Lecture 6
Advanced topics in international trade
The Vertical Fragmentation of Production

Julien Martin (IRES-UCLouvain)
Isabelle Méjean (Ecole Polytechnique, CREST, CEPR)

www.julienmartin.eu

APE-ENSAE, December 7th 2012
• **Introduction**: Definitions, Example, and Research Questions

• **Measuring international fragmentation**
  Hummels, Ishii, Yi 2001; *Johnson, Noguera 2012*; Johnson, Noguerra 2012 bis

• **Measuring the upstreamness of production**
  Fally 2011; Antras, Chor 2011; *Antras, Chor, Fally, Hillberry 2012*

• **Conclusion**
Firms may decide to buy inputs from a supplier: **outsourcing**

They may choose to produce inputs in a foreign country: **offshoring/vertical integration**. This induces **intra-firm trade** between related parties.

They may prefer buying intermediate inputs to a foreign supplier: **foreign outsourcing**

Firms and countries are specialized in different stages of production.\(^1\) The facilitation of international trade has enhanced the global division of production sequences. The phenomenon as been called **vertical specialization** by Balassa and Findlay, **slicing up the value chain** by Krugman, **fragmentation**, production sharing...

\(^1\)Costinot, Vogel, and Wang (2012) notice this is reminiscent to the division of operations, *all performed by distinct hands* - Adam Smith 1776.
GDP and Exports: Conceptually Different

• GDP Singapore 2004: $133 billion

• Total exports Singapore 2004: $202 billion

⇒ value vs value-added
Research questions

- Intermediate inputs: two thirds of international trade. This raises several questions. Topics relatively unexplored until 2-3 years.

- Is production more fragmented?
- Figures on trade flows and trade balances do not account for international fragmentation. Why not considering the value-added content of trade flows rather than their gross value?
- What are the determinants of international fragmentation (Johnson Noguera 2012, Yi 2003)?
- Are countries specializing in specific stages of the global production (Antras, Chor, Fally, Hillbery, 2012)?
- Is the trade collapse during the Great crisis due to global fragmentation?

⇒ To answer, we need a measure of fragmentation of production
Measuring vertical specialization

- Hummels, Ishii, and Yi (HIY; JIE 2001) ⇒ first paper measuring the level and evolution of vertical specialization in world trade. They measure the imported input content of exports. This methodology implicitly assumes that countries’ exports are entirely absorbed by the final demand abroad.

- Johnson & Noguera (JIE 2012) ⇒ improve HIY methodology to allow for two-way trade in intermediates (intermediates produced in A, exported to B, used to produce another intermediate, exported from B to A).

- Johnson & Noguera (2012 bis) generalize HIY, we focus on it in this lecture
Johnson Noguera (2012)

- S sectors, N countries, 1 variety by sector-country
- Production, sector s, country i: \( q_i(s) \)
- **Production is directed to both final and intermediate consumption, both at home and abroad**
- Final consumption, produced in country i, consumed in j: \( q_{ij}^c(s) \)
- Intermediate consumption sector s, used in sector t: \( q_{ij}^m(s, t) \)
- Market clearing for quantities produced by country i, sector s:
  \[
  q_i(s) = \sum_j q_{ij}^c(s) + \sum_s \sum_j q_{ij}^m(s, t)
  \]
- Expressed at current prices:
  \[
  y_i(s) = \sum_j c_{ij}(s) + \sum_s \sum_j m_{ij}(s, t)
  \]
- Exports from i to j in sector s: \( x_{ij}(s) = c_{ij}(s) + \sum_s m_{ij}(s, t) \)
• \( S \times 1 \) vector of production, in country \( i \): \( y_i \)

• \( S \times 1 \) vector of demand, in country \( j \) for goods from \( i \): \( c_{ij} \)

• \( A_{ij} \): \( S \times S \) IO matrix, with elements \( A_{ij}(s, t) = m_{ij}(s, t)/y_j(t) \)

\( \rightarrow \) inputs from sector \( s \) country \( i \) used by \( j \) to produce 1 unit of \( t \)

• Total use of inputs from \( i \) by \( j \): \( A_{ij}y_j \)

• One further writes:

\[
A \equiv \begin{pmatrix}
A_{11} & A_{12} & \ldots & A_{1N} \\
A_{21} & A_{22} & \ldots & A_{2N} \\
\vdots & \vdots & \ddots & \vdots \\
A_{N1} & A_{N2} & \ldots & A_{NN}
\end{pmatrix};
\]
\[
y \equiv \begin{pmatrix}
y_1 \\
y_2 \\
\vdots \\
y_N
\end{pmatrix};
\]
\[
c_j \equiv \begin{pmatrix}
c_{1j} \\
c_{2j} \\
\vdots \\
c_{Nj}
\end{pmatrix}
\]
The global market clearing condition writes:

\[ y = Ay + \sum_{j} c_j \quad \text{or} \quad y = \sum_{j} (I - A)^{-1} c_j \]

with \((I - A)^{-1} = \sum_{k=0}^{+\infty} A^k\)

In words: total consumption is the direct output absorbed + the output used to produce a final good + the output used to build the intermediate used to build a final good + ...

We can define the quantity from country \(i\) consumed in \(j\), either directly (exports of final goods or exports of inputs used to produce "domestic" final goods) or through exports from third countries incorporating inputs from country \(i\)

\[
\begin{pmatrix}
  y_{1j} \\
  y_{2j} \\
  \vdots \\
  y_{Nj}
\end{pmatrix} \equiv (I - A)^{-1} c_j
\]
Johnson Noguera (2012) - Definitions

- The value added to output ratio for sector $t$ country $i$ is:

$$r_i(t) = 1 - \sum_j \sum_s A_{ji}(s, t)$$

**Def. 1** country $i$’s value added absorbed in country $j$ is:

$$va_{ij} = \sum_s va_{ij}(s) = \sum_s r_i(s)y_{ij}(s)$$

**Def. 2** the sector level bilateral value added to exports ratio is:

$$va_{ij}(s)/x_{ij}(s)$$

**Def. 2** the aggregate bilateral value added to exports ratio is:

$$va_{ij}/\iota x_{ij}$$

where $\iota$ is a $1 \times S$ vector of ones
Johnson Noguera (2012) - Example

- 1 sector, 3 countries: the US (1), China (2), Japan (3)
- China imports inputs from the US and Japan
- China exports the final good (say an iPad) to the US only
- US and Japan export only intermediate goods
- The production can be represented as:

\[
\begin{pmatrix}
y_1 \\
y_2 \\
y_3
\end{pmatrix}
= \begin{pmatrix}
\alpha_{11} & \alpha_{12} & 0 \\
0 & \alpha_{22} & 0 \\
0 & \alpha_{32} & \alpha_{33}
\end{pmatrix}
\begin{pmatrix}
y_1 \\
y_2 \\
y_3
\end{pmatrix}
+ \begin{pmatrix}
c_{11} \\
c_{22} + c_{21} \\
c_{33}
\end{pmatrix}
\]

→ in the US, part of the production is used to produce the intermediate good, part is used by China to produce good 2, and the last part is consumed by US consumers
→ in China, part of the production is used to produce the final good, the rest is consumed in China and in the US
→ in Japan, part of the production is used to produce the intermediate good, part is used by China to produce good 2, and the last part is consumed by Japanese
This yields to the following system:

\[
\begin{align*}
y_1 &= \frac{1}{1 - \alpha_{11}} c_{11} + \frac{\alpha_{12}}{(1 - \alpha_{11})(1 - \alpha_{22})} c_{21} + \frac{\alpha_{12}}{(1 - \alpha_{11})(1 - \alpha_{22})} c_{22} \\
y_2 &= \frac{1}{1 - \alpha_{22}} c_{21} + \frac{1}{1 - \alpha_{22}} c_{22} \\
y_3 &= \frac{1}{1 - \alpha_{33}} c_{33} + \frac{\alpha_{32}}{(1 - \alpha_{33})(1 - \alpha_{22})} c_{22} + \frac{\alpha_{32}}{(1 - \alpha_{33})(1 - \alpha_{22})} c_{21}
\end{align*}
\]

Trade and VA balances:

\[tb_{12} = x_{12} - x_{21}\] and \[vab_{12} = (1 - \alpha_{11})y_{12} - (1 - \alpha_{12} - \alpha_{22} - \alpha_{32})y_{21}\]

After simple computations: \[tb_{12} + \alpha_{32}y_{21} = vab_{12}\]

The value added deficit between the US and China is smaller than the trade deficit: China’s trade contains Japanese content.
Johnson Noguera (2012) - Data

- GTAP 7.1 database
- Info on balance of payment statistics (World Bank / IMF)
- Info on Bilateral trade (COMTRADE)
- Info on: Input-Output tables (national sources)
- 57 sectors, 94 countries, in 2004

- Drawback 1: IO data are not bilateral $\Rightarrow$ proportionality assumptions (made for IO domestic/imports too)
- Drawback 2: The input content of domestic production and exports is supposed to be the same
Johnson Noguera (2012) - Results

• First compute the multilateral value added to exports ratio
  ⇒ large variations across countries: does it reflect the sector specialization of countries or differences in the VAX ratio within sectors, between countries?
  ⇒ Mainly the composition of exports, but rich countries tend to export with higher VAX ratio in manufacturing industries

• Then, they compute the bilateral value added export ratio
  ⇒ a given exporter has very different VAX for a given sector, depending on the partners (income differences and geography explain part of this variation)

• Last, they compare trade and value added balances
Table 4: Decomposing Trade: Absorption, Reflection, and Redirection

<table>
<thead>
<tr>
<th>Japan exports to:</th>
<th>U.S.</th>
<th>U.S. exports to:</th>
<th>Mexico</th>
<th>Canada</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>64.5%</td>
<td>U.S.</td>
<td>92.7%</td>
<td>Mexico</td>
</tr>
<tr>
<td>U.S.</td>
<td>11.1%</td>
<td>Canada</td>
<td>1.4%</td>
<td>U.S.</td>
</tr>
<tr>
<td>Japan</td>
<td>4.3%</td>
<td>Mexico</td>
<td>0.7%</td>
<td>Canada</td>
</tr>
<tr>
<td>Germany</td>
<td>2.5%</td>
<td>Japan</td>
<td>0.6%</td>
<td>Germany</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Germany exports to:</th>
<th>Czech Rep.</th>
<th>Korea exports to:</th>
<th>China</th>
<th>Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>74.8%</td>
<td>Czech Republic</td>
<td>57.7%</td>
<td>China</td>
</tr>
<tr>
<td>Germany</td>
<td>3.6%</td>
<td>Germany</td>
<td>11.7%</td>
<td>U.S.</td>
</tr>
<tr>
<td>U.K.</td>
<td>2.8%</td>
<td>U.K.</td>
<td>3.0%</td>
<td>Japan</td>
</tr>
<tr>
<td>U.S.</td>
<td>2.6%</td>
<td>U.S.</td>
<td>2.6%</td>
<td>Germany</td>
</tr>
</tbody>
</table>

See the text for details regarding the decomposition. The entries in the table describe the approximate share of bilateral exports to each destination that are ultimately consumed in that destination. Shares do not sum to one because we include only the top four destinations for each bilateral pair. Data is for 2004.
Figure 4: Bilateral Trade and Value Added Balances for the United States, by Partner (2004)

Note: Czech Republic, Estonia, Russia, Slovakia, and Slovenia are excluded due to missing data in 1970.
We have seen that i) VAX ratios have decreased for almost all countries from 1970, and ii) the VAX ratios are very different between sectors and between countries within sectors.

Questions: Do countries specialize in different stages of the production process? What determines such specialization?

⇒ We need a measure of industry downstreamness to answer those questions: how far is the industry/sector from final demand?
⇒ Antras and Chor (2012) and Fally (2012) propose 2 different measures of upstreamness
⇒ Antras, Chor, Fally, and Hillberry (2012) show they are equivalent and provide evidence on the determinants of the country level average upstreamness of exports
Let’s focus on a closed economy

Production can be written as a function of final consumption (cf sl.9):

\[ y(s) = c(s) + \sum_t d(s, t)c(t) + \sum_t \sum_u d(s, t)d(s, u)c(t) + .. \]

where \( d_{st} \) is the amount of good \( s \) needed to produce good \( t \)

ACFH propose to weight each of the term of this sum by the distance from final use (plus one):

\[ U_1 = 1 \times \frac{c(s)}{y(s)} + 2 \times \sum_t d(s, t)\frac{c(t)}{y(s)} + 3 \times \sum_t \sum_u d(s, t)d(s, u)\frac{c(t)}{y(s)} + .. \]

if \( U_1(s) = 1 \), the entire production is directly consumed. The larger \( U_1 \), the more upstream is the industry.
• \( \frac{d_{st}Y(t)}{Y(s)} \) share of \( s \) purchased by \( t \). The upstreamness of industry \( s \) is:

\[
U_2(s) = 1 + \sum_{t=1}^{N} \frac{d_{st}Y(t)}{Y(s)} U_2(t)
\]

• Defining the matrix \( \Delta \) with \( \frac{d_{st}Y(t)}{Y(s)} \) in entry \( s, t \):

\[
U_2 = [I - \Delta]^{-1} \begin{bmatrix} 1 \\ N \times 1 \end{bmatrix}
\]

• The more upstream the industries you serve as an intermediate, the more upstream you are.

• It turns out that \( U_1 \) and \( U_2 \) are equivalent.
In an open economy, production writes:

\[ y(s) = c(s) + \sum_t d(s, t)y(t) + x(s) - m(s) \]

We would like to focus on

\[ \delta_{st} = \frac{d_{st}Y(t) - x(s, t) + m(s, t)}{y(s)} \]

but data on \( x(s, t) \) and \( m(s, t) \) are not available

\[ \Rightarrow \] assume that the domestic content of production is the same as the export and import content of production

\[ \Rightarrow \] In such case, the measure of upstreamness remains valid as long as we consider

\[ \hat{d}_{st} = \frac{d_{st}y(s)}{y(s) + x(s) - m(s)} \]
ACFH 2012 - Data

- Use I-O matrix for the US in 2002 (see BEA website)
- Disaggregated data: 426 industries
- Use additional information on imports, exports, and inventories
- OECD STAN database to compare the rank correlation of industries’ upstreamness across countries
• Production from 19 industries goes to final use directly ($U = 1$)

• The more upstream industry is petrochemicals ($U = 4.65$)

• The average distance from final consumption is 2.

• For manufacturing, most downstream industries are automobile, furniture, and footwear; the most upstream are raw materials

• Rank correlation across countries is positive and significant: about 0.85 for the US and EU

• Capital intensive industries tend to be more upstream industries
### Table 6: Export Upstreamness and Country Characteristics

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Panel A: Country Upstreamness, All Exports (2002)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log (Real GDP per capita)</td>
<td>-0.035</td>
<td>0.146***</td>
<td>0.100**</td>
<td>0.156**</td>
<td>0.083</td>
</tr>
<tr>
<td></td>
<td>(0.032)</td>
<td>(0.054)</td>
<td>(0.047)</td>
<td>(0.060)</td>
<td>(0.142)</td>
</tr>
<tr>
<td>Rule of Law</td>
<td>-0.313***</td>
<td></td>
<td>-0.164*</td>
<td></td>
<td>-0.029</td>
</tr>
<tr>
<td></td>
<td>(0.070)</td>
<td></td>
<td>(0.091)</td>
<td></td>
<td>(0.103)</td>
</tr>
<tr>
<td>Private Credit / GDP</td>
<td>-0.585***</td>
<td>-0.404***</td>
<td></td>
<td>-0.437***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.123)</td>
<td>(0.128)</td>
<td></td>
<td>(0.136)</td>
<td></td>
</tr>
<tr>
<td>Log (Capital per worker)</td>
<td></td>
<td></td>
<td></td>
<td>0.156</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.131)</td>
<td></td>
</tr>
<tr>
<td>Years of Schooling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.085***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.031)</td>
</tr>
<tr>
<td><strong>$N$</strong></td>
<td>181</td>
<td>181</td>
<td>151</td>
<td>151</td>
<td>120</td>
</tr>
<tr>
<td><strong>$R^2$</strong></td>
<td>0.01</td>
<td>0.11</td>
<td>0.09</td>
<td>0.11</td>
<td>0.15</td>
</tr>
</tbody>
</table>
ACFH 2012 - Results

- $R^2$ very small

- Most of the results are not

- Financial development seems the most important determinant: countries with a high level of financial development specialize in downstream industries. This is also true for manufacturing: not an artefact due to financial services
## ACFH 2012 - Results

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Log (Real GDP per capita) × $U_i$</td>
<td>−0.036</td>
<td>−0.675***</td>
<td>−0.069</td>
<td>−0.542***</td>
<td>−0.543***</td>
<td>−0.543*</td>
</tr>
<tr>
<td></td>
<td>(0.050)</td>
<td>(0.209)</td>
<td>(0.049)</td>
<td>(0.205)</td>
<td>(0.204)</td>
<td>(0.277)</td>
</tr>
<tr>
<td>(Log (Real GDP per capita))^2 × $U_i$</td>
<td>0.036***</td>
<td>(0.011)</td>
<td>0.026**</td>
<td>(0.011)</td>
<td>0.026**</td>
<td>0.026</td>
</tr>
<tr>
<td>Rule of Law × $U_i$</td>
<td>−0.105***</td>
<td>−0.148***</td>
<td>−0.079***</td>
<td>−0.110***</td>
<td>−0.110***</td>
<td>−0.110*</td>
</tr>
<tr>
<td></td>
<td>(0.030)</td>
<td>(0.032)</td>
<td>(0.029)</td>
<td>(0.032)</td>
<td>(0.032)</td>
<td>(0.061)</td>
</tr>
<tr>
<td>(Private Credit / GDP) × $U_i$</td>
<td>−0.059</td>
<td>−0.072</td>
<td>0.010</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>(0.048)</td>
<td>(0.048)</td>
<td>(0.047)</td>
<td>(0.047)</td>
<td>(0.047)</td>
<td>(0.075)</td>
</tr>
<tr>
<td>Log (Capital per worker) × $U_i$</td>
<td>0.048</td>
<td>0.093**</td>
<td>0.142***</td>
<td>0.176***</td>
<td>0.194***</td>
<td>0.194***</td>
</tr>
<tr>
<td></td>
<td>(0.044)</td>
<td>(0.047)</td>
<td>(0.043)</td>
<td>(0.045)</td>
<td>(0.045)</td>
<td>(0.074)</td>
</tr>
<tr>
<td>Years of Schooling × $U_i$</td>
<td>−0.009</td>
<td>−0.001</td>
<td>−0.007</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>(0.009)</td>
<td>(0.009)</td>
<td>(0.009)</td>
<td>(0.009)</td>
<td>(0.009)</td>
<td>(0.016)</td>
</tr>
<tr>
<td>Log (Capital per worker) × log($k/l)_i$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>−0.040***</td>
<td>−0.040*</td>
<td>(0.012)</td>
<td>(0.024)</td>
<td>(0.027)</td>
<td></td>
</tr>
<tr>
<td>Years of Schooling × log($s/l)_i$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.073***</td>
<td>0.073***</td>
<td>(0.010)</td>
<td>(0.027)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Industry fixed effects?</th>
<th>Yes</th>
<th>Yes</th>
<th>Yes</th>
<th>Yes</th>
<th>Yes</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country fixed effects?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$N$</th>
<th>32822</th>
<th>32822</th>
<th>29215</th>
<th>29215</th>
<th>29215</th>
<th>29215</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R^2$</td>
<td>0.77</td>
<td>0.77</td>
<td>0.80</td>
<td>0.80</td>
<td>0.80</td>
<td>0.80</td>
</tr>
</tbody>
</table>
ACFH 2012 - Results

- $R^2$ are much higher
- GDP per capita has a non linear effect on trade flows depending the upstreamness of the industry
- Complementarity between rule of law and downstreamness
- Complementarity between physical capital and industry upstreamness
ACFH 2012 and Fally 2011 - Discussion

- Sectoral measure of distance to final demand ⇒ you have the average # of stages to final demand
- Average # of stages in the US: 1.95 in the 70s, 1.65 in 2002 (Fally, 2011)
- At first sight this goes against Johnson & Noguera findings
- But, in fact they measure to different things:
  - JN (2011) measure international fragmentation:
    ⇒ the fact that some stages are produced abroad
  - Fally (2011) measures production fragmentation:
    ⇒ if a stage that was produced in the US is now produced in China, no effect on his measure of fragmentation
- Fally explains the decrease in US production fragmentation by the growing importance of services and shift of production toward industries closer to final demand
Related papers

- Theory: Costinot, Vogel, Wang (REStud 2012): elementary theory of global supply chains. Countries that do less mistakes specialize in latter stages of production (where mistake is the most costly).

- Several papers on the role of product fragmentation to explain the great crisis. See Bems, Johnson, and Yi (2010): important role of demand spillovers during the crisis.

- di Giovanni & Levchenko (2010, AEJ:Macro) and Ng (2010, JIE) show that part of international business cycle comovement is due to the international fragmentation of production.
Some interesting extensions

- Link the change in production fragmentation to the increase in output volatility (see Carvalho Gabaix 2012)

- Use those measures to study the transmission of shocks (theory dvd by Acemoglu et al 2012)

- Impact of exchange rate movements on US current account deficit also depend on the vertical fragmentation of production across countries (see Méjean, Rabanal, and Sandri 2011)

- Does international fragmentation occur within firm boundaries? does it depend on the upstreamness of the production? (Antras & Chor 2012)
Non exhaustive bibliography


