.261	1.631	−0.200	0.809	0.123
	(−5.27)	(−3.09)	(1.43)	(5.10)	(−1.32)	(2.64)	(0.14)

Notes: Estimation results are listed columns, with *t*-statistics in parentheses. The dependent variable is the percentage share of the industry in GDP. All explanatory variables are in logarithms, and are listed as rows. Country and year fixed effects are not shown. There are 203 observations in regression. For further details on this table, see the text.

Harrigan (1997): Interpretation

- The overall fit (R^2), including fixed effects, is quite high: 0.95ish.
- Leaves overall message that in fitting a world-wide revenue function, technology differences are important. As we will see next lecture, this echoes a persistent theme in the NFCT literature, post-Trefler (1993).
- As theory would predict, the own-TFP effects (the bold diagonals) are almost always positive and statistically significant.
- As theory would predict, some cross-TFP, and cross-endowment coefficients are negative, but the location of these negative coefficients isn't very stable across specifications (see other tables).

Post-Harrigan (1997) I

- Harrigan has room for non-FPE, but not for non-"conditional FPE" (in the language of Trefler (1993, JPE), which we'll see shortly).
  - Put another way, $\frac{a^c_{Ki}}{a^c_{Li}}$ should be a constant for any two factors (e.g. K and L), within any good i and country c.
  - However, as will see next lecture, Davis and Weinstein (2001, AER) find that in a regression like $\frac{a^c_{Ki}}{a^c_{Li}} = \beta_i + \beta\frac{K^c}{L^c}$, the coefficient β is usually large and statistically significant. (See also Dollar, Wolff and Baumol (1988, AER).)
  - That is, for some reason, even the *relative* techniques that countries use are affected by local relative endowments.
  - This stands in contrast to a HO model with Hicks-neutral TFP differences across countries and sectors.

Post-Harrigan (1997) II

- Ways to rationalize this:
  1. Country-industry technology differences are not Hicks-neutral. This is probably true, but hasn't generated much work (in "goods content" of trade tests).
  2. Trade costs prevent any sort of FPE (i.e. different countries face different p^c's). This is also surely true (as we'll see in a later lecture, trade costs appear to be very high). Romalis (2004) introduces trade costs into a special sort of (essentially 2-country) HO model to make progress here. Morrow (2009) extends this to include technology differences.
  3. Countries are not all in the same cone of diversification (i.e. inside the "conditional FPE set"). Note that same cone of diversification means that all countries are incompletely specialized (i.e. all produce some of all goods), which sounds counterfactual. Schott (AER, 2003) builds on Leamer (JPE, 1987) and looks at whether Rybczinski regressions fit better if we allow countries to be in different cones.

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- Now we consider the case of $G \geq F$. As you saw in the theory lecture, in this case factor market clearing conditions lead to:

$$A^c(w^c)T^c = V^c - A^c(w^c)\alpha^c(p^c)Y^c$$

- Where $\alpha^c(p^c)$ is the expenditure share on each good.

- If we also have free trade ($p^c = p$), identical technologies ($A^c(.) = A(.)$), identical tastes ($\alpha^c(.) = \alpha(.)$), and factor endowments inside the FPE set so FPE holds ($w^c = w$), then this simplifies dramatically to the HOV equations:

$$A(w)T^c = V^c - s^c V^w.$$

Constructing the NFCT: An Aside

- In reality, production uses intermediates:
  - This means (for example) that the capital content of shoe production includes not only the *direct* use of capital in making shoes, but also the *indirect* use of capital in making all upstream inputs to shoes (like rubber).
  - Let $A(w)$ be the input-output matrix for commodity production. And let $B(w)$ be the matrix of direct factor inputs.
  - Then, if we assume that only final goods are traded, (it takes some algebra, due to Leontief, to show that) the only change we have to make to the HOV theorem is to use $\bar{B}(w) \equiv B(w)(I - A(w))^{-1}$ in place of $A(w)$ above.
    - Trefler and Zhu (JIE, 2010) show that the "only final goods are traded" assumption is not innocuous and propose extensions to deal with trade in intermediates.
    - See also recent work by Johnson and Noguera (JIE, 2012) on this and related issues..

Testing the HOV Equations

- How do we test $\bar{B}(w)T^c = V^c - s^c V^w$?
  - This is really a set of vector equations (one element per factor k).
  - So there is one of these predictions per country c and factor k.

- There are of course many things one can do with these predictions, so many different tests have been performed.
  1. Leontief (1953) and Leamer (JPE, 1980)
  2. Bowen, Leamer and Sveikauskas (AER, 1987)
  3. Trefler (JPE, 1993)
  4. Trefler (AER, 1995)
  5. Davis, Weinstein, Bradford and Shimpo (AER, 1997)
  6. Davis and Weinstein (AER, 2001)

Leontief's Paradox

- The first work based on the NFCT was in Leontief (1953)

- Circa 1953, Leontief had just computed (for the first time), the input-output table (which delivers $A^{US}(w^{US})$ and $B^{US}(w^{US})$) for the 1947 US economy.

Leontief's Paradox

- Leontief then argued as follows:
  - Leontief's table only had K and L inputs (and 2 factors was the bare minimum needed to test the HOV equations).
  - He used $\bar{B}^{US}(w^{US})$ to compute the K/L ratio of US exports: $F^{US}_{K/L,X} \equiv \bar{B}^{US}(w^{US})X^{US} = \$13,700$ per worker.
  - He didn't have $\bar{B}^{US}(w^{US})$ for all (or any!) countries that export to the US (to compute the factor content of US imports), so he applied the standard HO assumption that all countries have the same technology and face the same prices and that FPE and FPI hold. Hence: $\bar{B}^{US}(w^{US}) = \bar{B}^{c}(w^{c}), \forall c$.
  - He then used $\bar{B}^{US}(w^{US})$ to compute the K/L ratio of US imports: $F^{US}_{K/L,M} \equiv \bar{B}^{US}(w^{US})M^{US} = \$18,200$ per worker.
- The fact that $F^{US}_{K/L,M} > F^{US}_{K/L,X}$ was a big surprise, as everyone assumed the US was relatively K-endowed relative to the world as a whole.

Leamer (JPE, 1980)

- Leamer (1980) pointed out that Leontief's application of HO theory, while intuitive, was wrong if either trade is unbalanced, or there are more than 2 factors in the world.
  - Either of these conditions can lead to a setting where the US exports both K and L services—which is impossible in a balanced trade, 2-factor world. It turns out that this is exactly what the US was doing in 1947.
- In particular, Leamer (1980) showed that the intuitive content of HO theory really says that:
  - $\frac{K^{US}}{L^{US}} > \frac{K^{US}-F_K^{US}}{L^{US}-F_L^{US}}$, where $F_k^{US} \equiv \bar{B}(w)_k T^{US}$ is the factor content of US net exports in factor k.
  - This just takes a ratio of HOV equations, for two factors (K and L). HOV equations just say that, for an abundant factor K, the K/L ratio in production has to be greater than the K/L ratio in consumption.
  - But HOV does not necessarily say that the factor content of exports should exceed the factor content of imports, as Leontief (1953) had tested.

Bowen, Leamer and Sveikauskas (1987)

- BLS (AER, 1987) continued the serious application of HOV theory to the data that Leamer (1980) started.
  - BLS (1987), along with Maskus (1985), was the first real test of the HOV equations.
- Some details:
  - BLS only observed $\bar{B}(w)$ in the US in 1967, but they applied the standard HO assumption that $\bar{B}(w)$ is the same for all other countries in 1967 as it is in the US in 1967.
  - BLS noted that there is one HOV equation per country and factor: $C \times F$ equations, so $C \times F$ tests.
  - BLS had data on 12 factors and 27 countries

BLS (1987): Tests

- But how to test $\bar{B}(w)T^c = V^c - s^c V^w$?
  - They should hold with equality and most certainly do not.
  - Not even for the US! This should really worry us, since $\bar{B}(w)$ was calculated for the US, so at least $\bar{B}(w)Y^c = V^c$ should (and does, more or less) hold as an identity.
- BLS propose two tests:
  1. Sign tests: How often is it true that $\text{sign}\{F_k^c\} = \text{sign}\{V_k^c - s^c V_k^w\}$? Only 61 % of the time (not that much better than a coin toss).
  2. Rank tests: How often is it true that if $F_k^c > F_{k'}^c$ then $(V_k^c - s^c V_k^w) > (V_{k'}^c - s^c V_{k'}^w)$? Only 49 % of the time!
- This was considered to be a real disappointment. Maskus (1985) made a similar point, and put it well: The Leontief Paradox is not a paradox, but rather a "commonplace"!

Trefler (JPE, 1993)

- Trefler (1993) and Trefler (AER, 1995) extended this work in an important direction, by dropping the assumption that technologies are the same across countries.
  - Trefler (1993) in particular allowed countries to have different technologies in a *very* flexible manner.
- This is not only realistic, but also allows the HO model to be reconciled with the clear failure of FPE in the data.
- The key challenge was to incorporate productivity differences in a coherent, theory-driven way in which all of the attractions of the HO model would still hold, even though technologies differ across countries.

An Aside on Non-FPE

Leamer (JEL, 2007) has a nice way of viewing this...

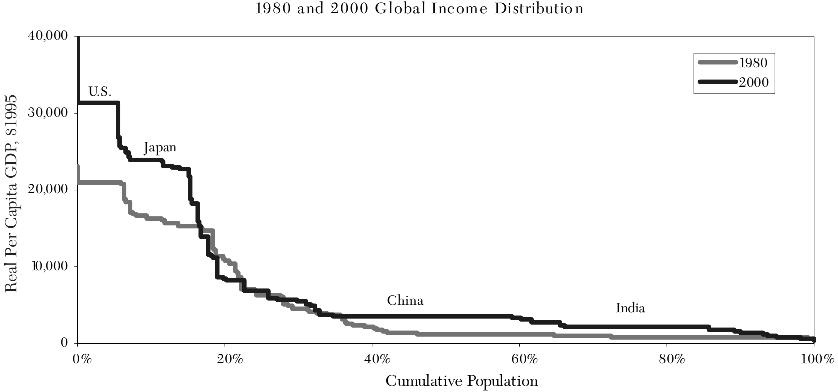

Figure 7. Global Labor Pools in 1980 and 2000

Trefler (1993): Set-up I

- Trefler (1993) adds factor- and country-specific productivity shifters (π_{ck}) to an otherwise standard HO model.
  - This is closely related to Leontief's preferred solution to his eponymous "paradox": The US is not labor-abundant when you just count workers. But if you count 'equivalent productivity workers' across countries, than the US *is* labor-abundant.
  - This amounts to defining factors in "productivity-equivalent" units: $V_{ck}^* \equiv \pi_{ck} V_{ck}$. (E.g. measuring workers in "efficiency-adjusted" units.)
  - So now factor prices also have to be in "productivity-equivalent" units: $w_{ck}^* \equiv \frac{w_{ck}}{\pi_{ck}}$ (E.g. measuring workers' wages in wage paid per "efficiency-adjusted" units of labor.)
- Trefler assumes that the only production-side differences across countries are these π_{ck} terms:
  - That implies that $\bar{B}_c^*(w_c^*) = \bar{B}_{c'}^*(w_{c'}^*)$.

Trefler (1993): Set-up II

- Then Trefler (1993) shows that all of the traditional HO logic goes through in terms of V^*_{ck} and w^*_{ck} rather than V_{ck} and w_{ck}:
  - HOV: $F^*_{ck} \equiv \bar{B}^*(w^*)T^c = \pi_{ck}V_{ck} - s^c V_k^{*w}$
  - FPE (now "conditional FPE"): $w^*_{ck} = w^*_{c'k}$

Trefler (1993): Methodology I

- What can you then do with these HO predictions? The central problem is that unlike the $\bar{B}(w)$ matrix, the $\bar{B}^*(w^*)$ matrix is not observable in any country.
  - Fundamentally, the π_{ck}'s are unknown.
  - In principle, we could estimate these using cross-country productivity/output data. But Trefler (1993) doesn't pursue this, for fear that such data isn't reliable enough. (Is this still a binding data constraint 25 yeas later?)
- Instead, Trefler *estimates* the π_{ck}s from the HOV equations.
  - It turns out that this estimation is trivial since there is a (unique) set of π_{ck} terms that make the HOV equations hold with equality (up to the normalization that one country's $\pi_{ck} = 1$ for all k; for Trefler, this country is the US).
  - So unrestricted country- and factor-specific productivity differences can make the HOV equations fit always and everywhere!

Trefler (1993): Methodology II

- Once we've estimated the $\widehat{\pi}_{ck}$ terms (which fit the HOV equations perfectly), how do we then assess the HO model?
  1. Trefler (1993) shows that there exist values of (hypothetical) data (i.e. T, $\bar{B}_{US}(w)$, s and V) such that some of the $\widehat{\pi}_{ck}$ terms will be *negative*. But if the estimated $\widehat{\pi}_{ck}$s are negative, this casts serious doubt on the notion that they are well-estimated productivity parameters. Reassuringly, only 10 out of 384 estimates are negative.
  2. Further, the logic so far hasn't used the FPE part of HO. So Trefler (1993) checks how well the estimated $\widehat{\pi}_{ck}$ terms (estimated off of trade data) bring about "conditional FPE" (i.e. adjust observed factor prices, which don't satisfy FPE, so that the constructed w^*_{ck}s come closer to satisfying FPE). See Figure 1 below.
  3. Other sensible restrictions: e.g., we tend to think that the US is more productive than most countries, so the $\widehat{\pi}_{ck}$ terms should be less than one most of the time. Reassuringly, this is true.

Trefler (1993): Results

The estimated π_{ck}s (for k as labor) correlate very well with relative wages

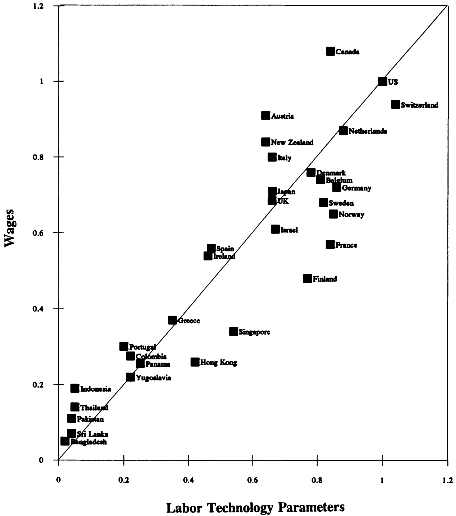

FIG. 1.—Wages and labor technology parameters

Trefler (AER, 1995)

- Trefler (1995) provides two advances in understanding about NFCT:
  1. He identifies 2 key facts about the NFCT data, which isolate 2 aspects of the data in which the HOV equations appear to fail. (Previous work hadn't said much more than, 'the HOV equations fail badly in the data.')
  2. He explores how a number of parsimonious (as opposed to the approach in Trefler (1993) which was successful, but—deliberately—anything but parsimonious!) extensions to basic HO theory can improve the fit of the HOV equations.

Fact 1: "The Case of the Missing Trade"

- Consider a plot of HOV deviations (defined as $\varepsilon_{ck} \equiv F_{ck} - (V_{ck} - s^c V_k^w)$) against predicted NFCT (i.e. $V_{ck} - s^c V_k^w$): Figure 1.
  - The vertical line is where $V_{ck} - s^c V_k^w = 0$ (where the model predicts zero trade).
  - The diagonal line is the actual "zero [factor content of] trade" line: $F_{ck} = 0$, or $\varepsilon_{ck} = -(V_{ck} - s^c V_k^w)$.

- This plot helps us to visualize the failure of the HOV equations:
  - If the "sign test" always passed, all observations would lie in the top-right or bottom-left quadrants. (They don't.)
  - If the HOV equations were correct, $\varepsilon_{ck} = 0$, so all observations would lie on a horizontal line. (They definitely don't.)
  - Most fundamentally, the clustering of observations along the "zero [factor content of] trade" line means that factor services trade is far lower than the HOV equations predict. Trefler (1995) calls this "the case of the missing trade."

Fact 1: "The Case of the Missing Trade"

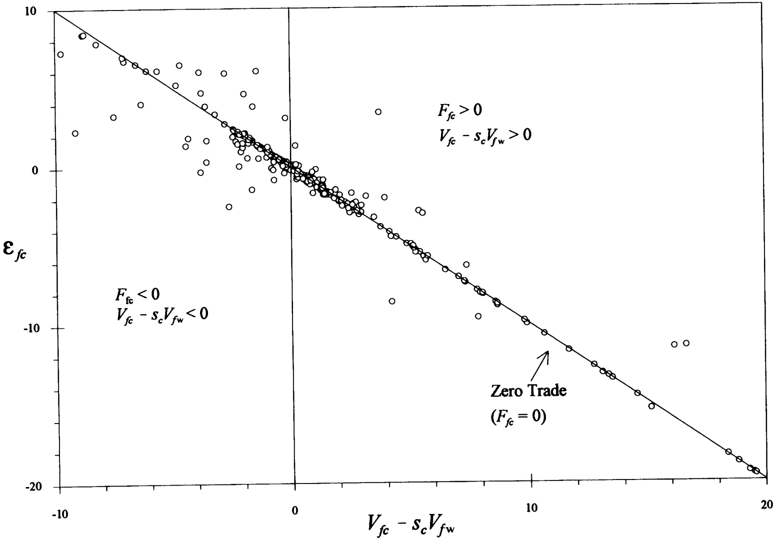

FIGURE 1. PLOT OF $\varepsilon_{fc} = F_{fc} - (V_{fc} - s_c V_{fw})$ AGAINST $V_{fc} - s_c V_{fw}$

Fact 2: "The Endowments Paradox"

- Trefler (1995) then looks at HOV deviations by country in Figure 2.
  - Here he plots the number of times (out of 9, the total number of factors k) that $\varepsilon_{ck} < 0$ (factor trade is less than predicted).
  - Because F_{ck} is so small (Fact 1), this is mirrored almost one-for-one in $V_{ck} - s^c V_k^w > 0$ (i.e. country c is abundant in factor k).
- The plot helps us to visualize another failing of the HOV equations:
  - Poor countries appear to be abundant in all factors (essentially they have ample endowments but a tiny share of world gdp).
  - This can't be true with balanced trade, and it is not true (in Trefler's sample) that poor countries run higher trade imbalances.
  - So this must mean that there is some omitted factor that tends to be scarce in poor countries.
  - A natural explanation (a la Leontieff) is that some factors are not being measured in "effective (i.e. productivity-equivalent) units".

Fact 2: "The Endowments Paradox"

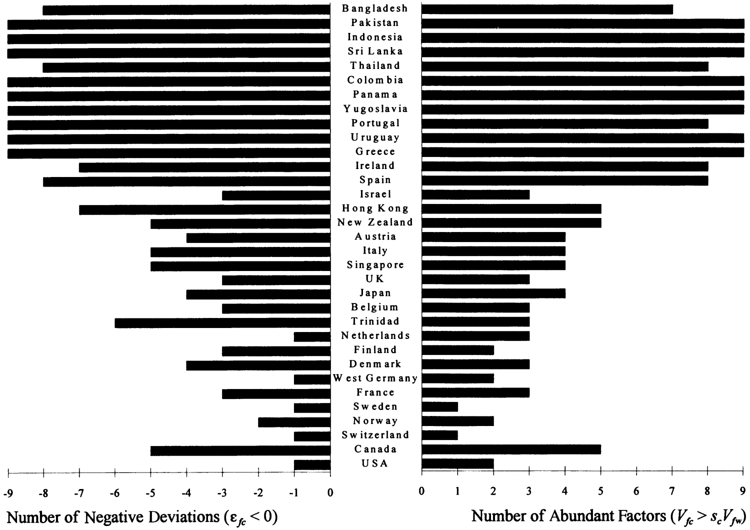

FIGURE 2. DEVIATIONS FROM HOV AND FACTOR ABUNDANCE

Trefler (1995): Altering the Simple HO Model I

- Trefler (1995) then (extending an approach initially pursued in BLS, 1987) seeks alterations to the simple HO model that:
  - Are parsimonious (i.e. they use up only a few parameters, unlike in Trefler, 1993).
  - Have estimated parameters that are economically sensible (analogous to considerations in Trefler, 1993).
  - Can account for Facts 1 and 2.
  - Fit the data well (in a 'goodness-of-fit sense): e.g. success on sign/rank tests.
  - Fit the data best (in a likelihood or model selection sense) among the class of alterations tried. (But the 'best' need not fit the data 'well').

Trefler (1995): Altering the Simple HO Model II

- The alterations that Trefler tries are:
  1. T1: restrict π_{ck} in Trefler (1993) to $\pi_{ck} = \delta_c$. ("Neutral technology differences").
  2. T2: restrict π_{ck} in Trefler (1993) to $\pi_{ck} = \delta_c \phi_k$ for less developed countries ($y^c < \kappa$, where κ is to be estimated too) and $\pi_{ck} = \delta_c$ for developed countries.
  3. C1: allow the s^c consumption shares to be adjusted to fit the data (this corrects for countries' non-homothetic tastes for investment goods, services and non-traded goods).
  4. C2: Armington Home Bias: Consumers appear to prefer home goods to foreign goods (tastes? trade costs?). Let α_c^* be the "home bias" of country c.
  5. TC2: $\delta_c = y_c / y_{US}$ and C2.

Trefler (1995): Results

By most tests, TC2 (neutral technological differences with Armington home bias) does best. Sign test is nearly perfectly accurate, mysteries improved considerably.

TABLE 1—HYPOTHESIS TESTING AND MODEL SELECTION

Hypothesis	Description: Parameters (k_i)	Description: Equation	Likelihood: $\ln(L_i)$	Likelihood: Schwarz criterion	Mysteries: Endowment paradox	Mysteries: Missing trade	Goodness-of-fit: Weighted sign	Goodness-of-fit: $\rho(F, \hat{F})$
Endowment differences								
H_0: unmodified HOV theorem	(0)	(1)	−1,007	−1,007	−0.89	0.032	0.71	0.28
Technology differences								
T_1: neutral	δ_c (32)	(4)	−540	−632	−0.17	0.486	0.78	0.59
T_2: neutral and nonneutral	ϕ_f, δ_c, κ (41)	(6)	−520	−637	−0.22	0.506	0.76	0.63
Consumption differences								
C_1: investment/services/ nontrade.	β_c (32)	(7)	−915	−1,006	−0.63	0.052	0.73	0.35
C_2: Armington	α_c^* (24)	(11)	−439	−507	−0.42	3.057	0.87	0.55
Technology and consumption								
TC_1: $\delta_c = y_c/y_{US}$	(0)	(4)	−593	−593	−0.10	0.330	0.83	0.59
TC_2: $\delta_c = y_c/y_{US}$ and Armington	α_c^* (24)	(12)	−404	−473	0.18	2.226	0.93	0.67

Notes: Here k_i is the number of estimated parameters under hypothesis i. For ''likelihood,'' $\ln(L_i)$ is the maximized value of the log-likelihood function, and the Schwarz-model selection criterion is $\ln(L_i) - k_i \ln(297)/2$. Let $\hat{F}_{fc}$ be the predicted value of F_{fc}. The ''endowment paradox'' is the correlation between per capita GDP, y_c, and the number of times $\hat{F}_{fc}$ is positive for country c (see Fig. 2). ''Missing trade'' is the variance of F_{fc} divided by the variance of $\hat{F}_{fc}$ (see Fig. 1). ''Weighted sign'' is the weighted proportion of observations for which F_{fc} and $\hat{F}_{fc}$ have the same sign. Finally, $\rho(F, \hat{F})$ is the correlation between F_{fc} and $\hat{F}_{fc}$. See Section V for further discussion.

Gabaix (1997)

- Trefler (1995)'s "missing trade" has had a strong impact on the way that NFCT empirics has proceeded since.
- Ironically however, as Gabaix (1997) (unpublished, but discussed in Davis and Weinstein (2003, *Handbook* survey of NFCT literature)) pointed out, "missing trade" makes the impressive fit of the $\widehat{\pi}_{ck}$s in Figure 1 of Trefler (1993) not that impressive after all.
  - That is, Gabaix (1997) showed that if trade is *completely* missing (i.e. $F_{ck} = 0$) then Trefler (1993) is finding the $\widehat{\pi}_{ck}$s such that $\widehat{\pi}_{ck} V_{ck} = s^c \sum_c \widehat{\pi}_{ck} V_{ck}$.
  - Therefore, Trefler's (1993) method approximates to comparing: $\frac{\widehat{\pi}_{ck}}{\widehat{\pi}_{c'k}} = \frac{Y^c / V_{ck}}{Y^{c'} / V_{c'k}}$.
  - That is, the relative productivity parameters are just GDP per factor; hence Figure 1 in Trefler (1993) isn't that surprising.

Davis, Weinstein, Bradford and Shimpo (AER, 1997)

- DWBS (1997) were the first to explore a different (from Trefler (1995)) sort of 'diagnostic' exercise on the HOV equations.
- In particular, they note that statements about the NFCT are really two statements about:
  1. The FC of Production: $\bar{B}^c(w^c)y^c = V^c$
  2. The FC of Consumption (really: 'Absorption', to allow for intermediates): $\bar{B}^c(w^c)D^c = s^c V^w$.
- DWBS (1997) use data on regions within Japan to test 1 and 2 separately, to thereby shed light on whether it's the failure of 1 or 2 (if not both) that is generating 'missing trade'

DWBS (1997): Factor Content of Production

- DWBS (1997) have data on $A^J(w^J)$, the input-output table, and $B^J(w^J)$, the primary factor use matrix, for Japan as a whole.
- Factor market clearing implies that $B^J(w^J)X^J = V^J$:
  - NB: Here, X^c is *gross output*, not value-added.
  - Note that this is not some sort of test of factor market clearing. Instead, this is an identity that must hold for the case of Japan since $B^J(w^J)$ is computed such that this is true.
  - At least, they *should* be computed this way! In the BLS (1987) data, where $B^{US}(w^{US})$ is used, it is not true that $B^{US}(w^{US})X^{US} = V^{US}$, which is worrying. The reason for this is that the $B(w)$ matrices come from statistical agencies who have their own definition of a factor (e.g., how do you define and measure 'capital'?), which isn't necessarily the same definition that researchers are using to define V^c.

DWBS (1997): Factor Content of Production

- So DWBS (1997) are deliberately not interested in testing the FC of Japan's production as a whole (i.e. $B^J(w^J)X^J = V^J$).
- Instead they test:
  - FPE and identical technologies for the entire world: $B^J(w^J)X^c = V^c$ (using 21 other countries c).
  - FPE and identical technologies within Japan: $B^J(w^J)X^r = V^r$ (using 10 regions of Japan, r).

DWBS (1997): Factor Content of Production

This scatter plot is a row of the vector equation $B^J(w^J)X^c = V^c$, plotted for all $c \neq J$

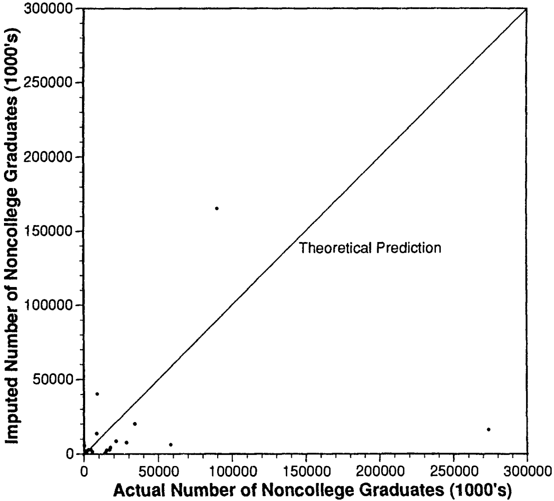

FIGURE 1. INTERNATIONAL PRODUCTION TEST: ACTUAL VERSUS IMPUTED NONCOLLEGE ENDOWMENT

DWBS (1997): Factor Content of Production

This scatter plot is a row of the vector equation $B^J(w^J)X^c = V^c$, plotted for all $c \neq J$

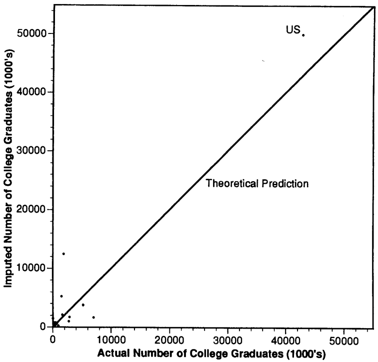

FIGURE 2A. INTERNATIONAL PRODUCTION TEST: ACTUAL VERSUS IMPUTED COLLEGE ENDOWMENT

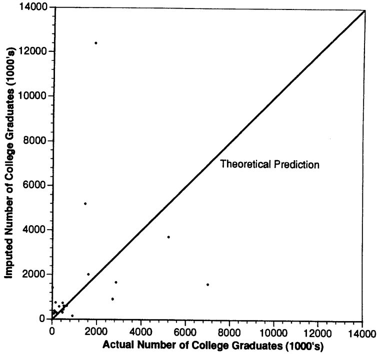

FIGURE 2B. INTERNATIONAL PRODUCTION TEST: ACTUAL VERSUS IMPUTED COLLEGE ENDOWMENT (WITHOUT U.S.)

DWBS (1997): Factor Content of Production

This scatter plot is a row of the vector equation $B^J(w^J)X^c = V^c$, plotted for all $c \neq J$

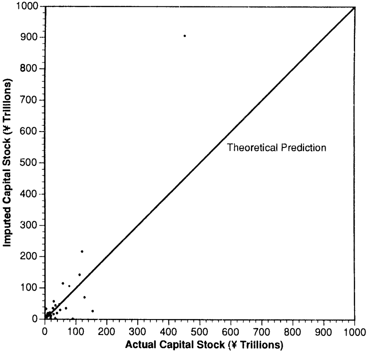

FIGURE 3A. INTERNATIONAL PRODUCTION TEST: ACTUAL VERSUS IMPUTED CAPITAL STOCK

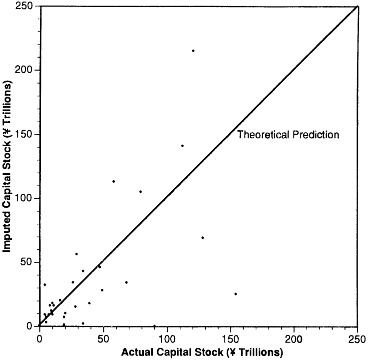

FIGURE 3B. INTERNATIONAL PRODUCTION TEST: ACTUAL VERSUS IMPUTED CAPITAL STOCK (WITHOUT U.S.)

FC of Production: Interpretation I

- The FC of production appears to perform very badly in the cross-country data.
  - This means that $B^c(w^c) \neq B^J(w^J)$.
  - This could arise due to non-FPE (i.e. $w^c \neq w^J$) or non-identical technologies ($B^c(w^J) \neq B^J(w^J)$).
  - DWBS (1997) don't seek to test which of these is at work.
  - They do note that the richer the country, the better the fit. But that could either be because of similar technologies or similar endowments (and hence production in the same cone of diversification), or both.

FC of Production: Interpretation II

- DWBS (1997) go on to look at the FC of production across Japanese regions.
  - These fit better, which is very nice.
  - However, we have to bear in mind that $B^J(w^J)$ was calculated to hold as an identity for all of Japan. So it is representative of some average Japanese region by construction. And hence we should expect the fit to improve somewhat compared to the cross-country results.
  - We should also bear in mind that just because FPE seems to hold well within Japan, this doesn't necessarily show that HO-style mechanisms made it so. Factors (and technology) could also be mobile. (But recall, in a strictly HO world, factors wouldn't actually *want* to move due to FPE! So this issue is quite subtle.)

DWBS (1997): Factor Content of Production

This scatter plot is a row of the vector equation $B^J(w^J)X^r = V^r$, plotted for all $r \in J$

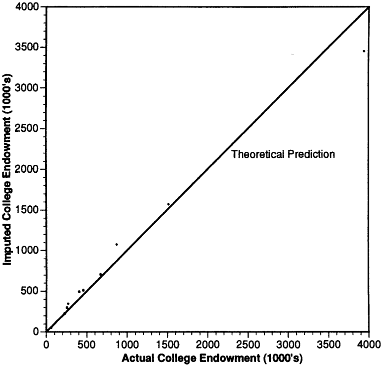

FIGURE 4. REGIONAL PRODUCTION TEST: ACTUAL VERSUS IMPUTED COLLEGE ENDOWMENT

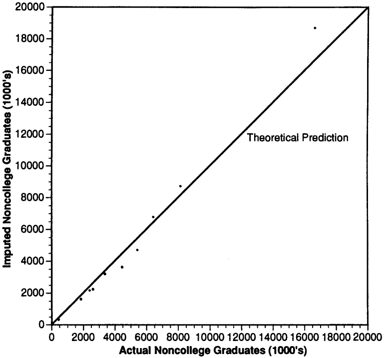

FIGURE 5. REGIONAL PRODUCTION TEST: ACTUAL VERSUS IMPUTED NONCOLLEGE ENDOWMENT

DWBS (1997): Factor Content of Production

This scatter plot is a row of the vector equation $B^J(w^J)X^r = V^r$, plotted for all $r \in J$

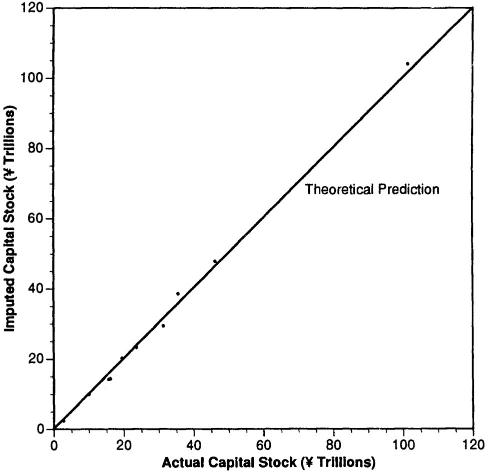

FIGURE 6. REGIONAL PRODUCTION TEST: ACTUAL VERSUS IMPUTED CAPITAL STOCK

DWBS (1997): Goods Content of Absorption

- DWBS (1997) have data on absorption D^r for each region of Japan. But they do not have this data for other countries in the world.
- With this data they test two hypotheses underpinning absorption:
  1. Identical and homothetic preferences (and identical prices) around the world: $D^c = s^c Y^w$ and $D^r = s^r Y^w$, where Y^w is world *net* output (i.e. GDP). This performs pretty well—see following Figures.
  2. Identical and homothetic preferences (and identical prices) within Japan: $D^r = \frac{s^r}{s^J} D^J$. This performs incredibly well: rank correlations across 45 commodities, or across regions, are almost uniformly above 0.95.

DWBS (1997): Goods Content of Absorption

This scatter plot is D^r vs $s^r Y^w$, for each commodity

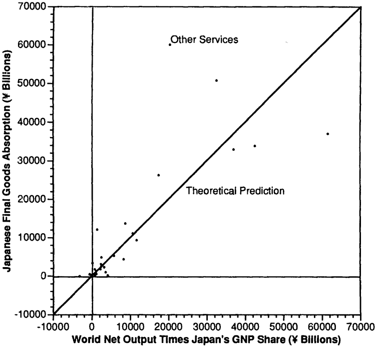

FIGURE 7. JAPANESE ABSORPTION TEST (ALL GOODS)

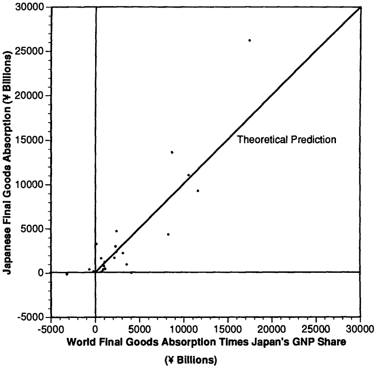

FIGURE 8. JAPANESE ABSORPTION TEST (ONLY TRADABLES)

DWBS (1997): Putting It All Together

- We have seen that (within Japan) the FC of production and the *goods* content of absorption both appear to fit well.
- So we can now put these two together to see how well the FC of trade fits (within Japan).
  - One might think that if both absorption and production fit well, then trade has to fit well by construction.
  - But that is not quite true, since the above test for absorption was done on *goods* not *factor* content.
  - To convert GC of absorption into FC of absorption we need to multiply goods absorption by $B^J(w^J)$, which is implicitly assuming that all countries use the same $B(.)$ matrix as Japan. (That is, we say: $B^J(w^J)D^r = s^r B^J(w^J)Y^w = s^r B^J(w^J)X^w = s^r V^w$.)
  - Figures 9 and 10 show that there is still significant missing trade inside Japan (Figure 9) and that this is primarily due to the absorption side of the factor content of trade being off (Figure 10).

DWBS (1997): Why is There Missing Trade?

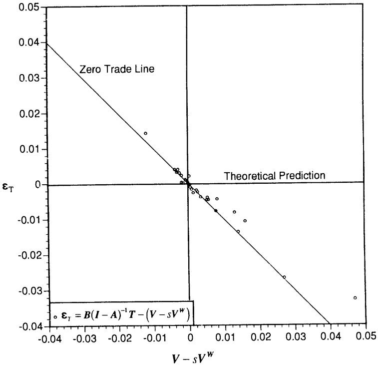

Figure 9. Trade Errors versus Factor Abundance (All Factors Calculated Relative to the World Endowment, $\mathbf{V}^W$)

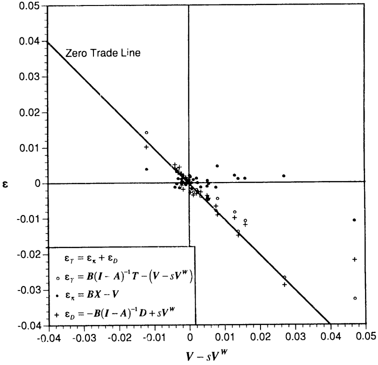

Figure 10. All Errors versus Factor Abundance (All Factors Calculated Relative to the World Endowment, $\mathbf{V}^W$)

DWBS (1997): Final Step

- The above findings suggest that the problem of the missing trade within Japan is primarily due to assuming that there is FPE (or identical technologies) around the world, or that: $B^J(w^J)X^w = s^r V^w$.
- So the last thing that DWBS (1997) do is to see how things look without this assumption.
    - That is, they simply use $B^J(w^J)X^w$ instead of assuming that this is equal to $s^c V^w$.
    - This is like assuming that there is FPE within Japan, but not necessarily across countries.
    - This (as Figure 11 shows) goes some way towards improving the fit.

DWBS (1997): Finding (Some) Missing Trade

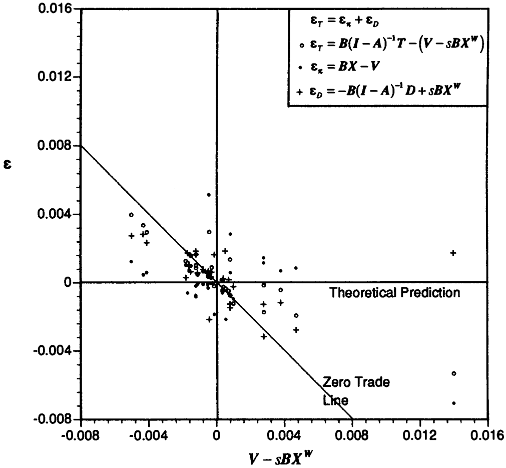

FIGURE 11. ALL ERRORS VERSUS FACTOR ABUNDANCE (ALL FACTORS CALCULATED RELATIVE TO THE IMPUTED WORLD ENDOWMENT, $\mathbf{BX}^W$)

Davis and Weinstein (AER, 2001)

- DWBS (1997) find that it is the FPE (or common technology) assumption that performs most poorly: when they restrict to trade within Japan, HO actually performs pretty well. That is, the failure of FPE seems to be a first-order problem for HO.
- So DW (2001) build on this and seek to understand the departures from FPE within the OECD.

DW (2001): "The Matrix"

- The key to this exercise is getting data on $\bar{B}^c(w^c)$ for all countries c in their sample (not easy!) All prior studies had used one country's $\bar{B}(w)$ matrix to apply to all countries.
  - Just taking a casual glance at these suggests that the $\bar{B}(w)$'s around the OECD are very different. So something needs to be done.
  - One approach would be just to use the data on $\bar{B}^c(w^c)$ for each country—but then the production side of the HOV equations would hold as an identity and that wouldn't be much of a test. (It does shed some light on things though, as Hakura (JIE, 2001) showed.)
  - DW instead seek to parsimoniously *parameterize* the cross-country differences in $\bar{B}^c(w^c)$ by considering 7 nested hypotheses, which drop standard HO assumptions sequentially, about how endowments affect both *technology* (i.e. $\bar{B}(.)$) and *technique* (i.e. $\bar{B}(w)$).

Davis and Weinstein (AER, 2001)

- The message from DWBS (1997) was that, when restricted to settings where FPE seems plausible (like within a country), HO actually performs pretty well. That is, the failure of FPE seems to be a first-order problem for HO.
- So DW (2001) build on this and seek to understand the departures from FPE within the OECD.

DW (2001): "The Matrix"

- The key to this exercise is getting data on $\bar{B}^c(w^c)$ for all countries c in their sample (not easy!) All prior studies had used one country's $\bar{B}(w)$ matrix to apply to all countries.
  - Just taking a casual glance at these suggests that the $\bar{B}(w)$'s around the OECD are very different. So something needs to be done.
  - One approach would be just to use the data on $\bar{B}^c(w^c)$ for each country—but then the production side of the HOV equations would hold as an identity and that wouldn't be much of a test. (It does shed some light on things though, as Hakura (JIE, 2001) showed.)
  - DW instead seek to parsimoniously *parameterize* the cross-country differences in $\bar{B}^c(w^c)$ by considering 7 nested hypotheses, which drop standard HO assumptions sequentially, about how endowments affect both *technology* (i.e. $\bar{B}(.)$) and *technique* (i.e. $\bar{B}(w)$).

DW (2001): The 7 Nested Hypotheses and 7 Results

"P"=Production, "T"=Trade

- "P1&T1": Standard HOV, common (US) technology. (The baseline.)
  - That is, P1: $B^{US}(w^{US})Y^c = V^c$ is tested.
  - That is, T2: $B^{US}(w^{US})T^c = V^c - s^c V^w$ is tested.
- "P2&T2": Common technology with measurement error:
  - Suppose the differences in $\bar{B}(w)$ we see around the world are just classical (log) ME.
  - DW look for this by estimating $\ln \bar{B}^c(w^c) = \ln \bar{B}(w)^\mu + \varepsilon^c$, where $\bar{B}(w)^\mu$ is the common technology around the world, and ε^c is the CME (i.e. just noise).
  - The actual regression across industries i and factors k is: $\ln \bar{B}^c(w^c)_{ik} = \beta_{ik} + \varepsilon^c_{ik}$, where β_{ik} is a fixed-effect.
  - Then (for P2), $\widehat{\bar{B}(w)}^\mu Y^c = V^c$ is tested, using $\widehat{\beta}_{ik}$ to construct $\widehat{\bar{B}(w)}^\mu$

DW (2001): Hypothesis 1 (Standard HOV)

This is 'P1', the *production* side of H1

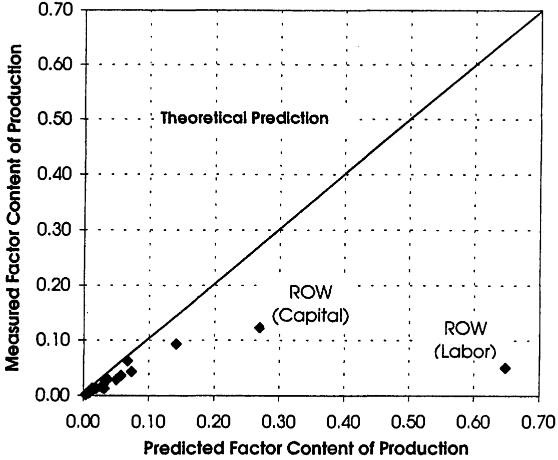

FIGURE 1. PRODUCTION WITH COMMON TECHNOLOGY (US) (P1)

DW (2001): Hypothesis 1 (Standard HOV)

This is 'T1', the *trade* side of H1

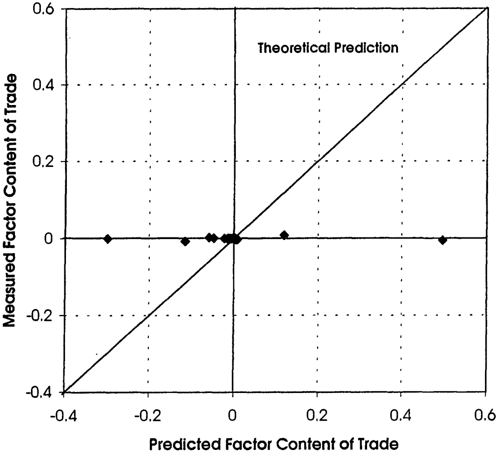

FIGURE 2. TRADE WITH COMMON TECHNOLOGY (US) (T1)

DW (2001): Hypothesis 2 (Measurement error)

This is 'P2', the *production* side of H2. Plot of 'T2' looks like 'T1', apparently.

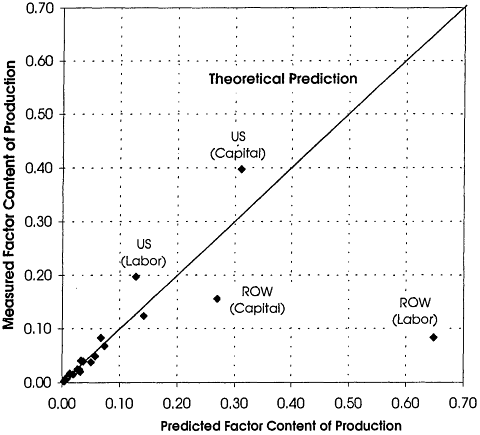

FIGURE 3. PRODUCTION WITH COMMON TECHNOLOGY (AVERAGE) (P2)

DW (2001): The 7 Nested Hypotheses and Results (cont)

- "P3&T3": Hicks-neutral technology differences:
  - Here, as in Trefler (1995), they allow each country to have a λ^c such that: $\bar{B}^c(w^c) = \lambda^c \bar{B}(\lambda^c w^c)$.
  - Note that this still has 'conditional FPE', so the *ratio* of techniques used across factors or goods will be the same across countries.
  - This translates into estimating θ^c in the regression: $\ln \bar{B}^c(w^c)_{ik} = \theta^c + \beta_{ik} + \varepsilon^c_{ik}$

DW (2001): Hypothesis 3 (Hicks-neutral tech diffs)

This is 'P3', the *production* side of H3. Plot of 'T3' looks like 'T1', apparently.

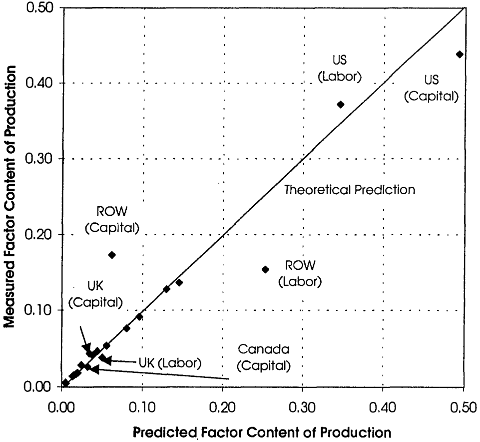

FIGURE 4. PRODUCTION WITH HICKS-NEUTRAL TECHNICAL DIFFERENCES (P3)

DW (2001): The 7 Nested Hypotheses and Results (cont)

- "P4&T4": DFS (1980) continuum model aggregation:
  - In a DFS-HO model with infinitessimally small trade costs, countries will use different techniques when they produce traded goods. However, this won't spill over onto non-traded goods.
  - If the industrial classifications in our data are really aggregates of more finely-defined goods (as in a continuum) then at the aggregated industry level it will look like countries' endowments affect their choice of technique.
  - To incorporate this, DW estimate $\ln \bar{B}^c(w^c)_{ik} = \theta^c + \beta_{ik} + \gamma_i^T \ln(\frac{K^c}{L^c}) \times TRAD_i + \varepsilon^c_{ik}$, where $TRAD_i$ is a dummy for tradable sectors.
  - Estimates of this are used to construct $\widehat{\bar{B}(w)}^{DFS}$ analogously to before. But this correction alters both the production and absorption equations (since the factor content of what country c imports depends on the endowments of each separate exporter to c).

DW (2001): Hypothesis 4 (DFS model aggregation)

This is ‘P4’, the *production* side of H4.

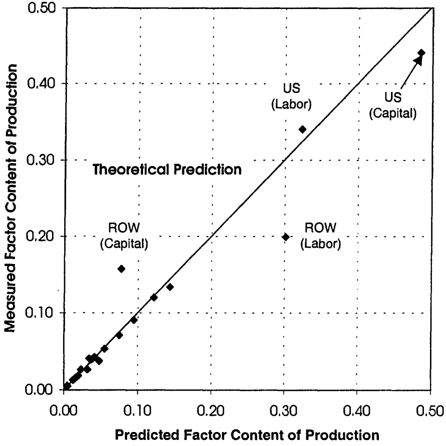

FIGURE 5. PRODUCTION WITH CONTINUUM OF GOODS MODEL AND FPE
(P4)

DW (2001): Hypothesis 4 (DFS model aggregation)

This is 'T4', the *trade* side of H4.

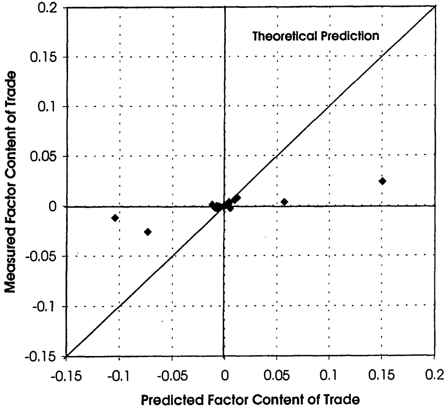

FIGURE 6. TRADE WITH CONTINUUM OF GOODS MODEL AND FPE (T4)

DW (2001): The 7 Nested Hypotheses and Results (cont)

- "P5&T5": DFS (1980) continuum model with non-FPE:
  - Another reason for $\gamma_i^T \neq 0$ in the regression above (other than aggregation) is the failure of FPE due to countries being in different cones of diversification. (See Helpman (JEP, 1999) for description.)
  - In this case, this effect *will* spill over onto non-traded goods (since factor prices affect technique choice in all industries).
  - To incorporate this, DW estimate $\ln \bar{B}^c(w^c)_{ik} = \theta^c + \beta_{ik} + \gamma_i^T \ln(\frac{K^c}{L^c}) \times TRAD_i + \gamma_i^{NT} \ln(\frac{K^c}{L^c}) \times NT_i \varepsilon_{ik}^c$, where NT_i is a dummy for non-tradable sectors.
  - Here, tests of the HOV analogue equations need to be more careful still, to make sure we use only the bits of the technology matrix that relate to tradable sector production.

DW (2001): Hypothesis 5 (DFS model with non-FPE)

This is 'P5', the *production* side of H5.

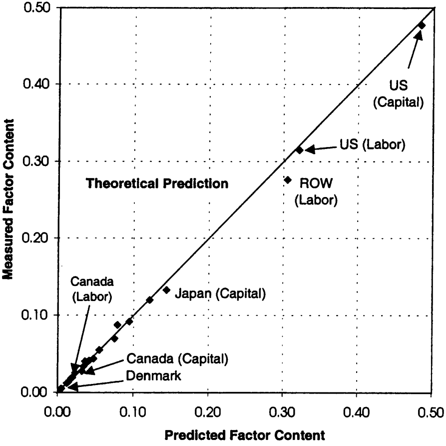

FIGURE 7. PRODUCTION WITHOUT FPE
(P5)

DW (2001): Hypothesis 5 (DFS model with non-FPE)

This is 'T5', the *trade* side of H5.

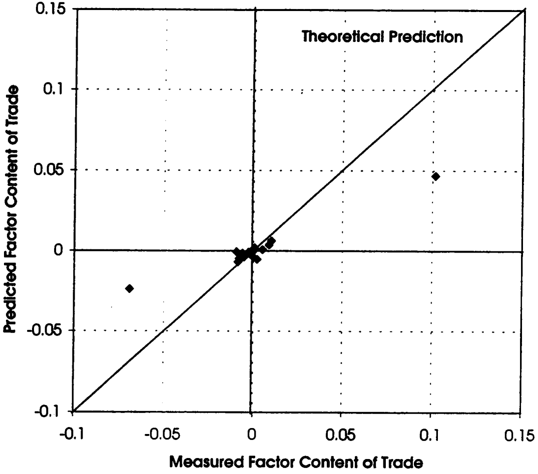

FIGURE 8. TRADE WITH NO-FPE, NONTRADED GOODS (T5)

DW (2001): The 7 Nested Hypotheses and Results (cont)

- "P7&T7": Demand-side differences due to trade costs:
  - Predicted imports in the HO setup are many times larger than actual imports. One explanation is trade costs.
  - To incorporate this, DW estimate gravity equations on imports, allowing them to estimate how trade costs (proxied for by distance) impedes imports.
  - They then use the predicted imports (from this gravity equation) in place of actual data on imports when testing the HOV trade equation (i.e. T7).
  - Note that this is not really an internally-consistent way of introducing trade costs. Trade costs also tilt relative prices (so countries want different ratios of goods), and relative factor prices (so techniques differ in ways that are not simply dependent on endowments).

DW (2001): Hypothesis 7 (Demand-side differences due to trade costs)

This is 'T7', the *trade* side of H7.

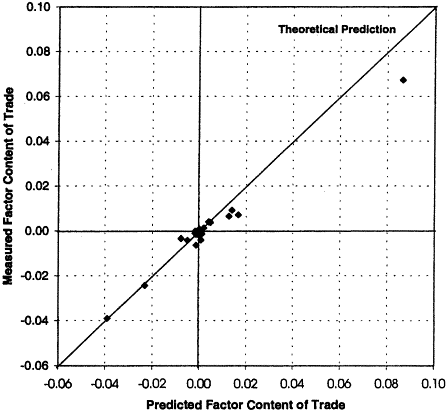

FIGURE 10. TRADE WITH NO-FPE, GRAVITY DEMAND SPECIFICATION, AND ADJUSTED ROW (T7)

DW (2001): Taking Stock

- DW (2001) conduct a formal model test on the production side off the model.
  - For the purposes of fitting production, and as judged by the Schwarz criterion (which trades off fit vs extra parameters used up in a particular way), P5 is “best”.
- However, because these hypotheses affect the absorption side too, a good fit on the production side doesn't guarantee a good fit on the trade side.
  - By all measures they consider (sign tests, regressions, “missing trade” statistic) T7 does best on the trade side.
  - And T7 has an R^2 of 0.76, which is pretty impressive when you consider how grand an exercise this is (accounting for production, consumption and trade around the OECD, in a relatively parsimonious model).

Subsequent Work on NFCT Empirics

- Antweiler and Trefler (AER, 2002):
  - Adding external returns to scale (as in parts of Helpman and Krugman (1985 book)) to HOV equations in order to estimate the magnitude of these RTS.
- Schott (QJE, 2003):
  - Even within narrowly-defined (10-digit) industries, the unit value of US imports vary dramatically across exporting countries (and this variation is correlated with exporter endowments).
- Trefler and Zhu (JIE, 2010):
  - The treatment of *traded* intermediates affects how you calculate the HOV equations properly.
  - Also a characterization of the class of demand systems that generates HOV. (That is, is IHP necessary?)
- Davis and Weinstein (2008, book chapter, "Do Factor Endowments Matters for North-North Trade?"):
  - Intra-industry trade and HOV empirics.

1. Introduction
2. Tests concerning the 'goods content' of trade
3. Factor content of trade tests
4. **Empirical work on the Specific Factors model**
5. Brief discussion of other tests
6. Areas for future research

Empirical Work on the Specific Factors Model

- Very little empirical work on the SF model. Why?
  - SF model is best thought of as the short- to medium-run of the H-O model so you'd expect an integrated, dynamic empirical treatment of the two models. However, most H-O empirics is done using a cross-section, which is usually thought of as a set of countries in long-run equilibrium. Hence, there was never a pressing need to think about adjustment dynamics (i.e. the SF model).
  - There is probably also a sense that a serious treatment of these dynamics is too complicated for aggregate data (even if aggregate panel data were available).
  - The heightened availability of firm-level panel data opens up new possibilities.
- We will look here at papers that have identified and tested aspects of SF model that are unique to SF model (at least relative to H-O).

Factor Price Responses to Goods Price Changes

- The classic distinction between the SF and HO models concerns their implications for how factor incomes respond to trade liberalization.
  - That is, how do factor prices respond to changes in goods prices (the "Stolper-Samuelson derivative": $\frac{dw}{dp}$)?
  - In SF model, as p falls in a sector, prices of factors specific to that sector fall too. Factor incomes are tied to the fate of the sector in which they work.
  - In HO model, as p falls, factor incomes are governed by full GE conditions. Factor prices may fall or rise (or with many sectors we might expect them not to move much).

- This distinction drives the empirical approach of a number of papers concerned with testing the SF vs the HO model:
  - Wages: Grossman (1987), Abowd (1987)
  - Capital returns: Grossman and Levinsohn (AER, 1989)
  - Lobbying behavior: Magee (1980)
  - Opinions about free trade: Mayda and Rodrik (EER, 2005)

Grossman and Levinsohn (1989)

- Testing the effect of goods price changes on factor returns:
  - Using wages is attractive: there is (probably) something closer to a 'spot market' (at which we observe the going price) for labor than there is for machines.
  - Using capital returns is also attractive: Can (with some assumptions) use data from stock markets, which provides high quality and high-frequency data, as well as the usual opportunities for an "event study" approach. (We are perhaps more likely to believe this is a setting where prices are set by forward-looking, rational agents facing severe arbitrage pressures.)
- In an innovative paper, GL (1989) follow the latter approach.

GL (1989): Setup

- GL (1989) draws on Pakes (1985):
  - Model of firm-level investment with capital adjustment costs.
  - Vector z_{it} summarizes (the log of) all state variables that firm i takes as given at date t.
  - For our purposes, the key element in z_{it} is the log price of imports in firm i's industry (a demand curve shifter).
  - Assume that firm i's country is a price-taker on world markets.

- Pakes (1985) predicts that:

$$r_{it} - r_{mt} = k_i(z_{it} - E_{t-1}[z_{it}]) - k_m(z_{mt} - E_{t-1}[z_{mt}])$$

- Where r is (log) realized returns on shares, the k's are constants, and m stands for the "entire market."
- That is, firm i gets excess realized returns ("excess" means: relative to the market) if its z_{it} is a surprise (relative to the overall market 'surprise').

GL (1989): Implementation I

- The key challenge is to construct measures of 'surprises': $z_{it} - E_{t-1}[z_{it}]$.
  - Import prices: GL model these as a multivariate autoregressive process in (lagged) import prices, foreign wages, and exchange rates. Once this is estimated, the residuals of the process can be interpreted as "surprises".
  - Other elements of z: domestic input prices (domestic energy prices and domestic wages), domestic macro variables (GNP, PPI, M1 Supply). All are converted into "surprises" through a VAR.
  - Surprises to 'market' (m): use same variables as above, but use *average* market import price rather than firm i's own industry's import price.

GL (1989): Implementation II

- The result is a regression of excess returns ($r_{it} - r_{mt}$) on "surprises" ("*NEWS*" in GL(1989) notation) to:
  - Import prices in firm i's industry ('*PSNEWS*).
  - Import prices in market, on average.
  - Domestic input prices.
  - Domestic macro variables.
- SF model predicts that coefficient on *PSNEWS* is positive. Simple calibration suggests coefficient in this model should be just above one.
- If capital could instantaneously reallocate across industries in response to surprises (as in H-O model) then the coefficient on *PSNEWS* would be zero.

GL (1989) Results

Regressions run one industry at a time; 'market' portfolio m is entire stock market

TABLE 3—ESTIMATION OF RANDOM-EFFECTS MODEL WITH TIME COMPONENTS (BASE CASE RESULTS FOR RISK NEUTRAL VERSION)[a]

Definition of Excess Return: $q_{it} = r_{it} - r_{mt}$

Determinants of Excess Return: $q_{it} = \Gamma_1 PSNEWS_{nt} + \Gamma_2 WSNEWS_t + \Gamma_3 ERNEWS_t + \Gamma_4 AGGMNEWS_t + \Gamma_5 PENEWS_t + \Gamma_6 WNEWS_t + \Gamma_7 GNPNEWS_t + \Gamma_8 PPINEWS_t + \Gamma_9 MSNEWS_t + \nu_{it}$

	SIC 262	SIC 242	SIC 301	SIC 345	SIC 32	SIC 331
PSNEWS	1.217[b]	0.476[c]	−0.357	1.152	0.827[c]	0.908[b]
	(0.449)	(0.280)	(1.25)	(0.819)	(0.476)	(0.343)
WSNEWS	−0.648	−0.209	−1.115	−2.214	1.230	2.071
	(0.834)	(1.21)	(2.83)	(1.59)	(0.854)	(1.43)
ERNEWS	–	0.724	–	–	0.133	–
		(0.784)			(0.442)	
AGGMNEWS	−0.044	0.192	0.351	0.103	−0.112	−0.410
	(0.275)	(0.414)	(0.498)	(0.499)	(0.219)	(0.386)
PENEWS	−0.164	−0.870[b]	−0.547	−0.542	−0.776[b]	−0.173
	(0.356)	(0.454)	(0.486)	(0.561)	(0.255)	(0.487)
WNEWS	4.376[b]	4.424[b]	4.828[b]	0.773	2.922[b]	0.225
	(1.21)	(1.81)	(1.89)	(2.18)	(1.10)	(1.78)
GNPNEWS	2.825[b]	0.310	1.166	4.167[c]	0.726	1.470
	(1.17)	(1.83)	(1.83)	(2.03)	(0.902)	(1.56)
PPINEWS	0.345	1.585	2.675	1.494	1.584[c]	1.279
	(1.07)	(1.59)	(1.86)	(2.18)	(0.853)	(1.62)
MSNEWS	2.784[b]	2.565	3.080[c]	4.628[b]	3.029[b]	1.407
	(1.23)	(1.68)	(1.63)	(1.99)	(0.978)	(1.62)
R^2	0.097	0.156	0.093	0.172	0.083	0.117
No. of Firms in SIC Group	9	5	7	2	16	16
Estimation Period	1974:2 to 1985:4	1974:3 to 1986:3	1976:3 to 1986:3	1975:2 to 1986:3	1974:2 to 1986:3	1975:1 to 1984:2

[a]Standard errors in parentheses.
[b]Significantly different from zero at the 5 percent level, two-tailed test.
[c]Significantly different from zero at the 10 percent level, two-tailed test.

Magee (1980): "Simple Tests of the S-S Theorem"

- Magee (1980) collects data from testimony given in a Congressional committee on the Trade Reform Act of 1973.
  - 29 Trade associations ("representing management") and 23 labor unions expressed whether they were for either freer trade or greater protection. These groups belong to industries.

- Striking findings, in favor of SF model (and against simple version of the S-S Theorem/HO model):
  1. K and L tend to agree on trade policy within an industry (in 19 out of 21 industries).
  2. Each factor is not consistent across industries. (Consistency is rejected for K, but not for L).
  3. The position taken by a factor (in an industry) is correlated with the industry's trade balance.

- Relatedly: As we shall see later in the course, lobbying models (most prominently: Grossman and Helpman (AER, 1994)) typically make the SF assumption for tractability.
  - Goldberg and Maggi (AER, 1999) find empirical support for this in the US tariff structure.

Mayda and Rodrik (EER, 2005)

- Mayda and Rodrik (2005) exploit internationally-comparable surveys (such as the World Values Survey) to look at how national attitudes to free trade differ across, and within, countries.
- Findings support both HO and SF models:
  - HO: People in a country are more likely to oppose trade reform if they are relatively skilled and their country is relatively skill-endowed. (Recall S-S: trade reform favors scarce factors.)
  - SF: People in import-competing industries are more likely to oppose trade reform (than those in non-traded industries).

Kohli (JIE, 1993): Introduction

- Kohli (1993) pursues a different distinction between SF and HO.
- Basic idea:
  - In a standard neoclassical economy, profit maximization leads to maximization of the total value of ouptut (i.e. GNP).
  - Further, the revenue (or 'GNP') function summarizes all information about the supply-side of the economy.
  - The solution to revenue maximization problem should depend, in some way, on whether the maximization is constrained (some factor cannot move across sectors, i.e. the SF model) or unconstrained (all factors can move, i.e. the HO model).
  - Kohli (1993) searches for a way to isolate how constrained and unconstrained GNP functions look in general, and then tests for this.

Kohli (1993): Details I

- Kohli (1993) works with the (net) *restricted* GNP/revenue function (Diewert, 1974):

$$\widetilde{R}(p_1, p_2, w, K) \equiv \max_{y_1, y_2, L} \{p_1 y_1 + p_2 y_2 - wL : (y_1, y_2, L, K) \in T\}$$

  - Where p is the goods price (in sector 1 or 2), y is output, L and K are labor and capital endowments, w is the wage, and T is the feasible technology set.
  - Here 'restricted' means that the allocation of K is fixed across sectors. Only L can be allocated to maximize (net) revenue/GNP.

- This is homogeneous (of degree 1) in K: $\widetilde{R}(p_1, p_2, w, K) = r(p_1, p_2, w)K$.

Kohli (1993): Details II

- Kohli makes one assumption that is not in the usual SF model: *relative* stocks of industry-specific capital are constant over time.
  - If this is true, then it is as if each industry was using a (different) amount of some *public* input.
- Kohli (1985) shows that if there is such a public input, and it is K, then the aggregate restricted revenue function is additively separable across industries:

$$\widetilde{R}(p_1, p_2, w, K) = \widetilde{R}^1(p_1, w, K) + \widetilde{R}^2(p_2, w, K)$$

- Note that, unlike in the general case, $\frac{\partial^2 \widetilde{R}}{\partial p_1 \partial p_2} = 0$. This is what Kohli (1993) tries to test.

Kohli (1993): Details III

- To make progress, Kohli (1993) needs to assume a functional form for $\widetilde{R}(.)$.
- In particular, he works with the 'Generalized Leontief' production function (Diewert, 1971) with disembodied technological change:

$$\begin{aligned}\widetilde{R}(p_1, p_2, w, K) &= [b_{11}p_1 + b_{22}p_2 + b_{LL}we^{\mu_L t} + 2b_{12}\sqrt{p_1}\sqrt{p_2} \\ &+ 2b_{1L}\sqrt{p_1}\sqrt{w}e^{-1/2\mu_L t} \\ &+ 2b_{2L}\sqrt{p_2}\sqrt{w}e^{-1/2\mu_L t}]Ke^{\mu_K t}\end{aligned}$$

- Note that the key testable restriction of the SF model is now $\frac{\partial^2 \widetilde{R}}{\partial p_1 \partial p_2} = b_{12} = 0$.
- Kohli tests this using aggregate US data from 1948-1987.

Kohli (1993) Results I

Two 'goods' (1 and 2) are Consumption and Investment. Also presented are joint cost function estimates (dual to the revenue function).

Table 2

Parameter estimates (t-values in parentheses).

Restricted joint cost function	JP	ANJIPQ	Revenue function	JP	ANJIPQ
a_{II}	932.15 (16.30)	1,002.8 (18.71)	b_{II}	2,000.4 (6.59)	1,964.5 (6.54)
a_{CC}	8,541.8 (20.09)	8,919.6 (21.76)	b_{CC}	4,734.8 (24.37)	4,730.6 (24.56)
a_{KK}	6,774.0 (15.29)	6,557.4 (15.31)	b_{LL}	1,982.9 (4.71)	2,144.7 (6.25)
a_{IC}	311.31 (2.86)	–	b_{IC}	−103.59 (−0.66)	–
a_{IK}	−766.12 (−7.18)	−527.22 (−8.83)	b_{IL}	−1,170.2 (−3.85)	−1,238.4 (−4.25)
a_{CK}	−6,949.5 (−16.67)	−6,994.4 (−16.66)	b_{CL}	−2,485.2 (−10.12)	−2,581.0 (−13.31)
μ_L	0.01052 (12.01)	0.00967 (10.06)	μ_L	0.01504 (18.90)	0.01500 (18.19)
μ_K	0.00203 (3.25)	0.00335 (6.77)	μ_K	0.00196 (4.04)	0.00216 (5.42)
LL	−494.59	−498.19	LL	−505.20	−505.42
R_p^2	0.94849	0.94531	R_p^2	0.93852	0.93831

Notes:

JP: joint production.

ANJIPQ: almost non-jointness in input prices and quantities.

Kohli (1993) Results II

So the SF model's restriction is not rejected when using the revenue approach. (It is when using the joint cost approach, but in an open economy it is perhaps more sensible to take prices as exogenous (revenue approach) than quantities as exogenous (cost approach).)

Table 3

Specific-factors model: tests statistics.

H_1	H_0	Restriction	Test statistic	df	$\chi^2 0.95$	$\chi^2 0.99$
(i) GL restricted joint cost function						
JP	ANJIQP	$a_{IC}=0$	7.20	1	3.84	6.63
(ii) GL revenue function						
JP	ANJIQP	$b_{IC}=0$	0.44	1	3.84	6.63

Notes:

JP: joint production.

ANJIPQ: almost non-jointness in input prices and quantities.

Other Work on the SF Model

- See "regional incidence" of trade shocks work in the next lecture (on trade and labor markets).
- And see some of the work on trade adjustment dynamics referred to below.
- Both of these can be thought of as versions of the SF model

Plan of Today's Lecture (HO Empirics, Part I)

1. Introduction
2. Tests concerning the 'goods content' of trade
3. Factor content of trade tests
4. Empirical work on the Specific Factors model
5. **Brief discussion of other tests**
6. Areas for future research

Other Tests of HO Theory

Too much to cover here, but briefly...(see syllabus and/or ask me if you want more references)

- Tests of FPE and 'factor price convergence'.
- Tests of the S-S theorem. (We will see some of this in the next lecture on trade and labor markets.)
- Tests of the Rybczinski theorem.
- Bilateral tests of NFCT in a non-FPE world:
  - Theory due to Helpman (1984).
  - Empirics in Choi and Krishna (JPE, 2004).
- Autarky price version of the HO theorems:
  - Bernhofen and Brown (2009); case of Japan, 1853.

Plan of Today's Lecture (HO Empirics, Part I)

1. Introduction
2. Tests concerning the 'goods content' of trade
3. Factor content of trade tests
4. Empirical work on the Specific Factors model
5. Brief discussion of other tests
6. **Areas for future research**

Areas for Future Work I

- In general, Baldwin (2009 book) has a nice discussion of this.
- Quantifying the relative importance of endowment vs technology differences for trade and/or welfare (i.e. HO vs Ricardo). Morrow (2009) extends Romalis (2004) to make progress here.
- Empirical HO with endogenous technology (e.g. skill-biased technological change). Traditional HO theory takes technology as identical across countries and, especially, exogenous to endowments, so ignores the ideas of directed technical change, adoption, learning by doing, external economies of scale, "appropriate technologies", etc.
- Endowments are not exogenous either, of course. At the simplest level, accumulable factors (K and H) are likely to respond to technological differences. (A "dynamic HO model".) This would be interesting to estimate in the data, and its presence potentially biases standard HO tests.

Areas for Future Work II

- HO with trade costs: they're big (as we'll see in lectures soon), but they're hard to add to perfectly competitive, homogeneous goods models.
- Empirical HO with heterogeneous firms (and fixed trade costs that induce selection): Bernard, Redding and Schott (ReStud, 2007) and Eaton and Kortum (2002) are possible frameworks for thinking about this.
- Empirical implications of assignment models with HO-style features (e.g. Trefler and Ohnsorge (JPE, 2007), Costinot (Ecta, 2009), and Costinot and Vogel (2009)).
- Incorporate into HO empirics some important features of emerging facts in other areas of trade: much of trade is in intermediate goods, is intra-firm, etc.
- HO with factor mobility and trade costs (i.e. economic geography).

Areas for Future Research III

- Tracing the short-, medium- and long-run factor adjustment to trade liberalizations or other natural experiments.
  - Can SF and HO models be unified in the data as the same model with different time horizons?
  - Ideally one could use firm-level panel data (which we will see lots of later in the course).
  - Trefler (2004 AER) does this well for Canada's liberalization (CUSFTA), as we will see later. But focus there was on productivity changes, rather than factor adjustment/mobility.
  - Muendler and Menezes-Filho (2007) and Dix-Carneiro and Kovak (2017) exploit rich data on Brazilian matched employer-employee records to track workers around a trade liberalization episode. We will see a bit of this next lecture.
  - Could we track other factors like capital/machines/land use?

Areas for Future Research IV

- Adjustment to trade liberalization with proper micro-founded adjustment costs, estimated rigorously:
  - Capital market adjustment frictions: Caballero-Engel (various), Bloom (Ecta, 2008), etc.
  - Labor market adjustment frictions: McLaren and Choudhuri (AER, 2010) on idiosyncratic location-specific utilities; Tybout et al (2009) on search frictions; Dix-Carneiro (Ecta, 2015).
- Further applications of the GL (1989) event-study approach to Trade questions? (E.g. Breinlich, JIE 2014, on stock price adjustments to Canada-US Free Trade Agreement of 1989.)