

# Centrality in Production Networks and International Technology Diffusion

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## Introduction : Backgrounds of R&D spillovers

- The spillover effects that foreign knowledge affects domestic productivity have been theoretically confirmed (Grossman and Helpman, 1990, 1991; Rivera-Batiz and Romer, 1991), while the channels of the international transmission of knowledge were less clear.
- However, in empirical analysis, the seminal paper by Coe and Helpman (1995) finds that a country's total factor productivity (TFP) depends not only on its domestic R&D stock but also on the R&D stock of foreign countries, using import-weighted sums of trade partners' cumulative R&D expenditure.
- Starting with their analysis, the study of international R&D spillovers have developed over the last three decades, both theoretically and empirically (i.e., Eaton and Kortum, 2002; Keller, 2004; Acharya and Keller, 2009), and those have shown that **trade is an important channel in the propagation of knowledge.**

# Introduction : Backgrounds of R&D spillovers

- Moreover, it has been noted that the foreign R&D variable captures **only** current-period bilateral trade.
  - It is clearly possible though that country A benefits from country C, D, E's technology **without importing from these source**, if country C, D, E export to country B, which in turn exports to country A.
- Lumenga-Neso et al. (2005) and Poetzsch (2017) use a trade share that also takes into account **indirect** demands with the idea of **the Leontief inverse matrix**.
  - While Nishioka and Ripoll (2012) introduce the R&D content of intermediate inputs, which focuses on R&D **embodied in trade volume** instead of shares.

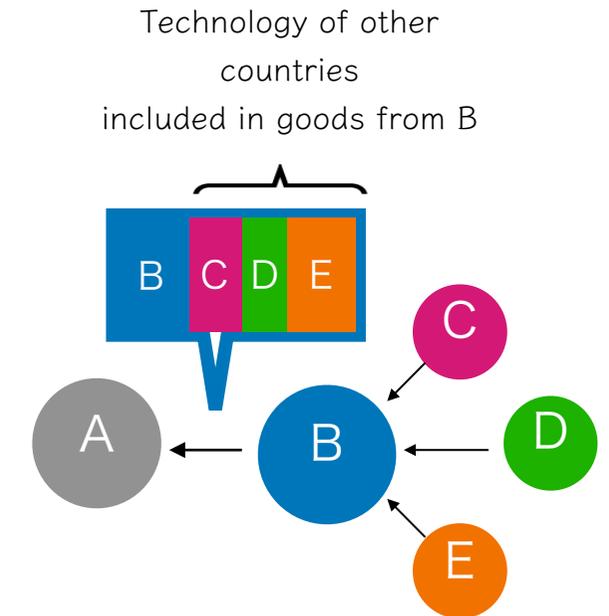


Figure 1:  
Direct and Indirect R&D spillovers

# Introduction : Backgrounds of R&D spillovers

- Also, Keller (2002) examines the degree of localization of technology by estimating different decay parameters for the late 1970s and the early 1990s.
  - The estimates indicate that it has **shrunk substantially** over time in absolute value, suggesting that the degree of localization has become **smaller** (Figure 2).
  - Keller concluded that this is due to the development of information and communication technologies.
- However, previous studies have **not fully** accounted the geography effect in international technology diffusion.

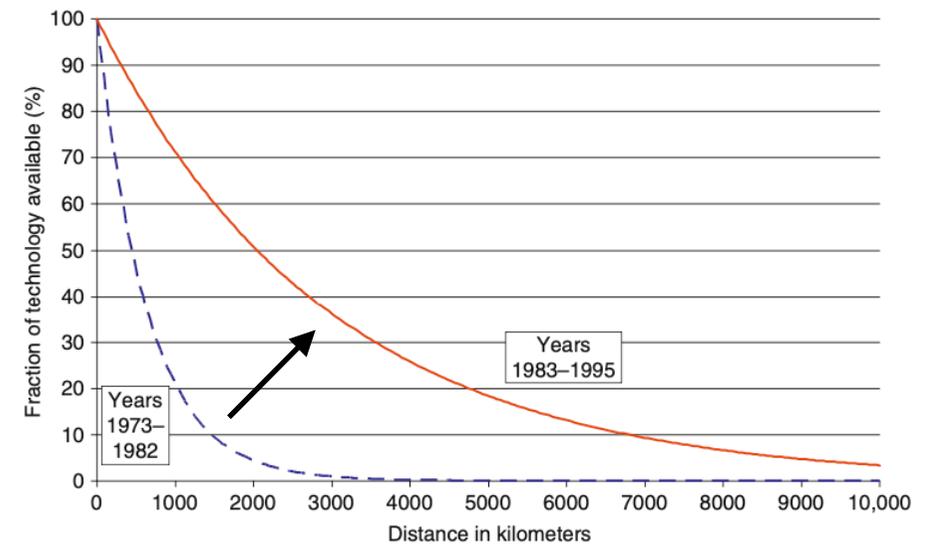


Figure 2:

Geographic localization of technology diffusion over time

Source: Keller (2010)

- The existence of hubs at the firm level that trade with many customers are confirmed from customs data (Bernard et al., 2007), and also the existence of hubs at the country and industry level are confirmed from global input-output table (Criscuolo and Timmis, 2018).
  - There are several analyses of hubs at the micro level, and hubs are important in the propagation of shocks (Acemoglu et al., 2012; Carvalho et al., 2014; Boehm et al., 2019) and knowledge (Alatas et al., 2016).
- However, there is still little on the role of hubs at the **macro (global) level**, and we do not know how regional hubs on trade help in the diffusion of technologies from other regions.
- As Figure 3 shows, each regional hub gather technology from that region and diffuse it to other regions, thereby it is considered that **the sector in country B1** benefits indirectly the countries' technology in other region.

# Introduction : Motivation

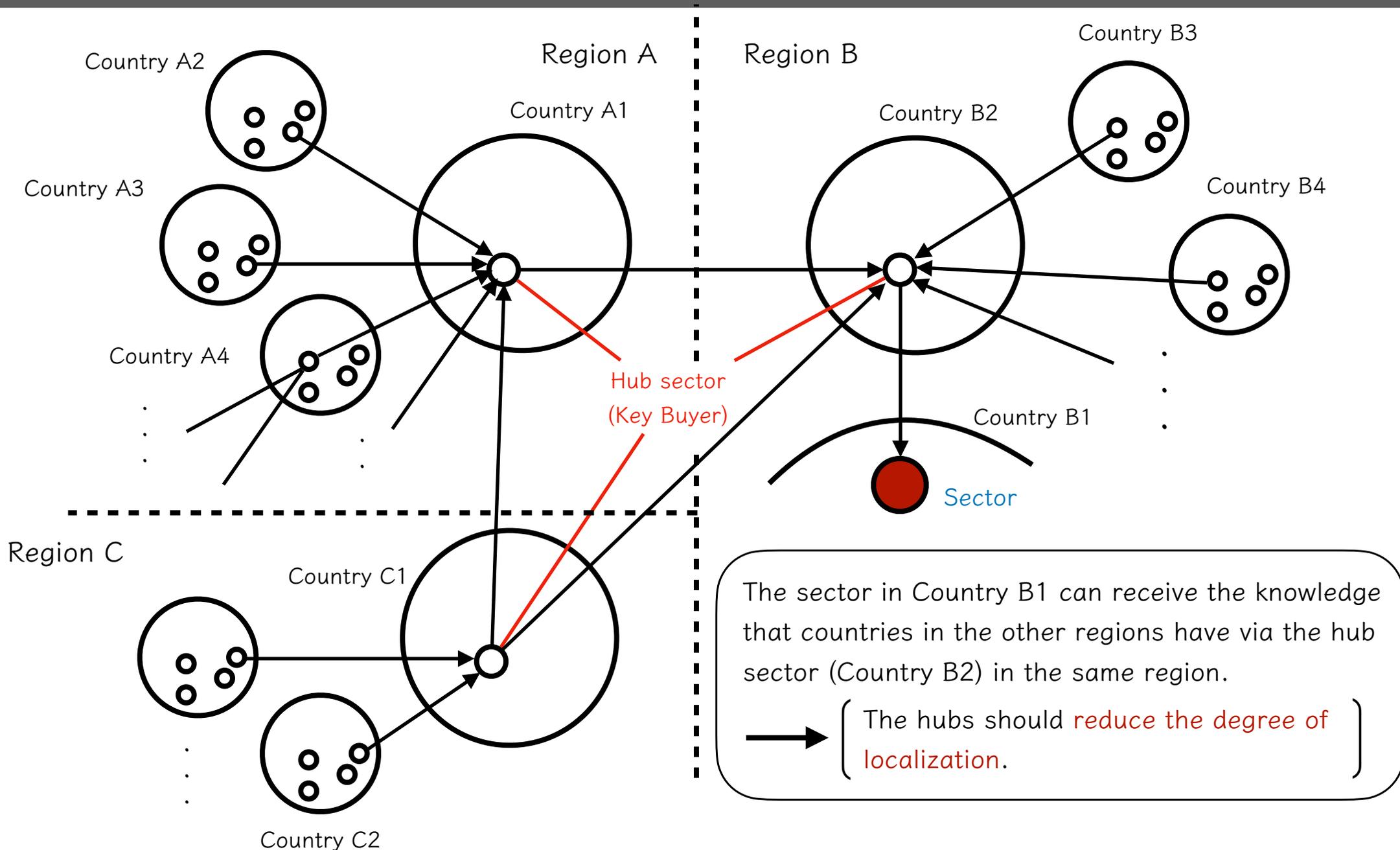


Figure 3: Overview of Trade

- How does *the structure of GVCs affect* the international spillover effect of knowledge?
  - Are the international R&D spillover effects from trading with high centrality countries greater than with peripheral countries?
  - Are the central country important in technology diffusion?

# Introduction : What I do

- In this study, I consider the (direct and indirect) spillover effects from goods traded for final demand generated in a country.
- To explore the role of central country in diffusion of technology, I focus on a country that are central in both the backward and forward linkages, as shown in Figure 4.
  - Key buyer can be said to be important in **gathering** knowledge from other countries.
  - Key supplier can be said to be important in **diffusing** knowledge to other countries.
- I investigate whether this kind of country is important as a **mediator** of diffusing other countries' technologies in trade.

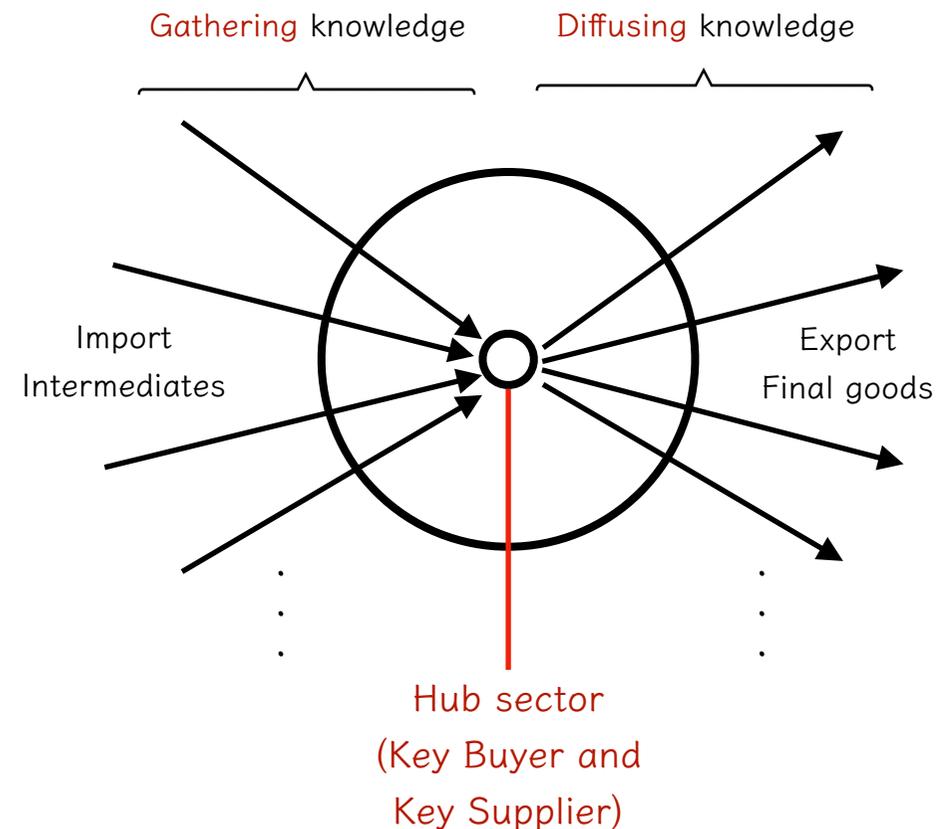


Figure 4:  
Hub sector

- Main results are:

1. The impacts of foreign R&D contents from high centrality exporters are **positively significant and highest**.
  - Basically, however, the spillover effect from abroad occurs only in imports from industries that are considered relatively important in trade.
2. I find that it is also statistically significant from exporters with **middle centrality**.
  - In particular, the increase in direct and indirect demand from country with middle centrality since 2002 is thought to have contributed to the results.
3. It turns out that trading with home industry does not always produce spillover effects, as the **proportion of domestic and foreign R&D contents flowing into a country is important**.

- In this study, I use a sample of 21 countries and 14 manufacturing industries from 1995 to 2007.
- The data used to construct variables is as follows:
  - The World Input-Output Database (input-output linkages)
  - The OECD ANBERD database (industry level R&D)
  - The OECD STAN database and the World Bank's World Development Indicators (deflators)
  - The WIOD Socio Economic Accounts (labor, capital, GDP)

- To consider the network effects in trade, I use the R&D contents embodied in final goods, following Nishioka and Ripoll (2012). Those are defined as follows:

$$V = D(I - B)^{-1}f$$

where  $D$  is the ratio of the R&D stock to output,  $B$  is a global intermediate input coefficients matrix, and  $f$  is final demand.

- I introduce “centrality” that capture the country’s importance in GVCs.
- Following Criscuolo and Timmis (2018), I calculate forward and backward centrality that defined as:

$$\text{Centrality}_{iht}^{fwd} = \eta(\mathbf{I} - \lambda\mathbf{W})^{-1}\mathbf{1},$$

$$\text{Centrality}_{iht}^{back} = \eta(\mathbf{I} - \lambda\mathbf{W}^{\top})^{-1}\mathbf{1}$$

where  $W$  represents input-output linkages matrix.  $\eta = 1 - \lambda$  is baseline centrality level, and  $\lambda$  is the parameter.

- The more forward centrality a country has, the more goods it exports to other countries; the more backward centrality a country has, the more goods it imports from other countries.

# Variables: Centrality measure

Table 1: Summary statistics of backward and forward centrality

	Backward centrality					Forward centrality				
	Obs.	Min	Max	Mean	Std. dev	Obs.	Min	Max	Mean	Std. dev
C15T16: Food, Beverages and Tobacco	273	0.59	5.13	1.89	1.13	273	0.51	2.21	0.89	0.48
C17T18: Textiles and Textile Products	273	0.55	2.00	1.16	0.35	273	0.51	4.60	1.22	0.87
C19: Leather, Leather and Footwear	273	0.51	2.41	0.74	0.34	273	0.51	2.55	0.69	0.40
C20: Wood and Products of Wood and Cork	273	0.53	1.84	0.79	0.32	273	0.52	2.25	0.86	0.37
C21T22: Pulp, Paper, Paper , Printing and Publishing	273	0.51	3.15	0.86	0.62	273	0.52	6.02	1.58	1.33
C23: Coke, Refined Petroleum and Nuclear Fuel	273	0.56	3.97	1.21	0.76	273	0.52	5.70	1.34	1.04
C24: Chemicals and Chemical Products	273	0.57	4.97	1.46	1.02	273	0.64	18.77	4.14	4.16
C25: Rubber and Plastics	273	0.55	2.32	0.88	0.41	273	0.51	3.16	1.28	0.72
C26: Other Non-Metallic Mineral	273	0.53	2.11	0.81	0.29	273	0.52	2.10	0.87	0.40
C27T28: Basic Metals and Fabricated Metal	273	0.59	5.57	1.54	1.10	273	0.61	12.9	2.77	2.46
C29: Machinery, Nec	273	0.56	5.37	1.25	1.03	273	0.55	8.97	1.86	1.96
C30T33: Electrical and Optical Equipment	273	0.56	5.19	1.58	1.15	273	0.50	12.6	2.86	3.06
C34T35: Transport Equipment	273	0.54	11.26	2.42	2.49	273	0.50	10.07	2.14	2.22
C36T37: Manufacturing, Nec; Recycling	273	0.53	2.55	0.96	0.47	273	0.51	2.06	0.82	0.35

Note : Author's calculation. This table is constructed using all observations. C15T16 - C36T37 represent industry codes.

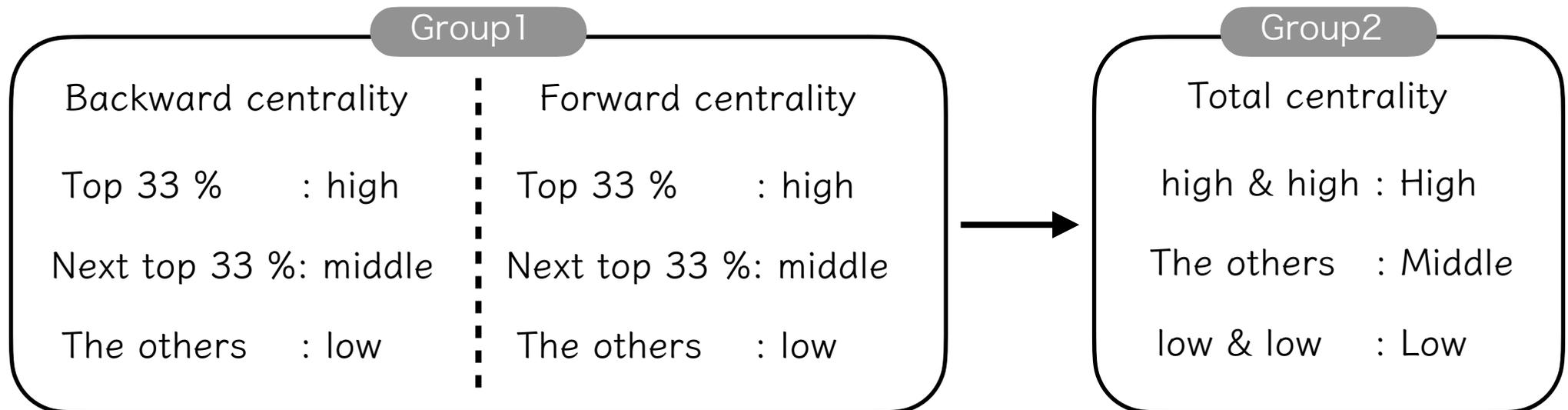
◇ Industries with high MAX values suggest the presence of a hub.

# Empirical strategy: Classifications of sample

- In empirical analysis, I divide my sample for examining my questions.
- For importer
  - I divide into 3 regions: "All", "Europe", and "North America".
    - This is because there are more hubs in Europe than in other regions, and European countries are **more likely to be involved with countries that are hubs**, so a larger effect is expected.
  - Also, I divide into 2 categories: "G5", "Non-G5".
    - This is because the degree of influence from other countries is expected to be different between G5 and Non-G5.
    - As will be discussed later, the ratio of domestic R&D contents to the total is very different between G5 and NonG5, which may affect the results.

# Empirical strategy: Classifications of sample

- For exporter (country)
  - This classification explores **which country has high centrality**.
    - Here, I identify the countries that are central to the import and export in each industry.
  - Based on the backward and forward centrality, I first divide 21 countries into three categories (“high”, “middle”, and “low”) in each industry in each year (Group 1).
  - Further, to explore **total** centrality, those that are “high” in both backward and forward linkages are “High”, those that are “low” in both are “Low”, and the others are “Middle” (Group 2).



# Empirical strategy: Classifications of sample

- For exporter (industry)
  - I further divide industries into central and non-central industries.
    - As shown in Table 1, there are **clear differences** in the distribution of centrality across industries.
  - In diffusion, I consider that it is important whether a hub exists or not in the industry.
    - For example, in the case of "Wood and Products of Wood and Cork", it is difficult to say that a hub exist.

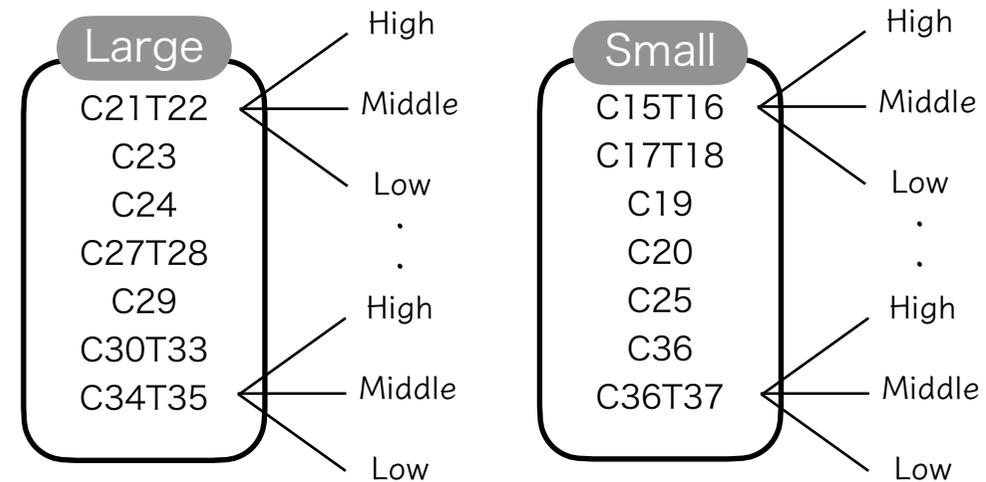


Figure 5:  
Classification of exporter

- Then, I classify the top 7 Max values of centrality in 14 industries as "Large" and the rest as "Small".
- In summary, the classification of exporters is represented in Figure 5.

- Following Nishioka and Ripoll (2012), I estimate the effects from the domestic ( $\beta$ ) and foreign ( $\rho_1, \rho_2$ , and  $\rho_3$ ) R&D content as follows:

$$\begin{aligned} \ln \text{TFP}_{iht} = & \alpha_{ih} + \alpha_t + \beta \left[ \sum_g D_{it}(g) T_{iit}(g, h) \right] \\ & + \rho_1 \left[ \sum_{j \neq i, i \in \text{ALL or EU or NA}, j \in \text{high}} \sum_{g \in \text{S or L}} D_{jt}(g) T_{jit}(g, h) \right] \\ & + \rho_2 \left[ \sum_{j \neq i, i \in \text{ALL or EU or NA}, j \in \text{middle}} \sum_{g \in \text{S or L}} D_{jt}(g) T_{jit}(g, h) \right] \\ & + \rho_3 \left[ \sum_{j \neq i, i \in \text{ALL or EU or NA}, j \in \text{low}} \sum_{g \in \text{S or L}} D_{jt}(g) T_{jit}(g, h) \right] + \epsilon_{iht} \end{aligned}$$

where  $i$ ,  $h$ , and  $t$  denote the country, industry, and year, respectively; TFP is calculated following the method of Caves (1982);  $T$  is equal to  $(I - B)^{-1} f$ .

- The results are reported in Table 2.

◇ It suggests that not only countries with high centrality but also countries with middle centrality are important in the diffusion of knowledge.

◇ Only in the North American countries are the results positively significant from the R&D contents from the home country.

Table 2: The results of exporter's centrality effects

	Small industries			Large industries		
	(1) All	(2) Europe	(3) North America	(4) All	(5) Europe	(6) North America
domestic, $\beta$	-0.019 (0.015)	-0.028 (0.019)	0.045** (0.023)	-0.025 (0.015)	-0.032 (0.020)	0.045** (0.021)
<b>exporter's centrality:</b>						
high, $\rho_1$	0.027* (0.015)	0.014 (0.021)	0.014 (0.028)	0.040** (0.019)	0.063*** (0.019)	0.013 (0.054)
middle, $\rho_2$	0.027 (0.019)	0.050 (0.028)	-0.031 (0.028)	0.034** (0.014)	0.036** (0.015)	-0.061 (0.040)
low, $\rho_3$	0.015 (0.012)	0.010 (0.016)	0.004 (0.017)	0.015* (0.008)	0.008 (0.011)	-0.003 (0.025)
constant	0.105 (0.096)	0.132 (0.123)	-0.134 (0.159)	-0.110* (0.061)	-0.150* (0.070)	-0.009 (0.241)
<i>N</i>	3819	3091	546	3819	3091	546
<i>R</i> <sup>2</sup>	0.867	0.855	0.957	0.870	0.860	0.958
Country-Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

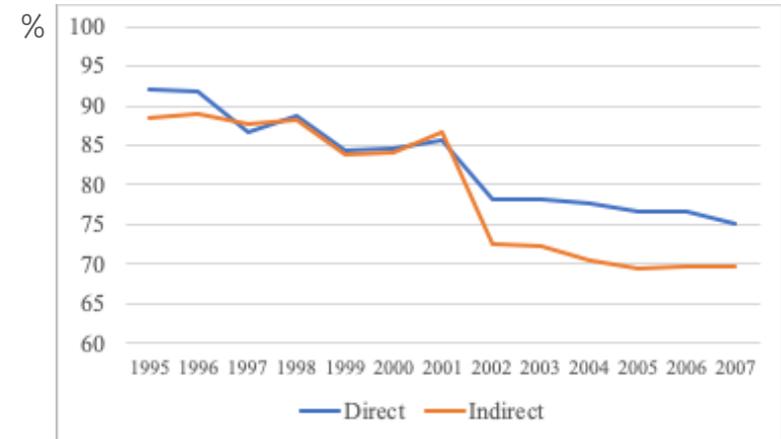
# The change of the foreign R&D contents

- The foreign R&D contents can decompose into direct and indirect:

$$\begin{aligned} Vf &= Vf\text{-direct} + Vf\text{-indirect} \\ &= DB^F f + D[(I - B)^{-1} - (I + B)]^F f \end{aligned}$$

- As Figure 6 shows, the direct and indirect demand from countries with middle centrality is on the rise, especially from 2001.
  - This is one of the reasons why the effects from a country with middle centrality are also statistically significant.
  - In fact, the results are significant when estimated by adding the dummy variables that is equal to 1 for the years 2002-2007 (Table 3).

The average of R&D contents share from high centrality (World): Electrical and Optical Equipment



The average of R&D contents share from middle centrality (World): Electrical and Optical Equipment

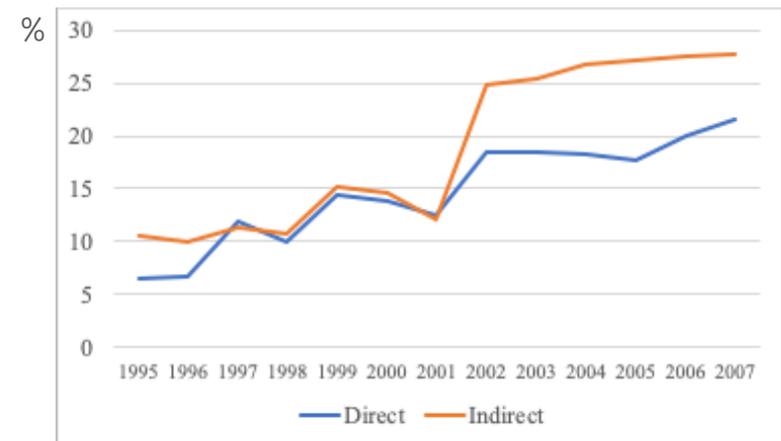


Figure 6:  
The average R&D contents share

Table 3: The results of exporter's centrality effects (+ dummy)

	Small industries			Large industries		
	(1) All	(2) Europe	(3) North America	(4) All	(5) Europe	(6) North America
domestic, $\beta$	-0.022 (0.015)	-0.032 (0.020)	0.040** (0.020)	-0.030* (0.017)	-0.042* (0.020)	0.046** (0.021)
<b>exporter's centrality:</b>						
high, $\rho_1$	0.037** (0.015)	0.029 (0.024)	-0.030 (0.024)	0.056** (0.021)	0.059** (0.023)	-0.002 (0.048)
middle, $\rho_2$	0.022 (0.019)	0.020 (0.027)	-0.017 (0.025)	0.015 (0.013)	0.028* (0.015)	-0.046 (0.069)
low, $\rho_3$	0.014 (0.012)	0.010 (0.015)	0.008 (0.024)	0.018* (0.009)	0.013 (0.011)	0.001 (0.044)
high*dummy	-0.016 (0.010)	-0.019 (0.019)	0.048 (0.041)	-0.024** (0.011)	0.021 (0.028)	0.039 (0.111)
middle*dummy	0.026* (0.012)	0.028 (0.021)	0.043 (0.037)	0.040** (0.015)	0.045** (0.023)	-0.050 (0.130)
low*dummy	-0.006 (0.007)	-0.007 (0.008)	-0.044 (0.033)	-0.015 (0.009)	-0.031* (0.015)	-0.004 (0.039)
constant	0.105 (0.094)	0.133 (0.120)	-0.140 (0.140)	-0.144** (0.064)	-0.192** (0.081)	0.018 (0.214)
<i>N</i>	3819	3091	546	3819	3091	546
<i>R</i> <sup>2</sup>	0.868	0.856	0.960	0.872	0.861	0.958
Country-Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses

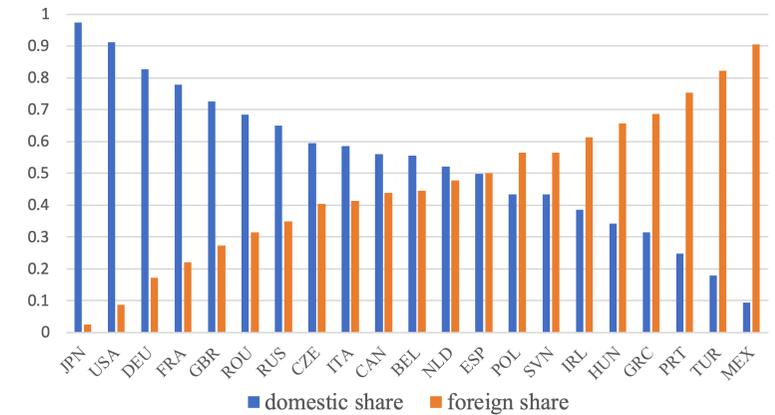
\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

◇ It finds that the effect has increased significantly since 2002 with the increase in direct and indirect demand from countries with middle centrality.

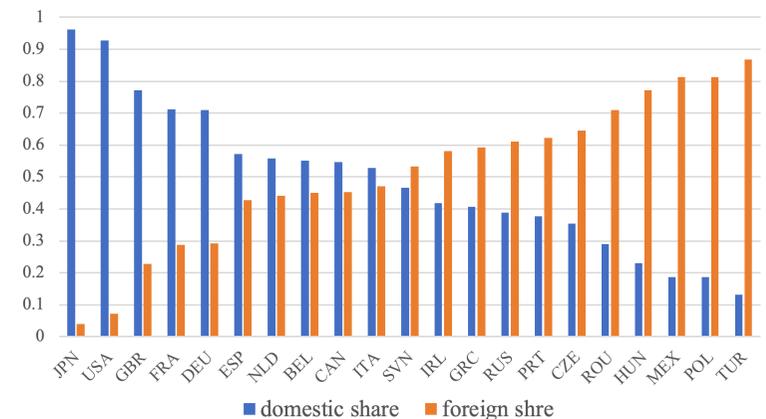
◇ The results suggest that countries with middle centrality have also become important in technology diffusion since 2002.

# Empirical strategy: Domestic R&D contents shares

- Next, I consider that the difference in effect between the G5 and Non-G5.
- The ratio of domestic R&D content to the total in G5 is **considerably higher** than in Non-G5, as shown in Figure 7.
- The ratio of domestic R&D contents to the total R&D content in the G5 is over 70% in all periods
- On the other hand, in the Non-G5, the ranking shifts rapidly within the period, and foreign R&D content also accounts for a large portion.



Panel (a): The R&D contents shares in 1995



Panel (b): The R&D contents shares in 2007

Figure 7: The R&D contents shares

# Empirical strategy: Comparison the effects between G5 and non-G5 countries

- Since the share of R&D contents may be important for the spillover effects, I divide the 21 countries in my sample into two categories: **G5 and non-G5 countries**.
  - The reason for NAFTA's results are the slightly different in Table 2 is considered that the U.S. that mostly accounts for its own R&D contents includes the sample.
- I set importer country as G5 and non-G5 countries instead of 3 regions, and estimate:

$$\begin{aligned} \ln \text{TFP}_{iht} = & \alpha_{ih} + \alpha_t + \beta \left[ \sum_g D_{it}(g) T_{iit}(g, h) \right] \\ & + v_1 \left[ \sum_{j \neq i, i \in \text{G5 or nonG5}, j \in \text{high}} \sum_{g \in \text{S or L}} D_{jt}(g) T_{jit}(g, h) \right] \\ & + v_2 \left[ \sum_{j \neq i, i \in \text{G5 or nonG5}, j \in \text{middle}} \sum_{g \in \text{S or L}} D_{jt}(g) T_{jit}(g, h) \right] \\ & + v_3 \left[ \sum_{j \neq i, i \in \text{G5 or nonG5}, j \in \text{low}} \sum_{g \in \text{S or L}} D_{jt}(g) T_{jit}(g, h) \right] + \epsilon_{iht} \end{aligned}$$

Table 4: G5 and non-G5 Results

◇ G5 is also obtained benefits from countries with high centrality, but Non-G5 is found to be influenced more by foreign countries, including the effects from countries with middle centrality.

◇ It is confirmed that the effect from the domestic R&D content is not the nature of North America, but the nature of the G5 that countries with high technological capabilities.

	Small		Large	
	(1) G5	(2) Non-G5	(3) G5	(4) Non-G5
domestic, $\beta$	0.102** (0.043)	-0.021 (0.015)	0.095*** (0.036)	-0.029* (0.016)
<b>exporter's centrality:</b>				
high, $v_1$	-0.019 (0.023)	0.029 (0.021)	0.058** (0.021)	0.060** (0.020)
middle, $v_2$	0.021 (0.023)	0.033 (0.026)	-0.013 (0.020)	0.039** (0.018)
low, $v_3$	-0.035 (0.026)	0.011 (0.015)	-0.039* (0.023)	0.001 (0.009)
constant	-0.755** (0.350)	0.076 (0.110)	-0.789*** (0.295)	-0.231*** (0.067)
<i>N</i>	910	2909	910	2909
<i>R</i> <sup>2</sup>	0.910	0.860	0.909	0.866
Country-Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Standard errors in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

- In the empirical analysis, it turns out that trading with high centrality does not always produce spillover effects, and that the proportion of domestic and foreign R&D contents flowing into a country is important.
- Therefore, I do three robustness checks for the results reported in Table 3.
  1. I use the **other classification of centrality** to show that the results do not vary with the centrality classification.
  2. I use **1 year lagged explanatory variables** for capturing the effects that are not reflected immediately after trade.

→  $\left( \begin{array}{l} \text{Basically, no results different from the important results were} \\ \text{obtained.} \end{array} \right)$

- This study is the first to consider and empirically analyze the position of the industry in GVCs for international R&D spillovers.
- To sum up the results:
  1. The impacts of foreign R&D contents from high centrality exporters are positively significant and highest.
  2. I find that it is also statistically significant from exporters with middle centrality.
  3. It turns out that trading with home industry does not always produce spillover effects, as the proportion of domestic and foreign R&D contents flowing into a country is important.
- In contrast to the claims of Keller (1998), my findings suggest that **which country imports from which country is important** in the international spillover effects.