# Centrality in Production Networks and International Technology Diffusion

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## Backgrounds and Problems

Starting with Coe and Helpman (1995), empirical studies of international R&D spillovers have developed over the last three decades. In this study I focus on two problems as follows:

**1.** While previous literature has **mostly considered direct (bilateral) trade relationships,** and few have even dealt with **indirect effects.**

- That is, previous studies do not consider the effects from technology of C, D, E and G.

→ ( Now that intermediate goods account for **more than two-thirds** of the total (Johnson and Noguera, 2012), the conventional measurement is not correct. )

**2.** It is also not very clear **from which countries imports** are important for spillovers (Keller, 1998).

→ ( It is considered that there is a **clear difference** in the effects that country A receives from country B and country F. )

R&D contents of other countries included in goods from B

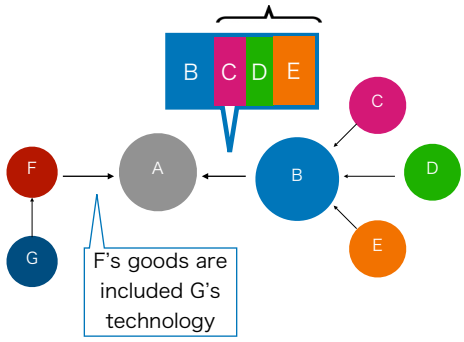


Figure 1: Overview of intermediates trade and R&D spillovers

## 1. R&D contents

- To solve the problem 1, I use **the R&D contents embodied in intermediates**, 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, f is final demand.

- Using this R&D contents, we can calculate **the spillover effects from goods of B, considering both of direct and indirect demands** (B and C to E in Figure 1) for final demand in country A.

## 2. Centrality Measure

- To deal with the problem 2, I introduce "centrality" that **capture the country's importance in GVCs.** Following Criscuolo and Timmis (2018a), 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, $\eta$ and $\lambda$ are the parameter.

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

## Empirical Strategy and Results

- In empirical analysis, I estimate the equation as follows:

$$\ln \text{TFP}_{iht} = \alpha_{ih} + \alpha_{it} + \alpha_{ht} + \beta_3 \Big[\sum_g D_{it}(g) T_{iit}(g,h)\Big] + \rho_1 \Big[\sum_{j\neq i, i\in \text{ALL or EU or NA}} \sum_{g\in\text{high}} D_{jt}(g) T_{jit}(g,h)\Big]$$
$$+ \rho_2 \Big[\sum_{j\neq i, i\in \text{ALL or EU or NA}} \sum_{g\in\text{middle}} D_{jt}(g) T_{jit}(g,h)\Big] + \rho_3 \Big[\sum_{j\neq i, i\in \text{ALL or EU or NA}} \sum_{g\in\text{low}} D_{jt}(g) T_{jit}(g,h)\Big]$$

where i is importer, h is industry, t is time.

- Now, I define $(I - B)^{-1} f \equiv T$, and decompose domestic and foreign factors.
- In estimation, I divide the import side into **three regions** and the export side into **three levels of centrality**.
- The results are reported in Table 1.
- **The highest spillover effects are gained from exporters with high centrality** in trade, both in forward and backward linkages. (Table1)
  - In forward linkages, it is also statistically significant for trading with **middle** centrality exporters.
  - However, the indirect effects in forward linkages are not statistically significant.

Table 1: Centrality Group Results

| | Backward centrality | | | | | | Forward centrality | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | All | | Europe | | North America | | All | | Europe | | North America | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| domestic, $\beta_3$ | -0.022 | -0.040* | -0.043 | -0.062** | 0.048** | 0.048** | -0.027 | -0.044* | -0.049* | -0.065** | 0.051** | 0.045* |
| | (0.021) | (0.024) | (0.027) | (0.030) | (0.018) | (0.023) | (0.021) | (0.024) | (0.027) | (0.030) | (0.021) | (0.024) |
| **Direct effects** | | | | | | | | | | | | |
| high, $\rho_1$ | 0.075** | | 0.078** | | -0.030 | | 0.061** | | 0.056* | | 0.028 | |
| | (0.033) | | (0.034) | | (0.027) | | (0.029) | | (0.031) | | (0.035) | |
| middle, $\rho_2$ | -0.003 | | 0.009 | | -0.027 | | 0.032** | | 0.053*** | | -0.075*** | |
| | (0.013) | | (0.018) | | (0.029) | | (0.015) | | (0.016) | | (0.027) | |
| low, $\rho_3$ | 0.011 | | 0.013 | | -0.018 | | -0.005 | | -0.003 | | -0.027 | |
| | (0.009) | | (0.013) | | (0.013) | | (0.013) | | (0.014) | | (0.016) | |
| **Inirect effects** | | | | | | | | | | | | |
| high, $\rho_4$ | | 0.117** | | 0.126** | | 0.039 | | 0.061 | | 0.089 | | -0.003 |
| | | (0.049) | | (0.058) | | (0.112) | | (0.059) | | (0.072) | | (0.098) |
| middle, $\rho_5$ | | 0.025 | | 0.050 | | -0.011 | | 0.092 | | 0.078 | | -0.010 |
| | | (0.041) | | (0.058) | | (0.080) | | (0.078) | | (0.091) | | (0.076) |
| low, $\rho_6$ | | -0.017 | | -0.033 | | -0.057 | | -0.024 | | -0.021 | | -0.011 |
| | | (0.029) | | (0.039) | | (0.035) | | (0.039) | | (0.050) | | (0.071) |
| constant | -0.127 | -0.335** | -0.078 | -0.332* | -0.013 | -0.370 | -0.114 | -0.173 | -0.028 | -0.176 | -0.260 | -0.138 |
| | (0.081) | (0.148) | (0.078) | (0.169) | (0.108) | (0.272) | (0.091) | (0.151) | (0.086) | (0.182) | (0.178) | (0.480) |
| Country-Year FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Country-Industry FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Industry-Year FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| $N$ | 3819 | 3819 | 3091 | 3091 | 546 | 546 | 3819 | 3819 | 3091 | 3091 | 546 | 546 |
| $R^2$ | 0.886 | 0.890 | 0.878 | 0.882 | 0.961 | 0.958 | 0.887 | 0.890 | 0.880 | 0.882 | 0.962 | 0.957 |
| $F$-stat ($\rho_1 = \rho_4$) | | 4.06 | | 5.45 | | | | | | | | |
| Prob $F > 0$ | | 0.04 | | 0.02 | | | | | | | | |
| $F$-stat ($\rho_1^{back} = \rho_1^{fwd}$) | 4.52 | | 3.29 | | | | 4.52 | | 3.29 | | | |
| Prob $F > 0$ | 0.03 | | 0.07 | | | | 0.03 | | 0.07 | | | |

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

## Contributions and Implications

- This study is the first to consider and empirically analyze the position of exporters in GVCs, and provides 2 contributions:
  - Estimating the spillover effects, **including indirect demands**.
  - Introducing "centrality" in trade, I provide new insights into **which countries are important to trade with in spillover effects**.
- In contrast to the claims of Keller (1998), these findings suggest that **which country imports from which country is important** in the international spillover effects.