Productivity, Trade, and the R&D Content of Intermediate Inputs

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Shuichiro Nishioka
West Virginia University

Marla Ripoll
University of Pittsburgh

Introduction

- Knowledge diffusion across countries and industries is a powerful engine to increase productivity.
- “Trade in intermediate inputs” is believed to be an important channel.
- In spite of its theoretical importance, the transactions in intermediate inputs across countries and industries have not examined comprehensively due to the lack of international data.
- Our paper provides the link between TFP and R&D knowledge embodied in intermediate transactions.

Overview of Today's Talk

1. Discuss a basic theory and explain why intermediate inputs are crucial for the TFP growth.
2. Review some influential papers about TFP and R&D diffusion. In particular, the controversial issue in this literature is how to develop the empirical measure of foreign R&D stocks.
3. Present the key variables in this paper: (1) the input-output structures, (2) R&D embodied in intermediate inputs, and (3) TFP.
4. Study the correlation between log of TFP and that of embodied R&D at the industry level.

1. A Theoretical View

- It is critical to understand a theory so that we will understand the motivations in the previous empirical works.
- Grossman and Helpman (1991, Chapter 3)
  - Key: Krugman's model (1979) of IRS. Varieties are considered as differentiated intermediate inputs.
  - There is a single final good with output y produced with the CES production function.

$$y = \left[\sum_{i=1}^{N} x_i^{(\sigma-1)/\sigma} \right]^{\sigma/(\sigma-1)}$$

  - where x_i is the quantity of input variety i=1,…, N and σ>1.
  - By assuming symmetry (x_i=x) and X=Nx, we have

$y=N^{1/(\sigma-1)}X$

- Increase in N (varieties = intermediate inputs) will increase output y since $\sigma>1$.
- Since we could label $A=N^{1/(\sigma-1)}$, $y=AX$ where technological progress A will depend on the number of intermediate inputs.
- Fixed costs (basis for IRS for Krugman’s model) are inversely proportional to the number of varieties already developed: Labor (R&D workers), α/N, is required as fixed costs.
- Gain from trade is simple: The fixed cost of creating a new variety in countries are $\alpha/[N+N^*]$.

2. Overview of Empirical Works

1. The most influential paper in the field is Coe and Helpman (EER, 1995).
   – Foreign R&D stock is developed from import shares.
2. Coe and Helpman’s (EER, 1995) way to develop the foreign R&D stock had been challenged
   – Keller (EER, 1998)
   – Lichtenberg and van Pottelsberghe de la Potterie (EER, 1998)
3. Keller (AER, 2002) developed the distance-weighted foreign R&D stock.
   – Macro economists argued that Keller’s distance-weighted foreign R&D stocks do not support the growth story at all.

Coe and Helpman (EER, 1995)

- Country's productivity (TFP) depends on cumulative accessible R&D stock.
  - R&D stock = The number of varieties in intermediate inputs.
- If R&D knowledge spillovers to other countries, a country's TFP depends not only on its domestic R&D stock but also on trade partners' R&D stock.
  - They employ the import-share-weighted sum of trade partners' R&D stocks.
  - $S_c = \sum_{c' \neq c} w_{cc'} S_{c'}$ where $w_{cc'} = IM_{cc'} / \sum_{c'} IM_{cc'}$

Important Issues

- Keller (EER, 1998) challenged the import-weighted R&D stocks. Randomly developed weights could work as good as Coe and Helpman's. Moreover, the simple sum works better.
- Lichtenberg and van Pottelsberghe de la Potterie (EER, 1998) propose a new weight:
  - $S_c = \sum_{c' \neq c} w_{cc'} S_{c'}$ where $w_{cc'} = IM_{cc'}/Y_{c'}$
  - Basically, S_c is R&D stock content of imports
- Use the idea of superconsistency in Stock (1987), they investigate the long-run co-integrated relationship.
- Recent paper: Coe, Helpman, and Hoffmaister (EER, 2009) employ the LP weight (EER, 1998) with the new econometric methods.

Keller (AER, 2002)

- Industry-level analysis of TFP and R&D stock.
- Separate "recipients" from "sources" of knowledge.
  - Worked on 12 industries from 14 OECD countries
  - G-5 countries (France, Germany, Japan, UK, and US) are sources of R&D stocks for non-G5 OECD countries.
- R&D activities are concentrated on
  - 5 countries (i.e., G5 spend around 80-90% of R&D expenditures).
  - 3 sectors (i.e., Chemicals: 22%, electrical machinery: 27%, and transport equipment: 21%).
- Use non-linear specification with the distance-based weights.

Estimation in Keller (AER, 2002)

- First, estimate total factor productivity (TFP) as a share-weighted difference between outputs and inputs for I=13 manufacturing industries in C=9 countries over the period (t) 1970-1995 according to Caves et al (EJ, 1982).
- Second, TFP depends on domestic knowledge (S_{cit}) and foreign knowledge (S_{hit}), weighted by geographic distance:

Geographic weight

$$\ln TFP_{cit} = d_{ci} + d_t + \beta \ln[S_{cit} + \gamma(\sum_{h\neq c} S_{hit} e^{-\delta D^{ch}})] + \varepsilon_{cit}$$

Elasticity of total knowledge capital

Weight on Foreign Knowledge

Foreign knowledge weighted by distance

Geographic distance between country *c* and *h*

Important Issues

- This is the industry-level study.
- As discussed in Klenow and Rodriguez-Clare (Handbook of Growth, 2005), Keller's evidence does not support the Macro-level data for non-OECD countries.
- Distance cannot distinguish intermediate inputs from final goods.
- Inter-industry transactions (e.g., Scherer, REStat, 1982; Gato and Suzuki, REStat 1989; Keller, JEG 2002) are not taken into account.

Structure of the Current Paper

- We explore the connection between TFP and R&D at the industry level.
- We use the concept similar to “factor content of trade” and introduce R&D content of intermediates.
  - Measure of R&D content from global matrix of country-by-industry intermediate transactions from OECD input-output tables.
  - 32 countries, 3 years (1995, 2000, 2005), 27 industries.
- Compute elasticity of industry-level TFP with respect to R&D content.

Placing Ours in the Literature

- Our evidence are based on (1) the industry-level variation, (2) the short-run elasticity, and (3) the sample from OECD and non-OECD countries.
- We like to improve the discussions on how to develop foreign R&D stocks by using the cross-industry and cross-country consistent weights.
- Improve the literature on R&D embodied in domestic and foreign inputs.
  - Scherer (REStat, 1982) and Gato & Suzuki (REStat, 1989) → one-country domestic transactions
  - Coe et al. (EER, 1995&2009), Litchtenberg et al. (EER, 1998, REStat, 2001) → aggregate cross-country studies

Trefler and Zhu (2010)

- g and $h = 1, \ldots, G$ be indexes for industries.
- i and $j = 1, \ldots, N$ be indexes for countries.
- Every good is consumed as a final product or as an intermediate input.
- Country j's output (Q_j is a $G\times G$ diagonal matrix):

$$Q_j = \sum_i \left(C_{ij} + H_{ij}\right)$$

- $B_{ij}(g, h)$ is the amount of intermediate input g from country i used to produce one unit of gross output of country j's good h.
- Intermediate required for country j from country i: $H_{ji}=B_{ij}Q_j$
- Total imports of country j from country i:

$$M_{ji} = H_{ji} + C_{ji} = B_{ij}Q_j + C_{ji}$$

Trefler and Zhu (2010)

- Global net output ($NG \times NG$)

$$T + C = Q - BQ = (I - B)Q$$

where

$$B = \begin{bmatrix} B_{11} & B_{12} & \cdots & B_{1N} \\ B_{21} & B_{22} & \cdots & B_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ B_{N1} & B_{N2} & \cdots & B_{NN} \end{bmatrix}, T = \begin{bmatrix} X_1 & -M_{21} & \cdots & -MN_1 \\ -M_{12} & X_2 & \cdots & -MN_2 \\ \vdots & \vdots & \ddots & \vdots \\ -M_{1N} & -X_{2N} & \cdots & X_N \end{bmatrix},$$

$$C = \begin{bmatrix} C_{11} & C_{21} & \cdots & C_{N1} \\ C_{12} & C_{22} & \cdots & C_{N2} \\ \vdots & \vdots & \ddots & \vdots \\ C_{1N} & C_{2N} & \cdots & C_{NN} \end{bmatrix}, \text{ and } Q = \begin{bmatrix} Q_1 & 0 & \cdots & 0 \\ 0 & Q_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & Q_N \end{bmatrix}.$$

R&D Content of Intermediates

- Country i's R&D stock ($1\times G$ row vector)

$$D_i Q_i = S_i$$

- Global vector of direct R&D requirements ($1\times NG$):

$$D = [D_1 \quad D_2 \quad \cdots \quad D_N]$$

- Total R&D content of intermediates

$$F = D(I - B)^{-1} BQ$$

  - Empirically, F is 1xNG vector for each year.

- R&D directly embodied to intermediates

$$F^d = DBQ$$

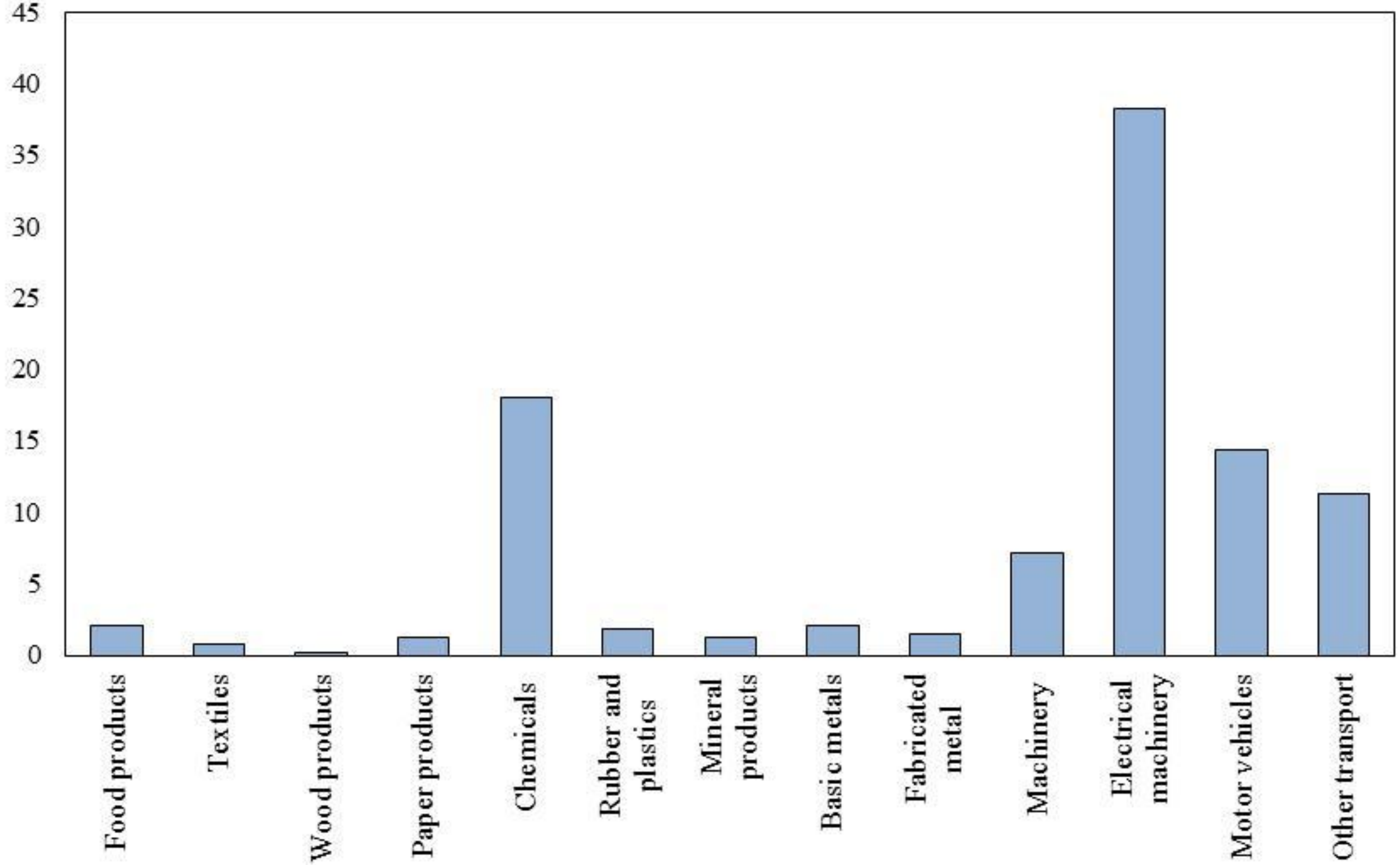
3. Data

- Global intermediate techniques matrix B
  - Foreign and domestic tables: OECD Input-Output Database
  - Industry-level bilateral imports from OECD STAN Bilateral Trade Database
  - Country j's purchases of foreign intermediates $B_{ij}Q_j$ from each trading partner i allocated according to its industry-level import shares (i.e., proportionality assumption).
    - E.g., China imports $20mil from Japan's machinery industry and China's machinery import is $100mil = Each industry in China imports 20% of its total demand for machinery products from Japan
- R&D data and TFP from OECD STAN.
- 32 countries, 3 years, and 27 industries. We examine 13 manufacturing industries.

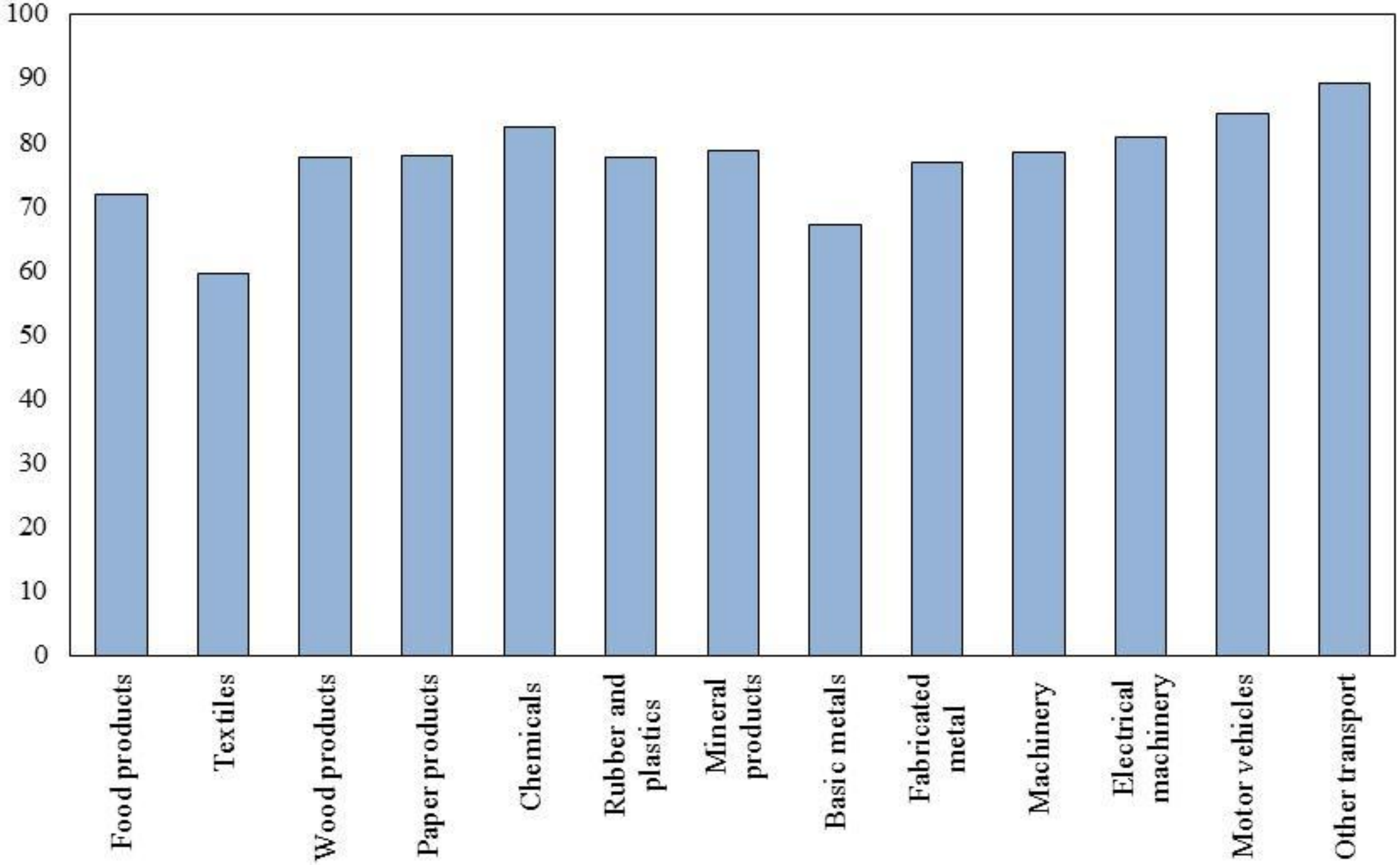
List of 13 Manufacturing

Industries	Branches of activities	OECD IO	ISIC Rev.3	High R&D
1	Food products	4	15-16	0
2	Textiles	5	17-19	0
3	Wood products	6	20	0
4	Paper products	7	21-22	0
5	Chemicals	9+10	24	1
6	Rubber and plastics	11	25	0
7	Mineral products	12	26	0
8	Basic metals	13+14	27	0
9	Fabricated metal	15	28	0
10	Machinery	16	29	0
11	Electrical machinery	17-20	30-33	1
12	Motor vehicles	21	34	1
13	Other transport	22-24	35	1

Cross-Industry R&D Expenditure



Shares of G5



100
90
80
70
60
50
40
30
20
10
0
Food products
Textiles
Wood products
Paper products
Chemicals
Rubber and plastics
Mineral products
Basic metals
Fabricated metal
Machinery
Electrical machinery
Motor vehicles
Other transport

Input-Output Structure

1.1. High R&D sectors

	G5 countries			Non-G5 countries		
	average	max value	min value	average	max value	min value
Intermediate inputs (input spending/output)	0.658	0.718 (FRA)	0.610 (USA)	0.684	0.765 (SVK)	0.505 (ISR)
Manufacturing inputs (input spending/output)	0.447	0.514 (FRA)	0.415 (GBR)	0.476	0.586 (CHN)	0.304 (GRC)
Own industry (input spending/output)	0.260	0.307 (FRA)	0.229 (USA)	0.270	0.382 (CAN)	0.152 (GRC)
Domestic share	0.571	0.785 (JPN)	0.348 (GBR)	0.308	0.842 (CHN)	0.041 (SVK)
Foreign share	0.429	0.652 (GBR)	0.215 (JPN)	0.692	0.959 (SVK)	0.158 (CHN)
Other mfg industries (input spending/output)	0.187	0.207 (FRA)	0.178 (GER)	0.206	0.304 (DNK)	0.114 (CAN)
Domestic share	0.479	0.578 (GBR)	0.447 (GER)	0.596	0.851 (SVN)	0.368 (TWN)
Foreign share	0.521	0.553 (GER)	0.422 (GBR)	0.404	0.632 (TWN)	0.149 (SVN)

1.2. Low R&D sectors

	G5 countries			Non-G5 countries		
	average	max value	min value	average	max value	min value
Intermediate inputs (input spending/output)	0.614	0.655 (FRA)	0.590 (JPN)	0.662	0.728 (HUN)	0.580 (CAN)
Manufacturing inputs (input spending/output)	0.333	0.365 (FRA)	0.304 (GBR)	0.379	0.463 (HUN)	0.305 (NZL)
Own industry (input spending/output)	0.180	0.210 (GER)	0.152 (GBR)	0.196	0.258 (KOR)	0.136 (IRL)
Domestic share	0.755	0.877 (JPN)	0.674 (GBR)	0.566	0.857 (CHN)	0.268 (BEL)
Foreign share	0.245	0.326 (GBR)	0.123 (JPN)	0.434	0.732 (BEL)	0.143 (CHN)
Other mfg industries (input spending/output)	0.153	0.167 (USA)	0.141 (JPN)	0.183	0.247 (CHN)	0.138 (ISR)
Domestic share	0.446	0.491 (USA)	0.385 (GER)	0.483	0.606 (BEL)	0.367 (PRT)
Foreign share	0.554	0.615 (GER)	0.509 (USA)	0.517	0.633 (PRT)	0.394 (BEL)

R&D Content (Domestic)

2.1. R&D content of domestic intermeidates (stock)

	Year 2000					Growth rate (%) between 1995 and 2005				
	min value		max value		average	min value		max value		average
Food products	14.3	(SVN)	15763	(USA)	1164	-15.9	(SVK)	31.5	(CHN)	2.98
Textiles	3.7	(SVK)	8549	(USA)	664	-23.1	(CZE)	31.7	(CHN)	-0.95
Wood products	3.2	(MEX)	3169	(USA)	211	-10.4	(TWN)	51.1	(CHN)	2.80
Paper products	5.4	(IRL)	16562	(USA)	963	-14.7	(SVK)	39.8	(CHN)	2.24
Chemicals*	6.0	(SVN)	36569	(USA)	2634	-17.9	(SVK)	40.0	(CHN)	4.65
Rubber and plastics	4.4	(IRL)	16104	(USA)	1208	-12.8	(SVN)	29.8	(CHN)	3.60
Mineral products	4.0	(SVN)	2945	(USA)	334	-9.1	(SVK)	23.6	(MEX)	2.85
Basic metals	0.6	(IRL)	12191	(JPN)	905	-20.6	(SVK)	44.5	(CHN)	1.76
Fabricated metal	4.3	(IRL)	9514	(USA)	804	-13.6	(SVK)	38.4	(CHN)	3.47
Machinery	8.0	(GRC)	23505	(JPN)	1989	-14.2	(SVK)	34.7	(CHN)	3.32
Electrical machinery*	10.7	(SVK)	65152	(USA)	5634	-10.3	(POL)	43.4	(CHN)	4.05
Motor vehicles*	1.2	(GRC)	60297	(JPN)	5088	-8.8	(ISR)	38.1	(CHN)	5.51
Other transport*	0.9	(HUN)	28689	(USA)	1674	-14.2	(CZE)	40.3	(CHN)	5.29

R&D Content (Foreign)

2.2. R&D content of foreign intermediates (stock)

	Year 2000			Growth rate (%) between 1995 and 2005		
	min value	max value	average	min value	max value	average
Food products	43.2 (SVN)	3443 (USA)	798	-3.4 (NLD)	13.4 (CHN)	3.71
Textiles	19.2 (NZL)	3832 (CHN)	608	-14.7 (NLD)	16.7 (TUR)	0.73
Wood products	7.3 (ISR)	811 (USA)	143	-4.5 (SVN)	30.9 (CHN)	5.27
Paper products	39.4 (SVN)	4050 (USA)	567	-4.5 (NLD)	23.2 (CHN)	3.59
Chemicals*	27.9 (NZL)	8267 (USA)	2155	-7.7 (NZL)	23.5 (CHN)	5.51
Rubber and plastics	54.1 (NZL)	3696 (USA)	827	-4.5 (ISR)	23.4 (CZE)	5.30
Mineral products	9.2 (NZL)	1367 (CHN)	238	-6.1 (IRL)	12.3 (TUR)	4.87
Basic metals	16.2 (NZL)	2695 (CHN)	581	-10.8 (NLD)	19.8 (CHN)	4.44
Fabricated metal	31.7 (NZL)	2794 (USA)	517	-5.2 (NLD)	16.4 (POL)	6.16
Machinery	60.0 (GRC)	5495 (GER)	1195	-6.9 (IRL)	16.0 (HUN)	6.17
Electrical machinery*	126.2 (GRC)	23057 (MEX)	5686	-2.8 (NLD)	36.6 (CHN)	6.71
Motor vehicles*	22.9 (ISR)	17358 (USA)	2988	-0.6 (DNK)	27.2 (CZE)	8.18
Other transport*	25.9 (GRC)	7352 (FRA)	1316	-8.1 (NLD)	20.9 (CHN)	2.03

R&D Content (Foreign)

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Production Function and TFP

- TFP index (Caves et al, 1982)
  - $ln(TFP_{iht}) = lnVA_{iht} - (\frac{1}{N})\sum_i lnVA_{iht} - \frac{1}{2}\left(\sigma_{iht} + \frac{1}{N}\sum_i \sigma_{iht}\right)\left[lnL_{iht} - (\frac{1}{N})\sum_i lnL_{iht}\right] - \left[1 - \frac{1}{2}\left(\sigma_{iht} + \frac{1}{N}\sum_i \sigma_{iht}\right)\right]\left[lnK_{iht} - (\frac{1}{N})\sum_i lnK_{iht}\right]$
- Implicit production function
  - $VA_{iht} = A_{iht}(L_{iht})^{\sigma_{ht}}(K_{iht})^{1-\sigma_{ht}}(F_{iht})^{\rho_h}$
- In turn,
  - $TFP_{iht} = A_{iht}(F_{iht})^{\rho_h}$
  - $lnTFP_{iht} = \alpha_{it} + \alpha_h + \rho_h lnF_{iht} + \varepsilon_{iht}$

TFP

2.3. TFP index

	Year 2000			Growth rate (%) between 1995 and 2005		
	min value	max value	average	min value	max value	average
Food products	0.461 (CHN)	1.896 (USA)	1.064	-4.4 (USA)	5.5 (KOR)	0.02
Textiles	0.482 (CHN)	2.134 (NLD)	1.091	-5.0 (JPN)	5.5 (KOR)	0.08
Wood products	0.461 (CHN)	1.811 (CAN)	1.062	-8.5 (USA)	8.8 (KOR)	0.14
Paper products	0.398 (CHN)	1.767 (USA)	1.063	-4.2 (PRT)	7.7 (KOR)	0.14
Chemicals*	0.398 (CHN)	1.712 (FRA)	1.062	-7.6 (HUN)	4.0 (CHN)	0.07
Rubber and plastics	0.427 (CHN)	1.553 (AUS)	1.068	-4.6 (TWN)	8.7 (CZE)	0.10
Mineral products	0.410 (CHN)	1.673 (NLD)	1.062	-4.4 (JPN)	7.0 (SVK)	0.10
Basic metals	0.397 (CHN)	1.783 (NOR)	1.056	-6.7 (DNK)	9.4 (IRL)	0.18
Fabricated metal	0.386 (CHN)	1.840 (CAN)	1.079	-4.4 (SWE)	8.8 (PRT)	0.09
Machinery	0.330 (SVK)	1.966 (CAN)	1.095	-6.3 (USA)	14.5 (SVK)	0.14
Electrical machinery*	0.373 (CHN)	2.376 (FIN)	1.110	-6.1 (NLD)	19.0 (SWE)	0.20
Motor vehicles*	0.373 (CHN)	1.781 (CAN)	1.049	-6.3 (HUN)	6.8 (CZE)	0.21
Other transport*	0.301 (CHN)	2.243 (CAN)	1.114	-7.7 (DNK)	8.0 (GER)	0.45

4. Empirical Framework and Results

- (A) Baseline specification
  - Estimate a single value of ρ for the following three groups:
    1. All 13 manufacturing industries.
    2. High-R&D intensive industries: Chemical products, electrical machinery, motor vehicles and other transport equipment.
    3. Low-R&D intensive industries.
  - To avoid the potential endogeneity and simultaneity (since G5 shares most part of F_{iht}), we report the baseline model for non-G5 27 countries as i

$$lnTFP_{iht} = \alpha_{it} + \alpha_h + \rho lnF_{iht} + \varepsilon_{iht}$$

Disaggregation 1

- Second set of specifications: disaggregation
  - (B) Disaggregate into own industry (*h*) and the other industries (≠*h*): How does chemical benefit from R&D in electronics?
    - $lnTFP_{iht} = \alpha_{it} + \alpha_h + \rho_1 ln\left[\sum_j D_{jt}(h) A_{jit}(h,h) Q_{it}(h)\right] + \rho_2 ln\left[\sum_j \sum_{g \neq h} D_{jt}(g) A_{jit}(g,h) Q_{it}(h)\right] + \varepsilon_{iht}$
  - (C) Disaggregate into to domestic (*i*) and foreign (≠*i*): How does China benefit from Japan?
    - $lnTFP_{iht} = \alpha_{it} + \alpha_h + \rho_3 ln\left[\sum_g D_{it}(g) A_{iit}(g,h) Q_{it}(h)\right] + \rho_4 ln\left[\sum_{j \neq i} \sum_g D_{jt}(g) A_{jit}(g,h) Q_{it}(h)\right] + \varepsilon_{iht}$

Disaggregation 2

- Further disaggregation
  - (D) Disaggregate the same industry to domestic and G5: How does Canadian automobile benefit from R&D in US automobiles?
    - $lnTFP_{iht} = \alpha_{it}+\alpha_h + \rho_2 ln\left[\sum_j \sum_{g\neq h} D_{jt}(g)A_{jit}(g,h)Q_{it}(h)\right] + \rho_5 ln[D_{it}(h)A_{iit}(h,h)Q_{it}(h)] + \rho_6 ln\left[\sum_{j\in G5} D_{jt}(h)A_{jit}(h,h)Q_{it}(h)\right]$
  - (E) Disaggregate R&D originated from the other industries to domestic and G5: How does Canadian automobile benefit from R&D in US electronics?
    - $lnTFP_{iht} = \alpha_{it}+\alpha_h + \rho_1 ln\left[\sum_j D_{jt}(h)A_{jit}(h,h)Q_{it}(h)\right] + \rho_7 ln\left[\sum_{g\neq h} D_{it}(g)A_{iit}(g,h)Q_{it}(h)\right] + \rho_8 ln\left[\sum_{j\in G5}\sum_{g\neq h} D_{jt}(g)A_{jit}(g,h)Q_{it}(h)\right] + \varepsilon_{iht}$

3.1. Recipient industries: All manufacturing

		Equation (A)		Equation (B)		Equation (C)		Equation (D)		Equation (E)	
		coef	*t*-stat	coef	*t*-stat	coef	*t*-stat	coef	*t*-stat	coef	*t*-stat
All countries, all industries	ρ	0.041	(3.214)**								
All countries, industry *h*	ρ_1			0.025	(1.953)*					0.019	(1.374)
All countries, other industries ($\neq h$)	ρ_2			0.011	(0.634)			0.006	(0.329)		
Country *i*, all industries	ρ_3					-0.018	(-1.141)				
Countries ($\neq i$), all industries	ρ_4					0.062	(3.316)**				
Country *i*, industry *h*	ρ_5							0.008	(1.077)		
G5, industry *h*	ρ_6							0.017	(1.293)		
Country *i*, other industries ($\neq h$)	ρ_7									-0.041	(-1.616)
G5, other industries ($\neq h$)	ρ_8									0.051	(1.796)*
Obs		1227		1227		1227		997		1032	
Adjusted R-2		0.698		0.697		0.699		0.691		0.689	
SIC		0.352		0.358		0.353		0.431		0.402	

3.2. Recipient industries: High R&D

		Equation (A)		Equation (B)		Equation (C)		Equation (D)		Equation (E)	
		coef	*t*-stat	coef	*t*-stat	coef	*t*-stat	coef	*t*-stat	coef	*t*-stat
All countries, all industries	ρ	0.082	(3.906)**								
All countries, industry *h*	ρ_1			0.078	(2.344)**					0.078	(2.174)**
All countries, other industries ($\neq h$)	ρ_2			-0.004	(-0.102)			-0.042	(-1.189)		
Country *i*, all industries	ρ_3					0.017	(0.698)				
Countries ($\neq i$), all industries	ρ_4					0.075	(2.921)**				
Country *i*, industry *h*	ρ_5							0.038	(2.625)**		
G5, industry *h*	ρ_6							0.075	(2.719)**		
Country *i*, other industries ($\neq h$)	ρ_7									0.007	(0.130)
G5, other industries ($\neq h$)	ρ_8									-0.006	(-0.108)
Obs		369		369		369		303		309	
Adjusted R-2		0.648		0.650		0.651		0.671		0.649	
SIC		1.315		1.321		1.319		1.300		1.331	

3.3. Recipient industries: Low R&D

		Equation (A)		Equation (B)		Equation (C)		Equation (D)		Equation (E)	
		coef	*t*-stat	coef	*t*-stat	coef	*t*-stat	coef	*t*-stat	coef	*t*-stat
All countries, all industries	ρ	0.004	(0.291)								
All countries, industry *h*	ρ_1			-0.003	(-0.246)					-0.009	(-0.596)
All countries, other industries ($\neq h$)	ρ_2			0.009	(0.445)			0.003	(0.125)		
Country *i*, all industries	ρ_3					-0.003	(-0.115)				
Countries ($\neq i$), all industries	ρ_4					0.013	(0.447)				
Country *i*, industry *h*	ρ_5							0.008	(0.754)		
G5, industry *h*	ρ_6							-0.016	(-1.189)		
Country *i*, other industries ($\neq h$)	ρ_7									-0.040	(-1.339)
G5, other industries ($\neq h$)	ρ_8									0.051	(1.543)
Obs		858		858		858		694		694	
Adjusted R-2		0.734		0.734		0.734		0.726		0.726	
SIC		0.354		0.362		0.362		0.443		0.442	

Robustness Checks

1. Directly embodied (How much does R&D indirectly embodied in intermediates contribute to TFP?)
2. Sample without non-OECD (China, South Africa, and Chinese Taipei)
3. R&D based on 5-year lag
4. 2-stage least squares by using the lagged variables (e.g., embodied R&D) as instruments. We need to drop year 1995 from the sample
5. We create the ROW aggregate (outside of 32 countries in the data set) from IO tables of Brazil, Indonesia, and India so as to take care of the input transactions through the ROW.

4.1. Recipient industries: All manufacturing

	(1)		(2)		(3)		(4)		(5)		(6)	
Notes	Benchmark		DBQ		-		5 year lag		2SLS		ROW	
Recipients	All		All		w/o non-OECD		All		All		All	
Types of R&D	Total		Direct		Total		Total		Total		Total	
	coef	*t*-stat	coef	*t*-stat	coef	*t*-stat	coef	*t*-stat	coef	*t*-stat	coef	*t*-stat
ρ	0.041	(3.214)**	0.041	(3.314)**	0.043	(3.141)**	0.040	(3.143)**	0.028	(1.803)*	0.041	(3.214)**
Obs	1227		1227		1110		1227		818		1227	
Adjusted R-2	0.698		0.698		0.637		0.698		0.698		0.698	
SIC	0.352		0.352		0.392		0.353		-		0.352	

4.2. Recipient industries: High R&D

	(1)		(2)		(3)		(4)		(5)		(6)	
Notes	Benchmark		DBQ		-		5 year lag		2SLS		ROW	
Recipients	All		All		w/o non-OECD		All		All		All	
Types of R&D	Total		Direct		Total		Total		Total		Total	
	coef	*t*-stat	coef	*t*-stat	coef	*t*-stat	coef	*t*-stat	coef	*t*-stat	coef	*t*-stat
ρ	0.082	(3.906)**	0.091	(4.756)**	0.083	(3.755)**	0.083	(3.943)**	0.084	(3.128)**	0.082	(3.903)**
Obs	369		369		333		369		246		369	
Adjusted R-2	0.648		0.643		0.562		0.648		0.673		0.648	
SIC	1.315		0.541		1.341		1.315		-		1.315	

Conclusion

- Endogenous growth models in the tradition of Grossman and Helpman (1991) feature trade in intermediate inputs as one of the channels by which technology diffuses across countries.
- Our findings are
  1. We took all global transactions in intermediate inputs.
     - Direct and indirect
     - Foreign and domestic
     - Foreign are further separated to countries.
  2. High R&D sectors in non G5 countries benefit from the own industries in G5 countries.