Centrality in Production Networks and International Technology Diffusion

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- Starting with Coe and Helpman (1995), the study of international R&D spillovers have developed over the last three decades, both theoretically and empirically (e.g., 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.
- Subsequent analyses that exploit a rising availability of global I-O tables confirm that international R&D spillovers diffuse through intermediate input usage (e.g., Piermartini and Rubinova, 2014; Badinger and Egger 2016; Foster-McGregor et al, 2016; Tajoli and Felice, 2018).

- 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 (Figure 1).
- 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.

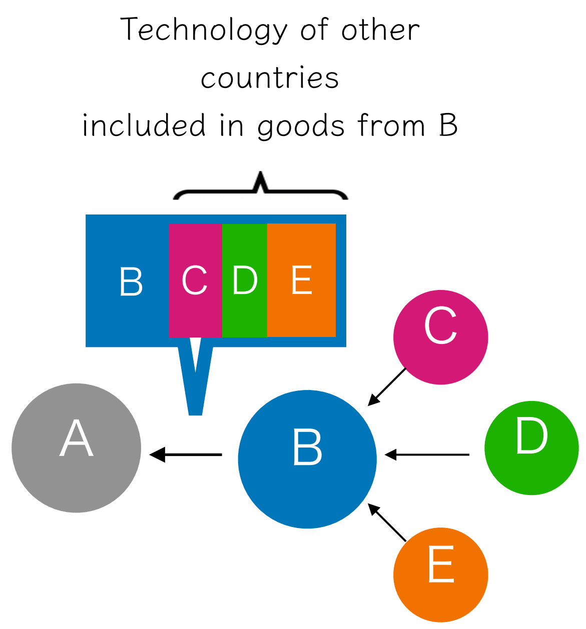


Figure 1:
Direct and Indirect R&D spillovers

Introduction : Backgrounds of R&D spillovers (Geography)

- 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.

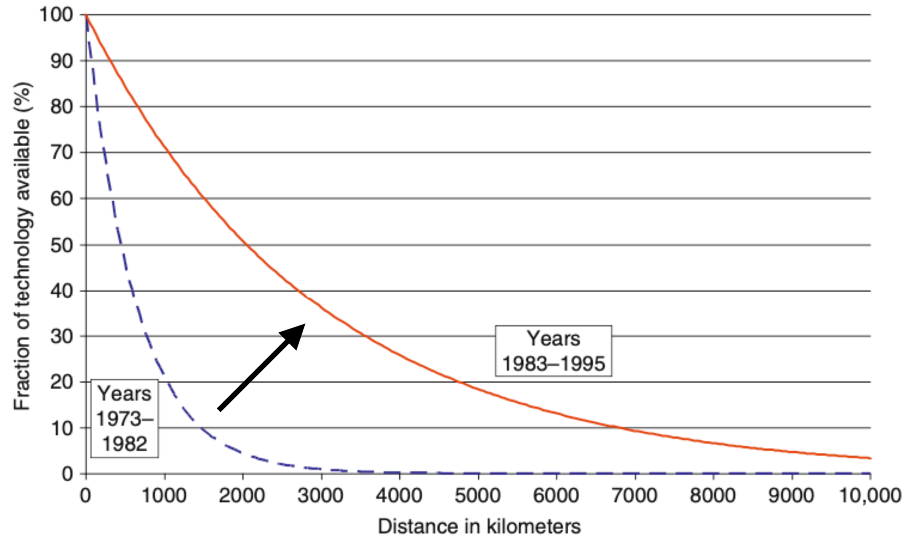
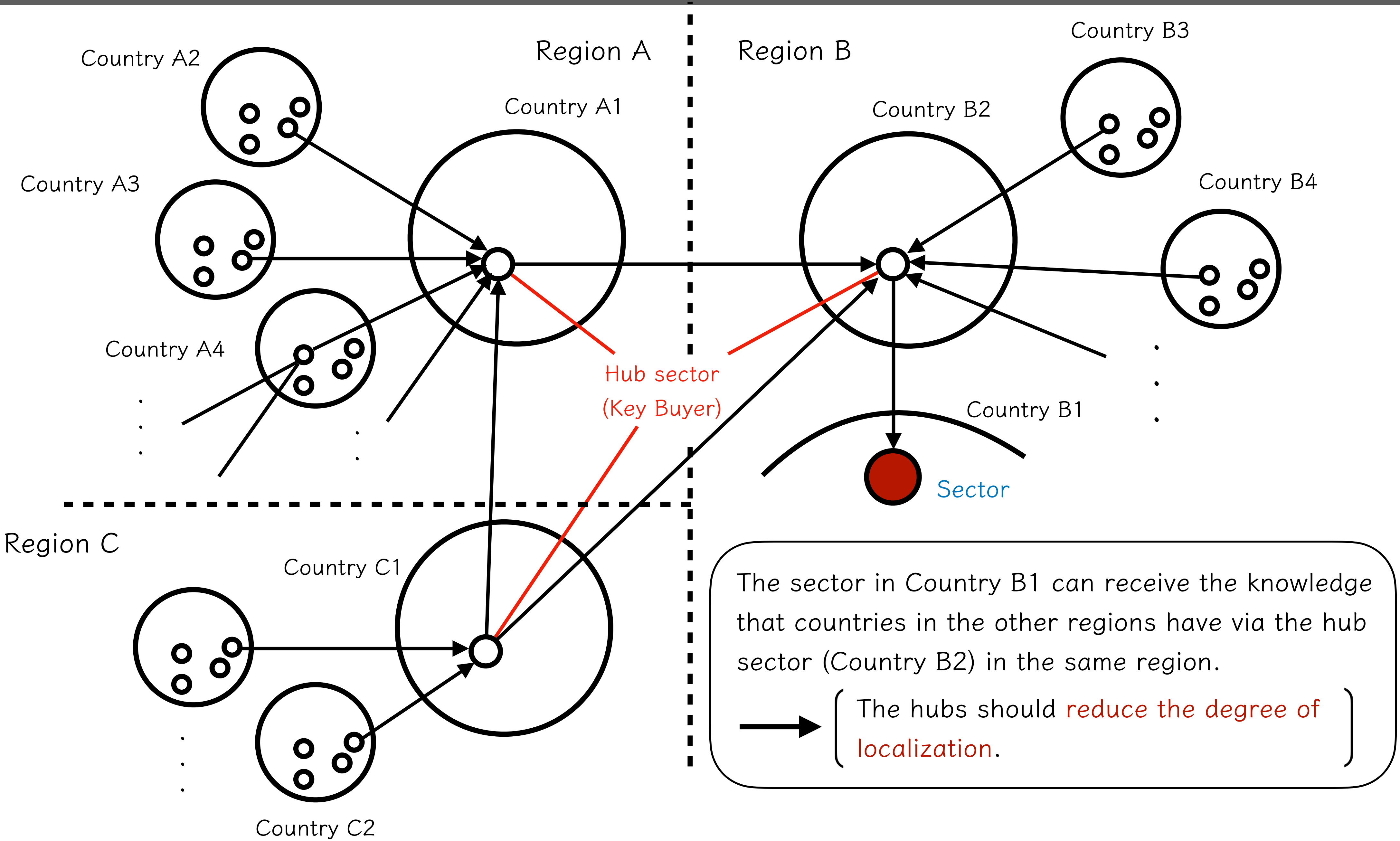


Figure 2:
Geographic localization of technology diffusion over time

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.



The sector in Country B1 can receive the knowledge that countries in the other regions have via the hub sector (Country B2) in the same region.

→ (The hubs should reduce the degree of localization.)

Figure 3: Overview of Trade

Introduction : Research questions

- 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.

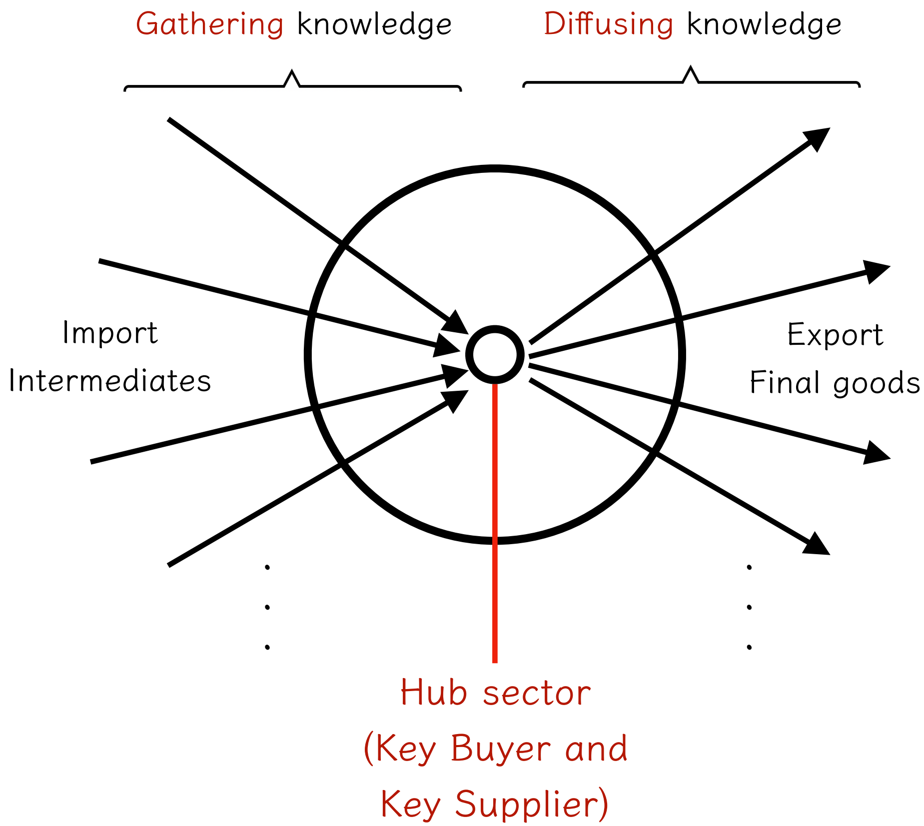


Figure 4:
Hub sector

Introduction : Main findings

- 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.

Data

- 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)

Variables: The R&D contents embodied in final goods

- 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.

Variables: Centrality measure

- 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 λ is the parameter (here, I set $\lambda = 0.5$).

- λ reflects the average share of intermediates in production (*see* Acemoglu *et al.*, 2012; Carvalho, 2014).
- The more forward centricity 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.
    - I use this classification for final estimation.

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).
  - Using Group 1, 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). I use Group 2 for estimation.

Group1

Backward centrality		Forward centrality	
Top 33 %	: high	Top 33 %	: high
Next top 33 %	: middle	Next top 33 %	: middle
The others	: low	The others	: low

→

Group2

Total centrality	
high & high	: High
The others	: Middle
low & low	: Low

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.
    - 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.

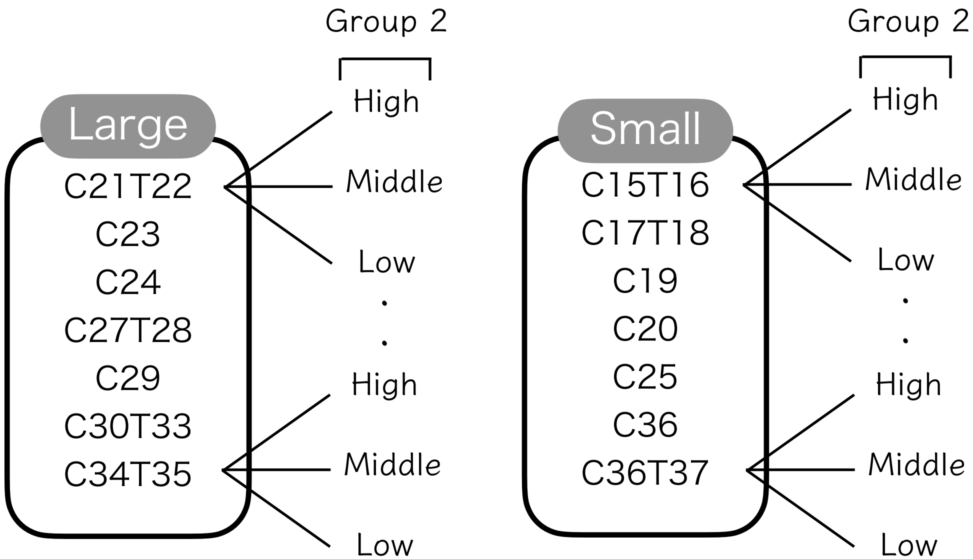


Figure 5:
Classification of *exporter*

Empirical strategy: Estimation

- Following Nishioka and Ripoll (2012), I estimate the effects from the domestic (β) and foreign ($\rho_1, \rho_2,$ and ρ_3) R&D content as follows:

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

  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.

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, β	-0.019	-0.028	0.045**	-0.025	-0.032	0.045**
	(0.015)	(0.019)	(0.023)	(0.015)	(0.020)	(0.021)
exporter's centrality:						
high, ρ_1	0.027*	0.014	0.014	0.040**	0.063***	0.013
	(0.015)	(0.021)	(0.028)	(0.019)	(0.019)	(0.054)
middle, ρ_2	0.027	0.050	-0.031	0.034**	0.036**	-0.061
	(0.019)	(0.028)	(0.028)	(0.014)	(0.015)	(0.040)
low, ρ_3	0.015	0.010	0.004	0.015*	0.008	-0.003
	(0.012)	(0.016)	(0.017)	(0.008)	(0.011)	(0.025)
constant	0.105	0.132	-0.134	-0.110*	-0.150*	-0.009
	(0.096)	(0.123)	(0.159)	(0.061)	(0.070)	(0.241)
N	3819	3091	546	3819	3091	546
R^2	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

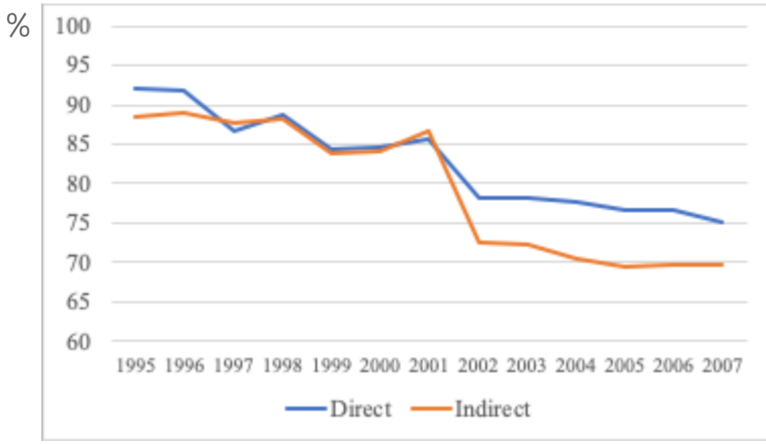
$^{*}\ p < 0.1$, $^{**}\ p < 0.05$, $^{***}\ p < 0.01$

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

$$V^f = V^{f\_\text{direct}} + V^{f\_\text{indirect}}$$
$$= DB^F f \quad + D[(I-B)^{-1} - (I+B)]^F f$$

- 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



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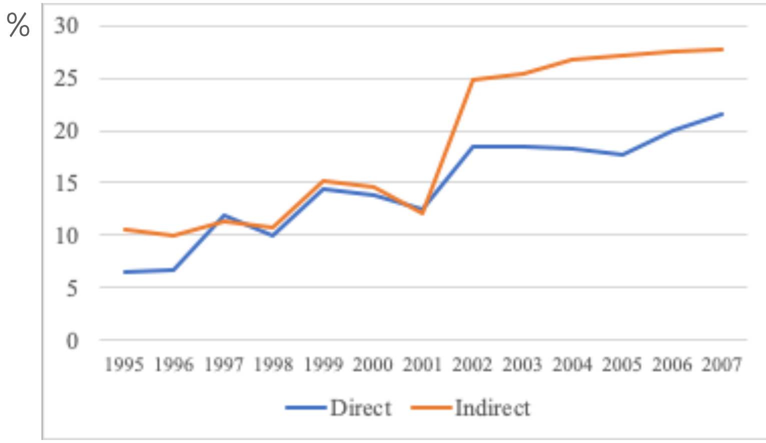


Figure 6:
The average R&D contents share

Results

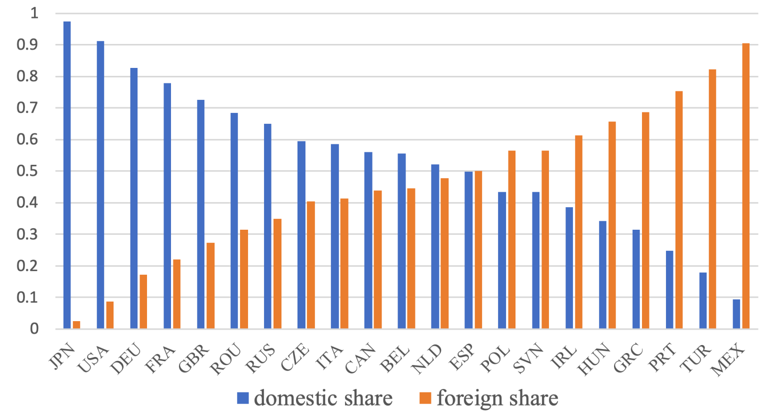
Table 3: The results of exporter's centrality effects (+ dummy)

	Small industries			Large industries		
	(1) All	(2) Europe	(3) North America	(4) All	(5) Europe	(6) North America
domestic, β	-0.022	-0.032	0.040**	-0.030*	-0.042*	0.046**
	(0.015)	(0.020)	(0.020)	(0.017)	(0.020)	(0.021)
exporter's centrality:						
high, ρ_1	0.037**	0.029	-0.030	0.056**	0.059**	-0.002
	(0.015)	(0.024)	(0.024)	(0.021)	(0.023)	(0.048)
middle, ρ_2	0.022	0.020	-0.017	0.015	0.028*	-0.046
	(0.019)	(0.027)	(0.025)	(0.013)	(0.015)	(0.069)
low, ρ_3	0.014	0.010	0.008	0.018*	0.013	0.001
	(0.012)	(0.015)	(0.024)	(0.009)	(0.011)	(0.044)
high*dummy	-0.016	-0.019	0.048	-0.024**	0.021	0.039
	(0.010)	(0.019)	(0.041)	(0.011)	(0.028)	(0.111)
middle*dummy	0.026*	0.028	0.043	0.040**	0.045**	-0.050
	(0.012)	(0.021)	(0.037)	(0.015)	(0.023)	(0.130)
low*dummy	-0.006	-0.007	-0.044	-0.015	-0.031*	-0.004
	(0.007)	(0.008)	(0.033)	(0.009)	(0.015)	(0.039)
constant	0.105	0.133	-0.140	-0.144**	-0.192**	0.018
	(0.094)	(0.120)	(0.140)	(0.064)	(0.081)	(0.214)
N	3819	3091	546	3819	3091	546
R^2	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

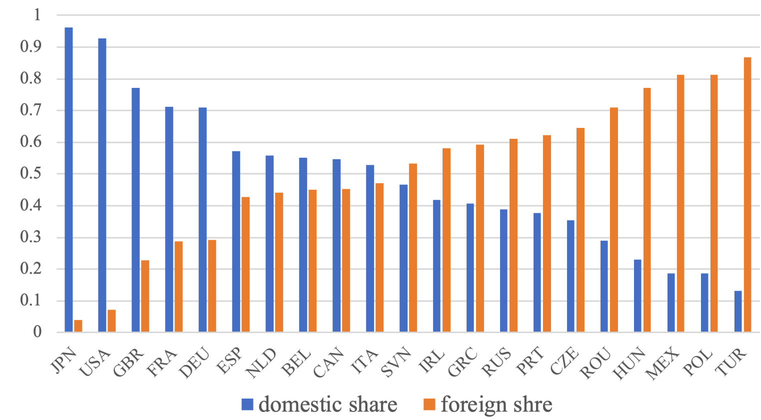
Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

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:

$$
\begin{aligned}
\ln \mathrm{TFP}_{iht} = \alpha_{ih} + \alpha_t + \beta\Big[\sum_g D_{it}(g)T_{iit}(g,h)\Big] \\
+ \upsilon_1\Big[\sum_{j\neq i, i\in \text{G5 or nonG5},\ j\in \text{High}} \sum_{g\in \text{S or L}} D_{jt}(g)T_{jit}(g,h)\Big] \\
+ \upsilon_2\Big[\sum_{j\neq i, i\in \text{G5 or nonG5},\ j\in \text{Middle}} \sum_{g\in \text{S or L}} D_{jt}(g)T_{jit}(g,h)\Big] \\
+ \upsilon_3\Big[\sum_{j\neq i, i\in \text{G5 or nonG5},\ j\in \text{Low}} \sum_{g\in \text{S or L}} D_{jt}(g)T_{jit}(g,h)\Big] + \epsilon_{iht}
\end{aligned}
$$

Table 4: G5 and non-G5 Results

	Small		Large	
	(1) G5	(2) Non-G5	(3) G5	(4) Non-G5
domestic, β	0.102**	-0.021	0.095***	-0.029*
	(0.043)	(0.015)	(0.036)	(0.016)
exporter's centrality:				
high, υ_1	-0.019	0.029	0.058**	0.060**
	(0.023)	(0.021)	(0.021)	(0.020)
middle, υ_2	0.021	0.033	-0.013	0.039**
	(0.023)	(0.026)	(0.020)	(0.018)
low, υ_3	-0.035	0.011	-0.039*	0.001
	(0.026)	(0.015)	(0.023)	(0.009)
constant	-0.755**	0.076	-0.789***	-0.231***
	(0.350)	(0.110)	(0.295)	(0.067)
N	910	2909	910	2909
R^2	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
$^{*}\ p < 0.1$, $^{**}\ p < 0.05$, $^{***}\ p < 0.01$

Robustness checks

- 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.

→ (Basically, no results different from the important results were obtained.)

Conclusions

- 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.