ECO 745: Theory of International Economics

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Fall 2015 - Lecture 17

Linkages and Fragmentation in International Trade

Have focused on models of trade where production takes place in a single stage with no linkages

- Limited attention to horizontal linkages: output used as intermediate input in CES fashion
- Linkages amplify impact of trade: foreign inputs cheaper ⇒ lower domestic production costs

In practice, production is internationally fragmented

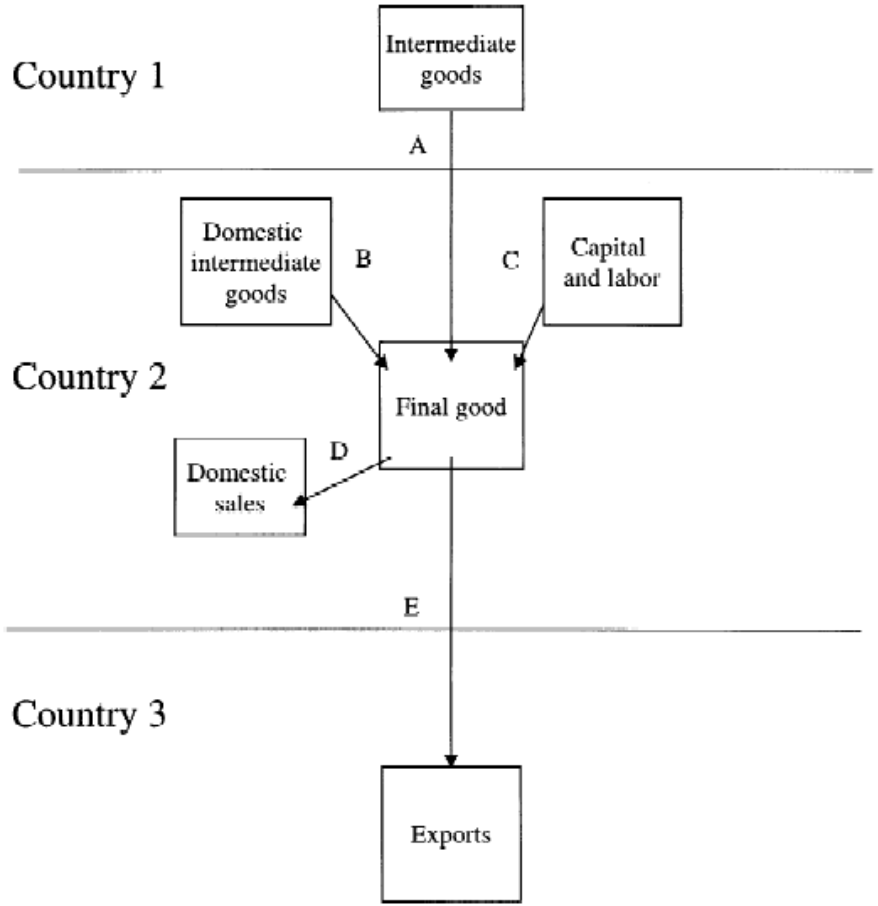
- Horizontal Fragmentation: Produce same output in multiple locations, e.g. can either export or engage in FDI and set up a foreign affiliate to produce your good directly in foreign market
- Vertical Fragmentation: Production occurs in stages, e.g. product components can be manufactured in one country, then assembled into final product in another country.

Vertical Specialization

Hummels, Ishii, and Yi (2001) discuss sequential vertical specialization

- Difficult to tell whether goods are intermediate inputs or final outputs from trade flow data
- Solution: Use input-output tables
- Focus on chains where intermediate input is imported and used to produce a final output, which is then exported

Diagram of Simple Vertical Specialization



Hummels, Ishii, and Yi (2001)

Measuring Vertical Specialization

Measure Vertical Specialization in industry i in country k as

$$VS_{ki} = \left(\frac{\text{imported intermediates}}{\text{gross output}}\right) \times \text{exports}$$

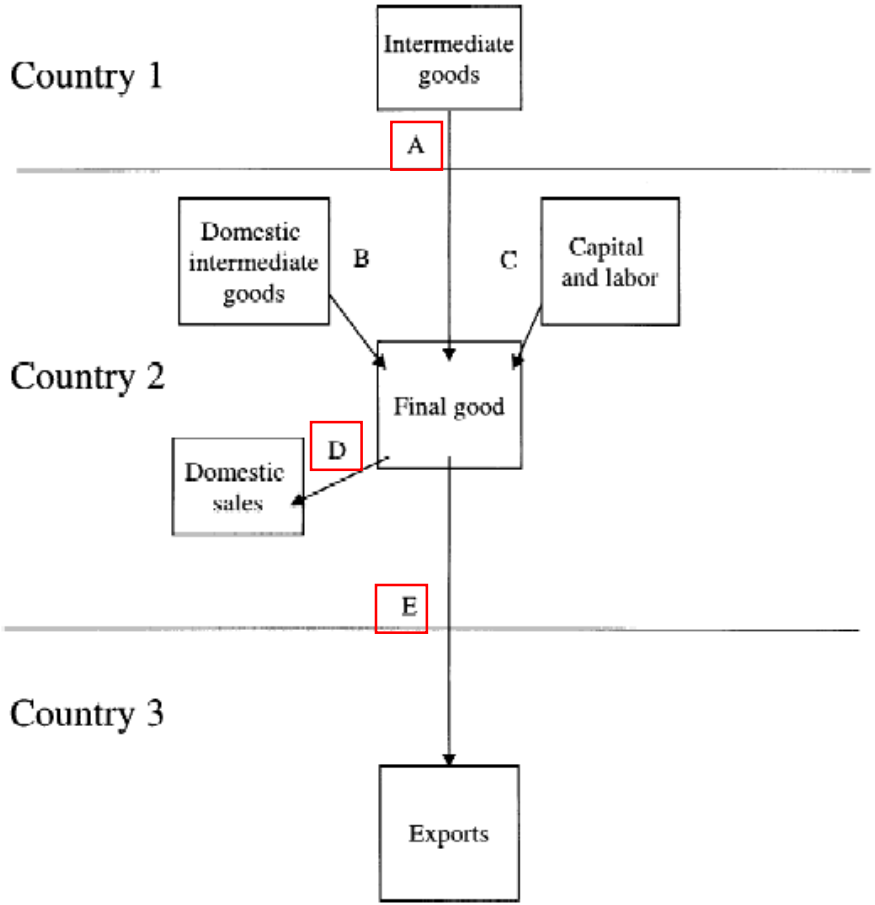
Total Vertical Specialization for country k as share of total exports is

$$\text{VS share of total exports} \equiv \frac{VS_k}{X_k} = \frac{\sum_i VS_{ki}}{\sum_i X_{ki}} = \sum_i \left[\left(\frac{X_{ki}}{X_k}\right)\left(\frac{VS_{ki}}{X_{ki}}\right)\right]$$

where X_{ki} is exports in industry i for country k.

- Export-weighted average of industry VS export shares

Diagram of Simple Vertical Specialization



$$VS_{2i} = \left(\frac{\text{imported intermediates}}{\text{gross output}}\right) \times \text{exports}$$

$$= \left(\frac{\text{A}}{\text{D+E}}\right) \times \text{E}$$

Hummels, Ishii, and Yi (2001)

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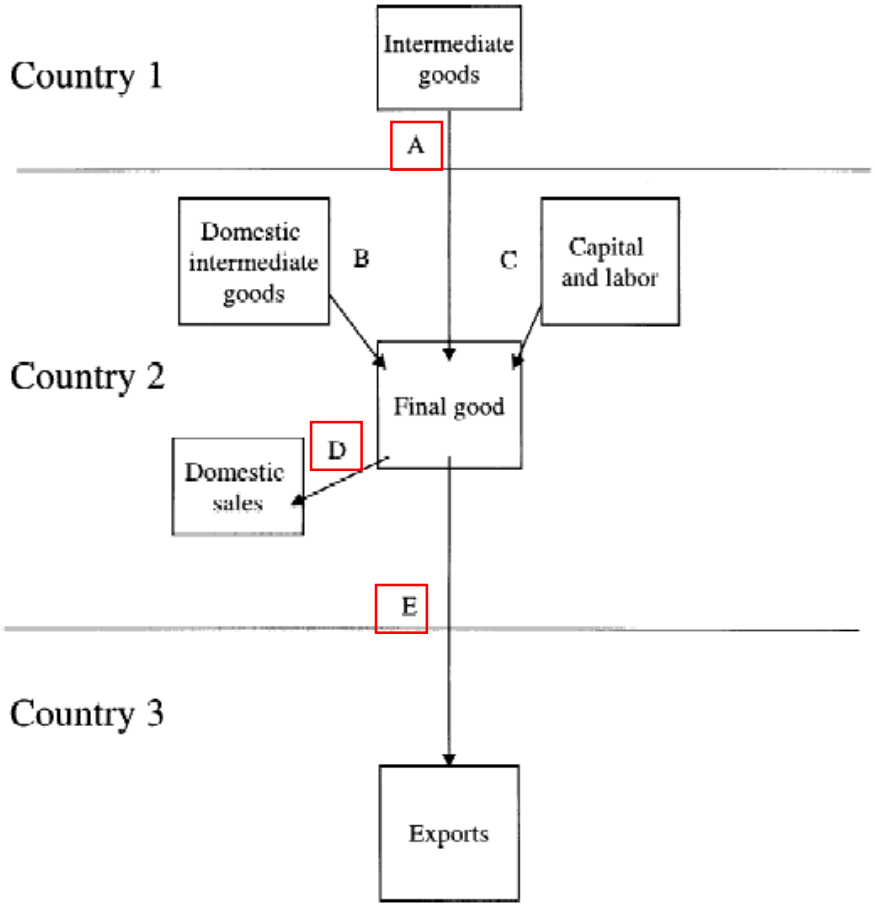

$$VS_{2i} = \left(\frac{\text{imported intermediates}}{\text{gross output}}\right) \times \text{exports}$$

$$= \left(\frac{\text{A}}{\text{D+E}}\right) \times \text{E}$$

If only one industry:

$$\frac{VS_2}{X_2} = \left(\frac{\text{A}}{\text{D+E}}\right)$$

Suppose extreme example: $D = 0$, then

$$\frac{VS_2}{X_2} = \left(\frac{\text{A}}{\text{E}}\right)$$

Hummels, Ishii, and Yi (2001)

Data and Findings

Data:

- Source 1: OECD Input-Output Tables for ten countries between 1968–1990
- Source 2: Input-Output tables from national statistical agencies for Ireland, Korea, Taiwan
- Source 3: Exports from foreign owned plants or “maquiladoras”

Data and Findings

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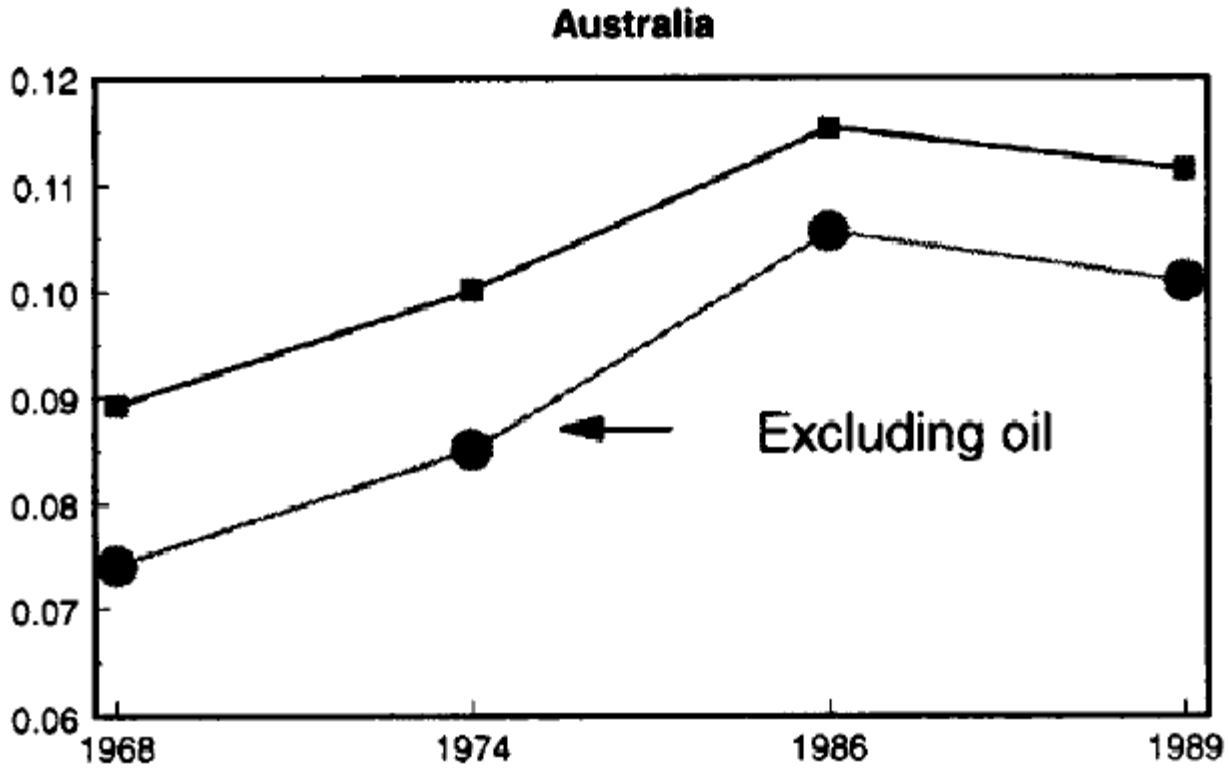
Findings:

- Significant variation in VS share across countries; higher VS for lower GDP countries
- VS share grew for all countries except Japan, net increase ~22 % over 20 year period
- Higher levels, but smaller increases for Ireland, Korea, and Taiwan
- Changes driven by changes in industry VS intensities, not by industry composition of exports

Evolution of Vertical Specialization Share



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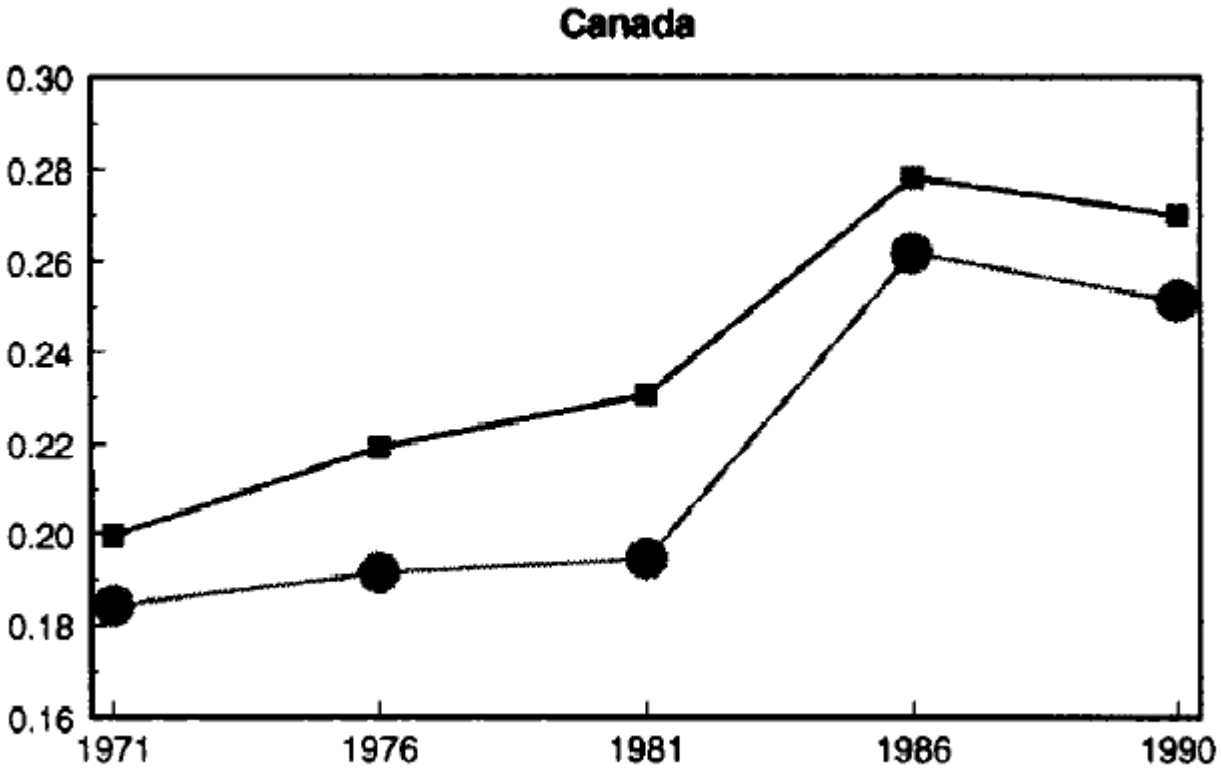

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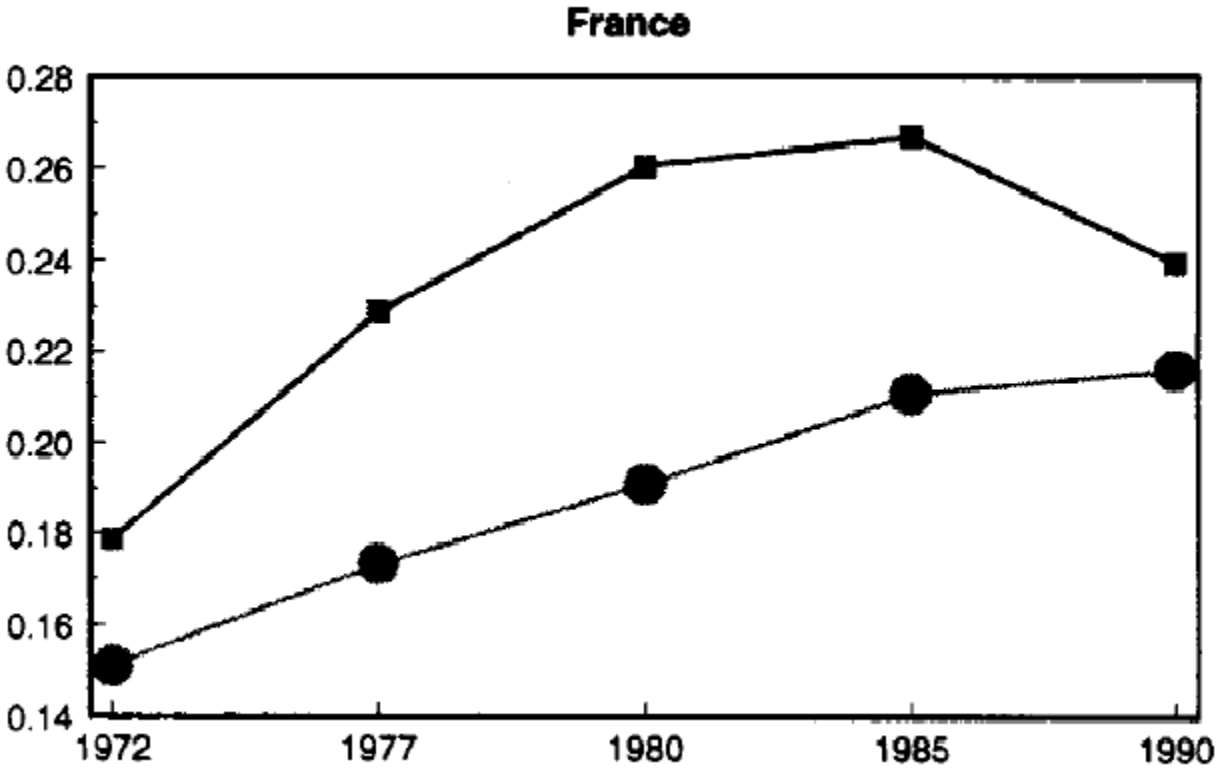

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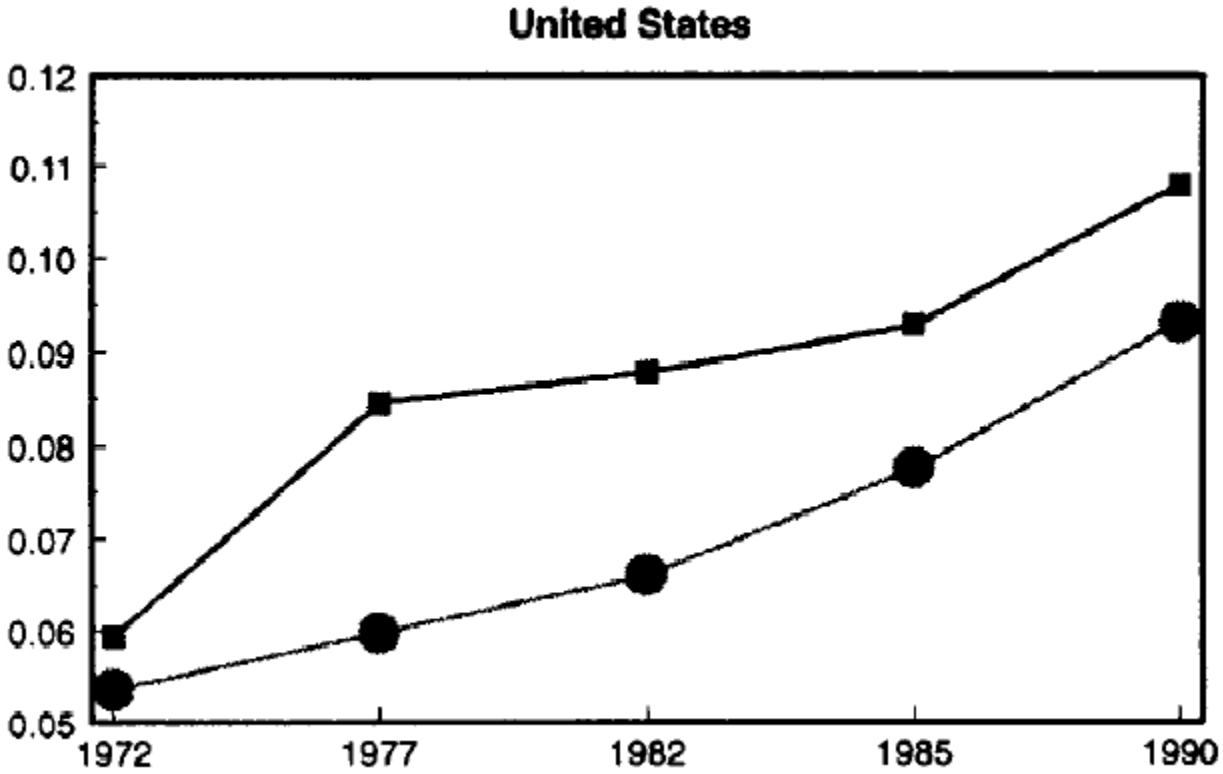

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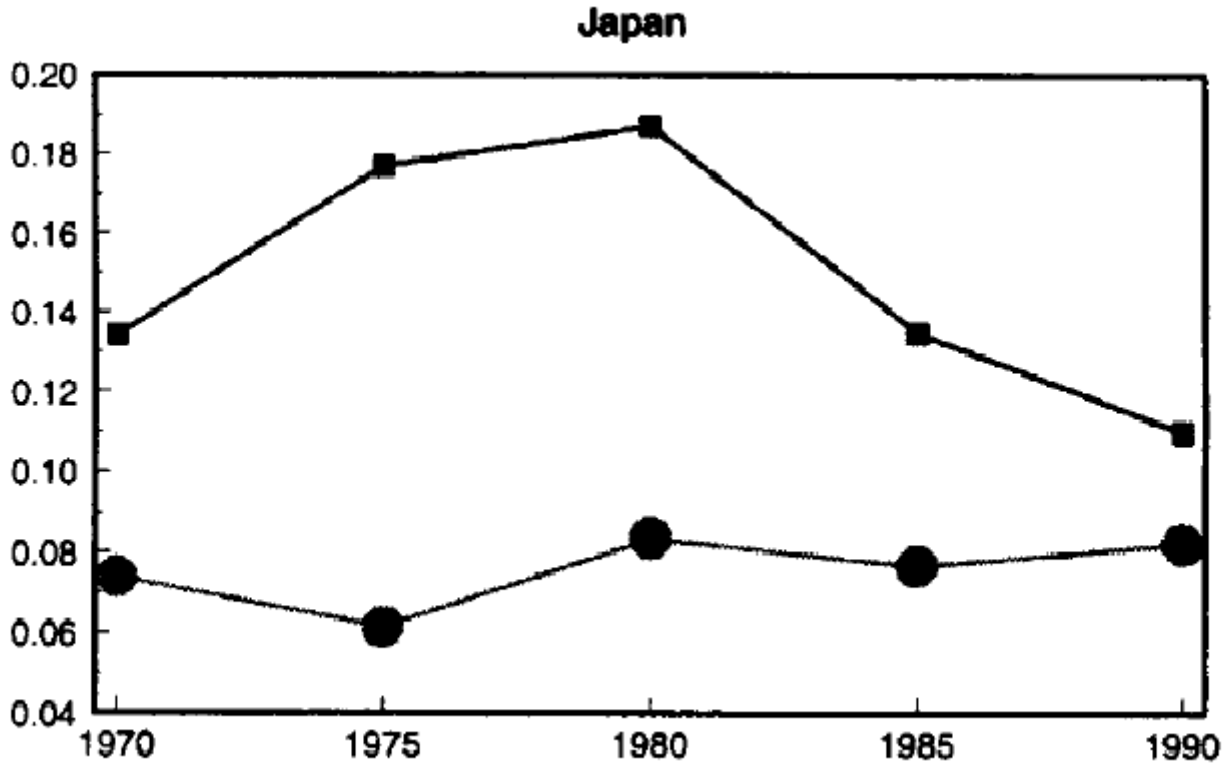
Evolution of Vertical Specialization Share



Hummels, Ishii, and Yi (2001)

Evolution of Vertical Specialization Share

Fig. 3. Vertical specialization: Ireland, Korea, Taiwan, and Mexico.

Hummels, Ishii, and Yi (2001)

Vertical Specialization Important Portion of Growth in Trade

Table 1
World VS exports[a]

	Set of countries			
	1		2	
	Countries' share of world exp	VS share of exports	Countries' share of world exp	VS share of exports
1970	0.60	0.165	0.74	0.180
1990	0.63	0.211	0.82	0.236
Growth in VS share		28.4%		31.3%
Contribution of VS exports to growth in exports/GDP		30.1%		32.5%

Hummels, Ishii, and Yi (2001)

Changes Driven by Industry VS Share Intensity

Sources of cross-country differences in VS share of total exports (final year)[a]

	Difference between VS share and VS share of representative country	Contribution of: (%)	
		Difference in sector VS intensity	Difference in sector share of total exports
Australia	−0.108	52.4	47.5
Canada	0.051	86.1	13.8
Denmark	0.077	85.3	14.7
France	0.020	70.9	29.1
Germany	−0.024	134.2	−34.2
Italy	0.049	68.1	31.9
Japan	−0.110	92.1	7.9
Netherlands	0.150	88.3	11.7
United Kingdom	0.039	83.7	16.3
United States	−0.112	103.8	−3.8

Hummels, Ishii, and Yi (2001)

Vertical Specialization

Conclusions of Hummels, Ishii, and Yi (2001)

- Vertical Specialization important and growing portion of trade
- Increase in Vertical Specialization is occurring at the industry level
- Shortcoming: Only simplest version of vertical fragmentation considered.

Expand view of vertical specialization

- **Yi (2003): Can it explain growth in world trade?**
- Yi (2011): Can it explain home bias in international trade?

Vertical Specialization and Growth in World Trade

Yi (2003) interested in explaining growth in world trade

- From 1962–2000, world trade increased by ~300 percent
- Tariffs already relatively low in 1962, average tariff fell from 15% to 4%

Calibrates two-country dynamic Ricardian model of VS to tariff reductions

- Model generates almost all growth in VS and 50 percent of total growth in U.S. trade
- Model without VS, generates only 13 percent of the growth in U.S. trade
- Higher welfare gains from fall in tariffs in model with VS
- Static models not able to match growth in trade without unrealistically high trade elasticity

Framework Overview

- Two countries: H, F
- Two factors of production: K, L
- Each country produces a single non-traded final good
  - Used for consumption and investment
- Continuum of tradable intermediate goods $z \in [0,1]$
  - Two (vertical) stages of production for each intermediate good.
  - Countries will specialize in a stage of production for each good: e.g. H for stage 1, F for stage 2.
  - Four potential patterns of specialization for each good: HH, FF, HF, FH

Stage 1

In Stage 1, each good $z \in [0,1]$ is produced from capital and labor.

- Country i's production function for stage 1 of good z is

$$y_1^i(z) = A_1^i(z)\left(k_1^i(z)\right)^{\alpha}\left(l_1^i(z)\right)^{1-\alpha}$$

where $A_1^i(z)$ is country i's productivity for good z in stage 1

Stage 2

In Stage 2, each good $z \in [0,1]$ is produced from capital, labor, and intermediate inputs

- Country i's production function for stage 1 of good z is

$$y_1^i(z) = \left(x_1^i(z)\right)^{\theta} \left[A_2^i(z) \left(k_2^i(z)\right)^{\alpha} \left(l_2^i(z)\right)^{1-\alpha}\right]^{1-\theta}$$

  where $A_2^i(z)$ is country i's productivity for good z in stage 2

- $x_1^i(z)$ is country $i's$ use of the stage 1 good (not necessarily produced in country i)

Stage 3: Final Good Production

Non-traded final good created from CES aggregate of stage 2 goods:

$$Y^i = \left\{ \int_0^1 [x_2^i(z)^{\frac{\sigma-1}{\sigma}} \, dz \right\}^{\frac{\sigma}{\sigma-1}}, \qquad i = H, F$$

- $x_2^i(z)$ is country i's use of the stage 2 good, and σ is the elasticity of substitution.
- Final good can be used for either consumption or investment

Firm Maximization

Firms are perfectly competitive in each stage.

- Stage 1 firms maximize

$$p_1(z)y_1^i(z) - w^i l_1^i(z) - r^i k_1^i(z), \qquad i = H, F$$

Stage 2 firms maximization depends whether stage 1 occurred in same country or not

- If stage 1 occurred domestically, then maximization problem is

$$p_2(z)y_2^i(z) - p_1(z)x_1^i(z) - w^i l_1^i(z) - r^i k_1^i(z), \qquad i = H, F$$

- If stage 1 occurred in foreign country , then maximization problem is (τ is tariff rate, not iceberg)

$$p_2(z)y_2^i(z) - (1+\tau)p_1(z)x_1^i(z) - w^i l_1^i(z) - r^i k_1^i(z), \qquad i = H, F$$

Firm Maximization

Stage 3 firm maximization is

$$P^i Y^i - \int_{z \in \{HH^i, FH^i\}} p_2(z) x_2^i(z) dz - \int_{z \in \{FF^i, HF^i\}} (1+\tau) p_2(z) x_2^i(z) dz$$

- Where P^i and Y^i are the price and output of the non-traded final good in country i

Representative Household

Representative household in country i maximizes

$$\sum_{t=0}^{\infty} \beta^t \log C_t^i$$

Subject to sequence of budget constraints

$$P_t^i C_t^i + P_t^i \left[K_{t+1}^i - (1-\delta)K_t^i\right] = w_t^i L^i + r_t^i K_t^i + T_t^i \quad \overbrace{\equiv P_t^i Y_t^i}^{\text{gross output of final good}}$$

and capital accumulation formula

$$K_{t+1}^i = (1-\delta)K_t^i + I_t^i$$

- Where δ is the capital depreciation rate. C_t^i is final output used for consumption, I_t^i is final output used for consumption. T_t^i is tariffs rebated to consumers.

Market Clearing Conditions

Labor market clears in each country

$$L^i = \int_0^1 l_1^i(z)dz + \int_0^1 l_2^i(z)dz\,, \qquad i = H, F$$

Capital market clears in each country

$$K^i = \int_0^1 k_1^i(z)dz + \int_0^1 k_2^i(z)dz\,, \qquad i = H, F$$

Stage 1 goods market clears

$$y_1(z) \equiv y_1^H(z) + y_2^F(z) = x_1^H(z) + x_1^F(z)$$

Stage 2 goods market clears

$$y_2(z) \equiv y_2^h(z) + y_2^F(z) = x_2^H(z) + x_2^F(z)$$

Market Clearing Conditions

Stage 3 goods market clears

$$\left\{\int_0^1 [x_2^i(z)^{\frac{\sigma-1}{\sigma}}\, dz\right\}^{\frac{\sigma}{\sigma-1}} \equiv Y^i = C_t^i + \left[K_{t+1}^i - (1-\delta)K_t^i\right], \qquad i = H, F$$

Together, these conditions imply trade is balanced in each period.

Patterns of Specialization

Four patterns of specialization: HH, FF, HF, FH

- Patterns determined by relative total factor productivities (think Dornbusch Fischer Samuelson)

$$A_1(z) \equiv A_1^H(z)/A_1^F(z); \;\; A_2(z) \equiv A_2^H(z)/A_2^F(z)$$

- Vertical Specialization patterns are HF and FH, under free trade occur if

$$A_1(z) > \left(\frac{r^H}{r^F}\right)^{\alpha} \left(\frac{w^H}{w^F}\right)^{1-\alpha} > A_2(z), \qquad \text{(HF)}$$

$$A_1(z) < \left(\frac{r^H}{r^F}\right)^{\alpha} \left(\frac{w^H}{w^F}\right)^{1-\alpha} < A_2(z), \qquad \text{(FH)}$$

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- Vertical Specialization patterns are HF and FH, under free trade occurs for good z if

$$A_1(z) > \left(\frac{r^H}{r^F}\right)^{\alpha} \left(\frac{w^H}{w^F}\right)^{1-\alpha} > A_2(z), \qquad \text{(HF)}$$

$$A_1(z) < \left(\frac{r^H}{r^F}\right)^{\alpha} \left(\frac{w^H}{w^F}\right)^{1-\alpha} < A_2(z), \qquad \text{(FH)}$$

- Can order products declining by $A_1(z)$ (country 1 relatively best at good 0)
    - Will be a cutoff good, where country 1 produces stage 1 goods to left and country 2 to the right

Vertical Specialization: Case with Same $A(z)$ Ordering in Both Stages

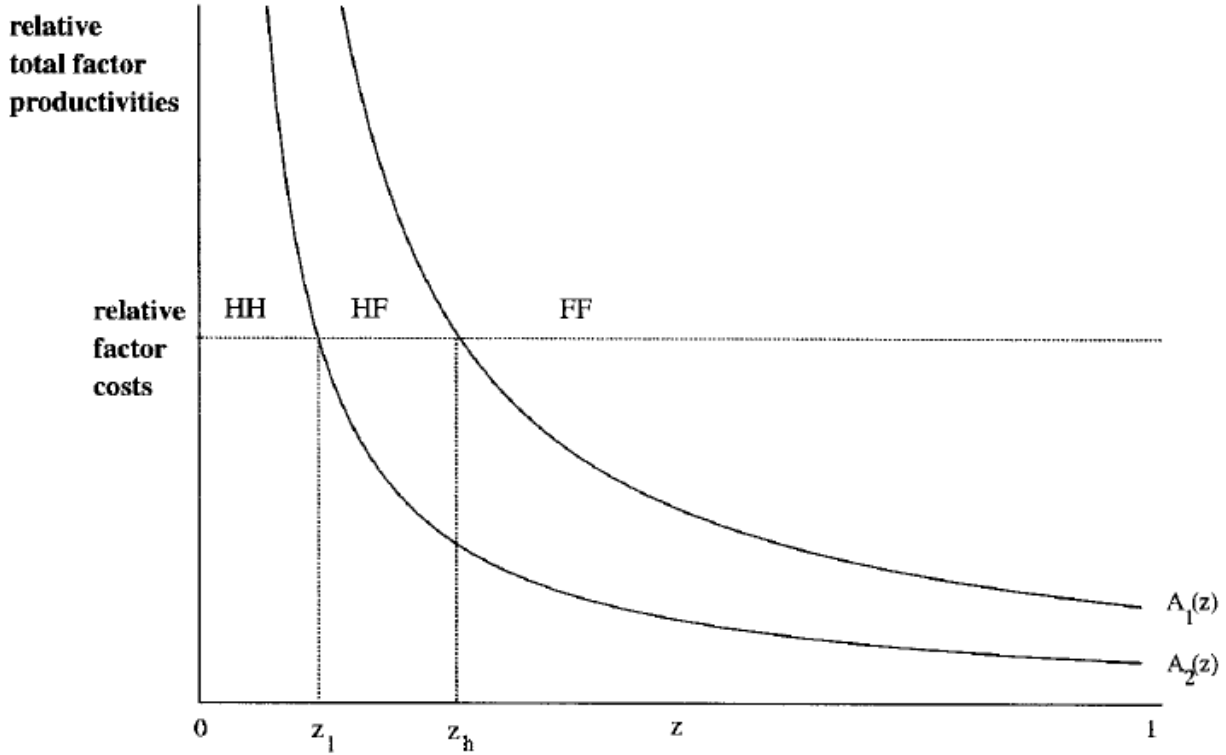

FIG. 5.—Vertical model: free trade. *HF* denotes that Home produces the first stage and Foreign produces the second stage.

Yi (2003)

Vertical Specialization Cutoffs

Cutoff, z_l, separating HH production from HF production given by

$$\rho^{\alpha}\omega^{1-\alpha} = A_2(z_l)$$

- Where ρ is ratio of home to foreign rental rates, ω ratio of home to foreign wages

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Tariffs reduce degree of vertical specialization with a non-linear impact

- Tariffs impose a tax on first stage of production twice: first when stage 1 good exported to foreign country, second when stage 2 good imported back
- Tariffs can eliminate VS while still being low enough to allow trade in second stage goods

Vertical Specialization with Tariffs

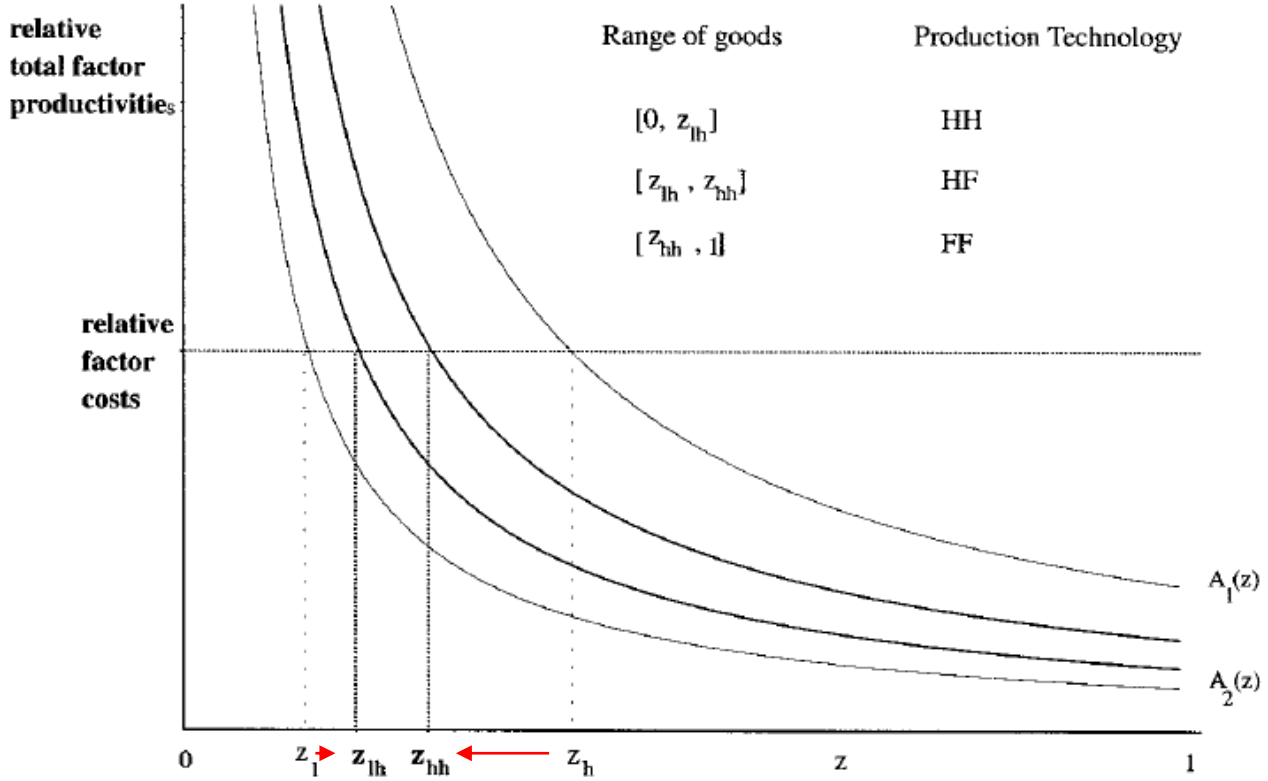

FIG. 6.—Vertical model: tariffs (home consumer's perspective)

Yi (2003)

Nonlinear Impact of Tariffs

Consider simplified case of model with only one factor of production: labor (model is static)

- Let tariffs be low enough so that VS occurs
- z_l is cutoff separating HH production from HF production, arbitrage condition for HH, HF given by

$$\omega = (1+\tau)^{\frac{1+\theta}{1-\theta}} A_2(z_l)$$

Import share of output is $1 - z_l$. "Hat calculus" (assuming no change in relative wage) yields

$$\widehat{1-z_l} = \left(\frac{1+\theta}{1-\theta}\right)\left[\frac{z_l}{(1-z_l)\eta_{A_2}}\right]\left(\widehat{1+\tau}\right)$$

where $\eta_{A_2} < 0$ is elasticity of stage 2 relative productivity, $A_2(z_l)$, with respect to z_l

Nonlinear Impact of Tariffs

Now suppose tariffs high enough so that no VS occurs, but trade still occurs

- z_l is arbitrage good between HH and HF, arbitrage condition given by

$$\omega = (1+\tau)A(z_l) \equiv (1+\tau)\left[\left(A_1(z_l)\right)^{\theta}\left(A_2(z_l)\right)^{1-\theta}\right] \equiv (1+\tau)\left[\left(\frac{A_1^H(z_l)}{A_1^F(z_l)}\right)^{\theta}\left(\frac{A_2^H(z_l)}{A_2^F(z_l)}\right)^{1-\theta}\right]$$

Import share of output still $1 - z_l$. "Hat calculus" (assuming no change in relative wage) yields

$$\widehat{1-z_l} = \left[\frac{z_l}{(1-z_l)\eta_A}\right]\left(\widehat{1+\tau}\right)$$

where $\eta_A = \eta_{A_2} < 0$ is elasticity of overall relative productivity, $A(z_l)$, with respect to z_l

- Difference in formula given by $(1+\theta)/(1-\theta)$. If $\theta = \frac{2}{3}$, impact of tariffs 5 times higher with VS.

Model Calibration

Home country is United States, Foreign country is Rest of Developed World (ROW)

- US manufacturing GDP/World manufacturing GDP $=$ 51% in 1963, 35% in 1976, 26% in 1995
- Assume annual growth rate of ROW rel. to US is $1.33^{\frac{1}{14}}$ from 1963–1976, $1.07^{\frac{1}{32}}$ from 1976–1999
- Construct tariff series from manufacturing tariff data for U.S., E.C., and Japan

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- Construct tariff series from manufacturing tariff data for U.S., E.C., and Japan
- Standard parameters: $\alpha = 0.36$, $\beta = 0.96$, $\delta = 0.13$
- Input share of first stage output in second stage: $\theta = 2/3$, as value added $\approx 1/3$ gross output

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- Input share of first stage output in second stage: $\theta = 2/3$, as value added $\approx 1/3$ gross output
- Elasticity of substitution in stage 3 CES aggregator: $\sigma = 1$ (Cobb-Douglas)
- Initial Capital/Labor ratios set to steady state values given initial tariffs
- ROW labor force set so that ROW GDP and U.S. GDP identical in 1962

Model Calibration: Stages of Production

- Need to determine what are stage 1 exports and what are stage 2 exports
- Use input-output tables to identify industries that are mostly/rarely intermediate inputs
- “Narrow” Stage 1 industries: Paper, Industrial Chemicals, Drugs and Medicine, Petroleum and Coal Products, Rubber and Plastic Products, Nonmetallic Mineral Production, Iron and Steel, NonFerrous Metals, Electrical Apparatus
- “Stage 2 industries: Food, Beverages, and Tobacco; Textiles, Apparel, and Leather; Motor Vehicles, Ship-Building, Aircraft, Office and Computing Machinery, Radio and Telivision, Non-Electical Machinery

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- “Stage 2 industries: Food, Beverages, and Tobacco; Textiles, Apparel, and Leather; Motor Vehicles, Ship-Building, Aircraft, Office and Computing Machinery, Radio and Telivision, Non-Electical Machinery
- “Broad” Stage 1 industries: Narrow + All Manufacturing

Vertical Specialization

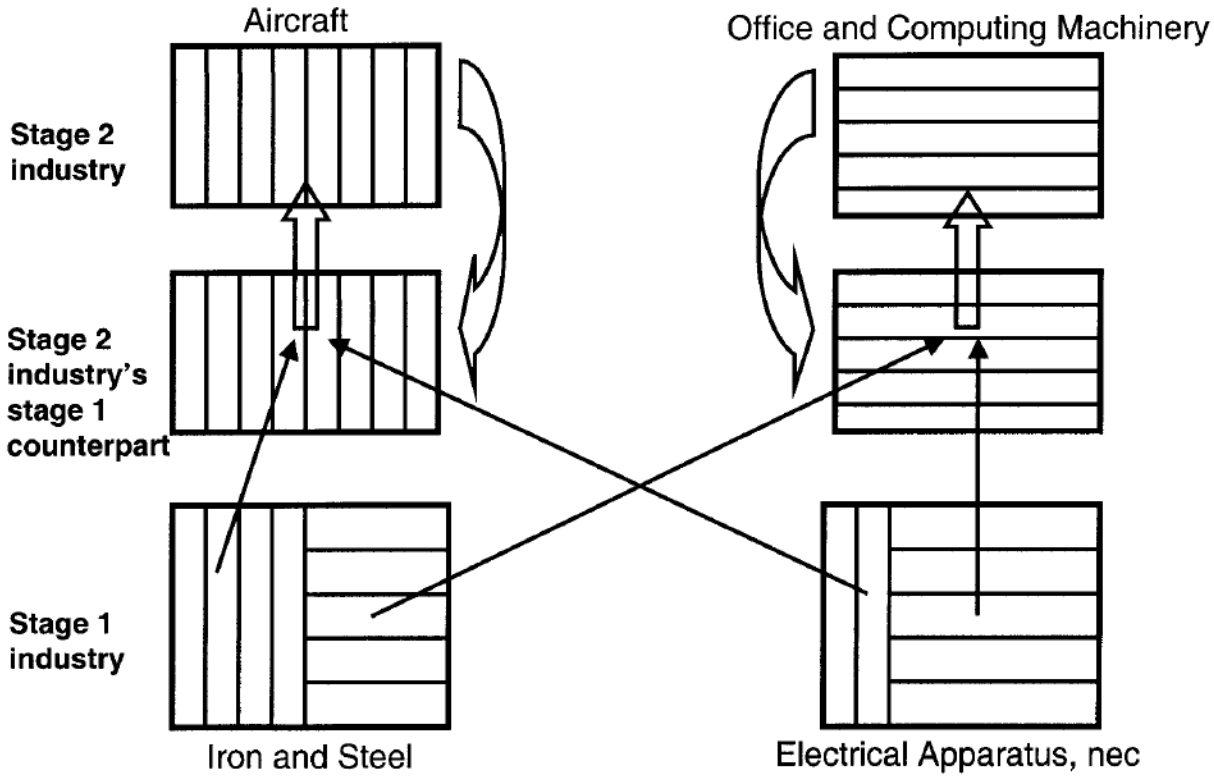


FIG. 7.—Stage 1 and stage 2 input-output relations

Yi (2003)

Model Calibration: Relative Productivities

- Can't infer relative productivities directly
- Solution: Use Balassa's RCA index for each stage of production $k = 1,2$

$$RCA_{ij} = \frac{X_{ij,k}/X_i}{X_{Wj,k}/X_W}$$

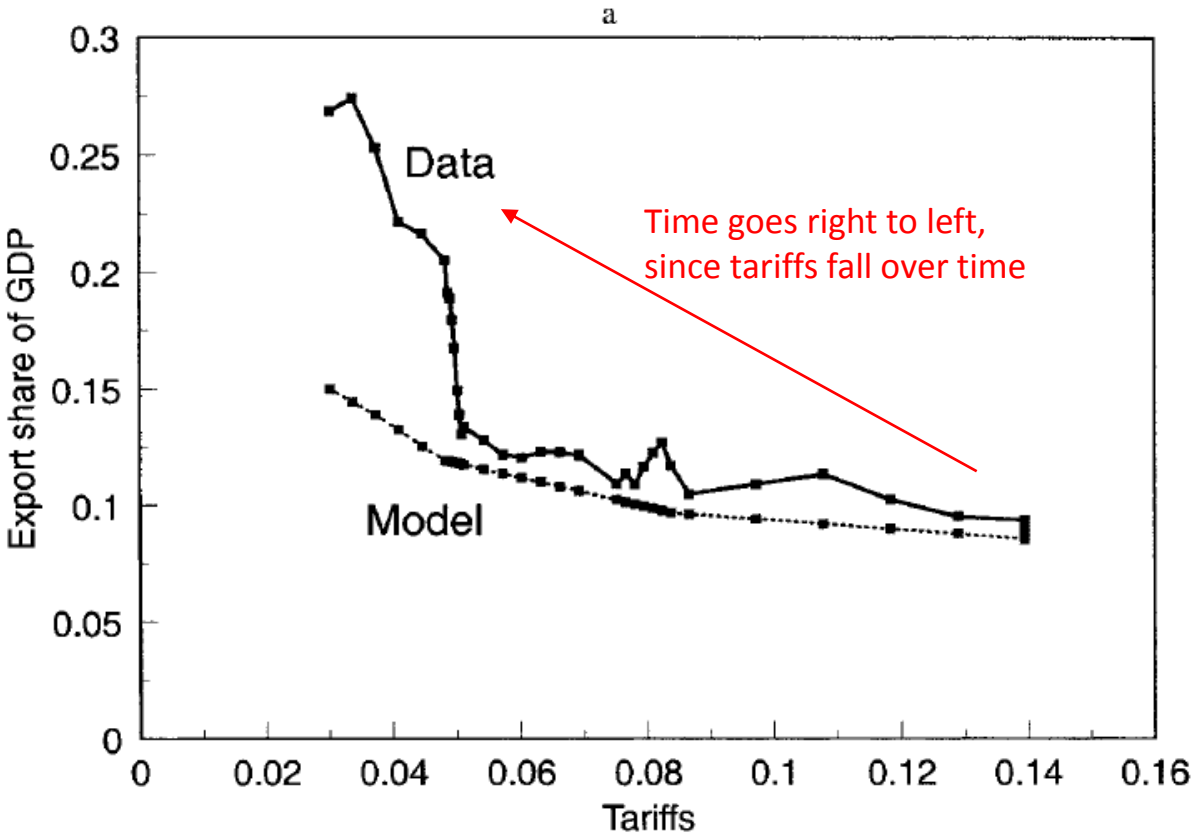
- If assumptions of his model hold, RCA index will reveal comparative advantage (flat tariff rate)
- Use RCA index as proxy for relative productivities $A_1(z)$ and $A_2(z)$

Calibration Summary

TABLE 1
PARAMETERS USED IN BENCHMARK CALIBRATIONS

Parameter	Parameter Name	Parameter Value
β	Preference discount factor	.96
α	Capital's share in production	.36
δ	Depreciation rate on capital	.13
θ	Share of first-stage output in second-stage production	.67
σ	Elasticity of substitution in stage 3 aggregator	1
$A_1(z)$	Narrow benchmark case stage 1 relative productivity	$1.26z^2 - 2.53z + 1.88$
$A_2(z)$	Narrow benchmark case stage 2 relative productivity	$3.095z^2 - 3.38z + 1.63$
$A_1(z)$	Broad benchmark case stage 1 relative productivity	$0.686z^2 - 1.478z + 1.63$
$A_2(z)$	Broad benchmark case stage 2 relative productivity	$3.088z^2 - 3.401z + 1.567$

Results: Rise in Export Share of GDP



Yi (2003)

Results: Rise in Share of Vertical Specialization

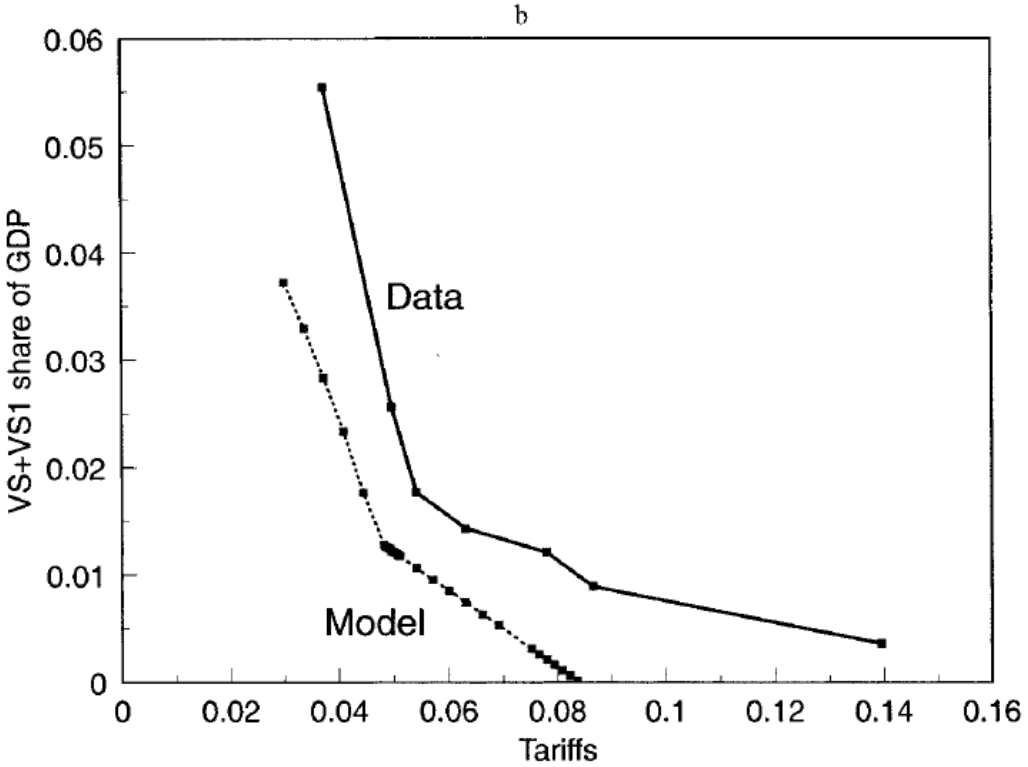


FIG. 8.—Narrow case: exports and VS+VS1 against tariffs

Yi (2003)

Results

- Model explains roughly 35% of trade growth
  - Broad model ~50%

TABLE 2
RESULTS FROM BENCHMARK VERTICAL MODEL

	U.S. Data*	Narrow Case	Broad Case
	A. Export Growth (Percent)		
1962–99†	213.0	74.8	113.0
1962–76	36.2	16.2	47.4
1976–99	130.0	50.4	44.6
1962–89	73.9	37.9	87.2
1989–99	80.1	26.8	13.8
	B. Elasticity of Export Growth with Respect to Tariffs		
1962–99	22.0	7.8	11.8
1962–76	6.9	3.1	9.0
1976–99	28.4	11.0	9.7
1962–89	9.4	4.8	11.1
1989–99	42.1	14.1	7.3
	C. Export Share of GDP: Root Mean Square Error		
1962–99		**.049**	**.032**
1962–76		.015	.006
1976–99		.061	.041
1962–89		.015	.016
1989–99		.091	.056
	D. Vertical Specialization (Percentage of GDP)		
1962	.36	.00	.00
1977	1.21	.21	1.50
1990	2.56	1.22	4.25
1997	5.54	2.83	5.46

* U.S. data are adjusted in panels A and B.
† The fraction explained for the narrow case is 35.1 percent and for the broad case 53.0 percent.

Results

- Model explains roughly 35% of trade growth
  - Broad model ~50%
- Captures non-linearity in elasticity for high τ

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1962–89	73.9	37.9	87.2
1989–99	80.1	26.8	13.8
	B. Elasticity of Export Growth with Respect to Tariffs		
1962–99	22.0	7.8	11.8
1962–76	6.9	3.1	9.0
1976–99	28.4	11.0	9.7
1962–89	9.4	4.8	11.1
1989–99	42.1	14.1	7.3
	C. Export Share of GDP: Root Mean Square Error		
1962–99		**.049**	**.032**
1962–76		.015	.006
1976–99		.061	.041
1962–89		.015	.016
1989–99		.091	.056
	D. Vertical Specialization (Percentage of GDP)		
1962	.36	.00	.00
1977	1.21	.21	1.50
1990	2.56	1.22	4.25
1997	5.54	2.83	5.46

* U.S. data are adjusted in panels A and B.
† The fraction explained for the narrow case is 35.1 percent and for the broad case 53.0 percent.

Results

- Model explains roughly 35% of trade growth
  - Broad model ~50%
- Captures non-linearity in elasticity for high τ
- Model explains roughly 50% of VS growth
  - Broad model ~100%

TABLE 2
RESULTS FROM BENCHMARK VERTICAL MODEL

	U.S. Data*	Narrow Case	Broad Case
	A. Export Growth (Percent)		
1962–99†	213.0	74.8	113.0
1962–76	36.2	16.2	47.4
1976–99	130.0	50.4	44.6
1962–89	73.9	37.9	87.2
1989–99	80.1	26.8	13.8
	B. Elasticity of Export Growth with Respect to Tariffs		
1962–99	22.0	7.8	11.8
1962–76	6.9	3.1	9.0
1976–99	28.4	11.0	9.7
1962–89	9.4	4.8	11.1
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* U.S. data are adjusted in panels A and B.
† The fraction explained for the narrow case is 35.1 percent and for the broad case 53.0 percent.

Failure of Single Stage Model

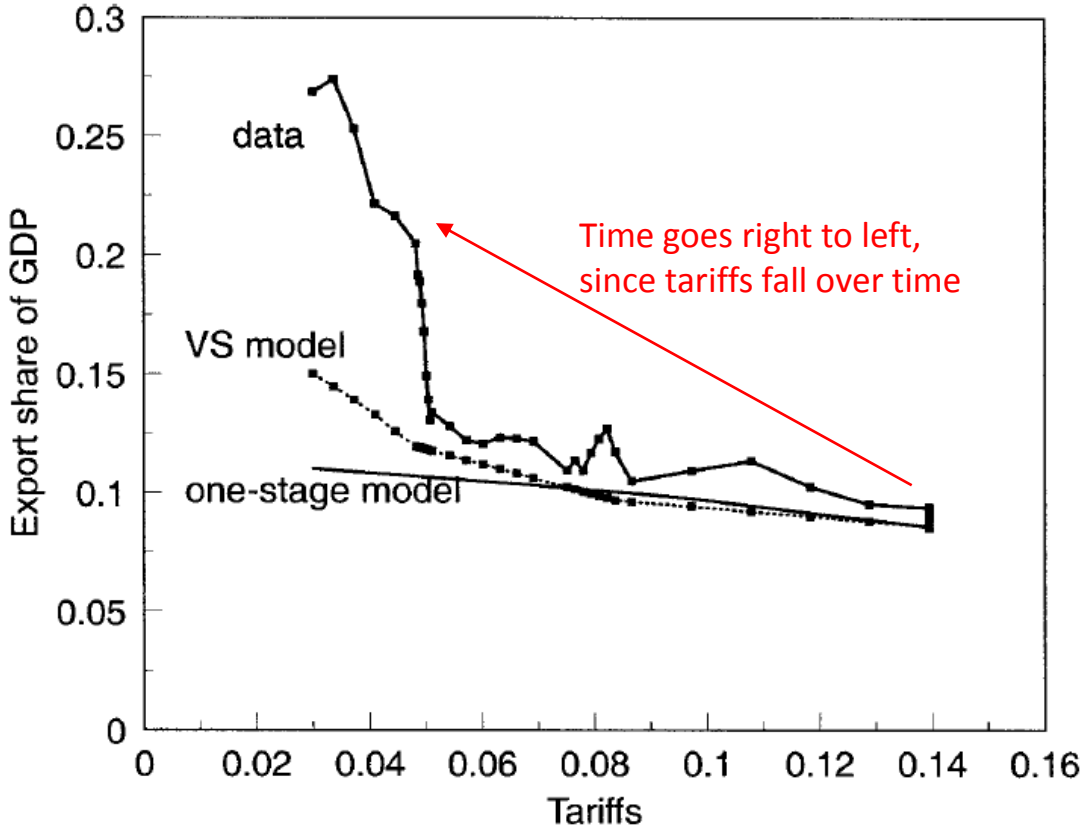

FIG. 10.—Narrow case: vertical model vs. one-stage model

Yi (2003)