Productivity Effects of Internal and External R&D: Evidence on Market Competition and Spillover Interactions

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Introduction

- **Internal R&D**: proprietary R&D investment conducted internally by the firm, in-house R&D activities
- **External R&D**: R&D investment outsourced to external entities, externally contracted R&D investment
- Examine how internal and external R&D investments affect total factor productivity (TFP) under varying levels of **market competition**
- Examine how internal and external R&D **spillover effects** affect TFP under varying levels of **market competition**

Introduction

- Compare productivity effects of internal vs. external R&D
- Assess how market competition moderates these effects

- Compare productivity effects of internal R&D spillover vs. external R&D spillover
- Assess how market competition moderates these effects

- Provide empirical evidence on the role of competitive pressure in shaping the effectiveness of firm-level innovation strategies

Introduction

- First: **Internal R&D** tends to generate more tailored and proprietary innovations, leading to **greater productivity gains**
- Second: Both internal and external R&D investments exhibit **higher performance** in markets characterized by **intense competition**
- Third: Spillover effects from externally acquired R&D are substantially larger than those from internal R&D
- Fourth : Both internal and external R&D generate **stronger spillover effects in less competitive markets**

Theoretical Background

$$TFP_{it} = \Phi_{in}(M_{it}) IRD_{it}^{\theta_{in}} + \Phi_{ex}(M_{it}) ERD_{it}^{\theta_{ex}} + \Psi_{in}(M_{it}) S_{it,in}^{\gamma_{in}} + \Psi_{ex}(M_{it}) S_{it,ex}^{\gamma_{ex}}$$

- IRD_{it} and ERD_{it}: internal and external R&D
- $S_{in,it}$ and $S_{ex,it}$: internal and external R&D spillovers
- $\theta_{in}, \theta_{ex}, \gamma_{in}, and\ \gamma_{ex}$: coefficients associated with marginal effects of internal and external R&D investments and their spillover variables (less than one)
- $\Phi_{in}, \Phi_{ex}, \Psi_{in}, and\ \Psi_{ex}$: *markup-dependent productivity coefficients* and *markup-dependent spillover coefficients*
- M_{it}: markups for each firm

Theoretical Background

- First
  - $\frac{\partial TFP_{it}}{\partial IRD_{it}} = \Phi_{in}(M_{it})\theta_{in} IRD_{it}^{\theta_{in}-1} > 0$ and $\frac{\partial TFP_{it}}{\partial ERD_{it}} = \Phi_{ex}(M_{it})\theta_{ex} ERD_{it}^{\theta_{ex}-1} > 0$
  - $\frac{\partial TFP_{it}}{\partial S_{it,in}} = \Psi_{in}(M_{it})\gamma_{in} S_{it}^{\gamma_{in}-1} > 0$ and $\frac{\partial TFP_{it}}{\partial S_{it,ex}} = \Psi_{ex}(M_{it})\gamma_{ex} S_{it}^{\gamma_{ex}-1} > 0$

Theoretical Background

- Second: $\frac{\partial TFP_{it}}{\partial IRD_{it}} > \frac{\partial TFP_{it}}{\partial ERD_{it}}$
  - In-house research generates a larger share of tacit, firm-specific knowledge that is difficult to codify and imitate, allowing the innovating firm to capture a greater portion of the returns (Nelson and Winter, 1982; Teece, 1986)

  - External R&D—through licensing or contract research—tends to produce more standardized knowledge with weaker protection against imitation, thereby reducing the focal firm's ability to fully appropriate its benefits (Cohen and Levinthal, 1989; Cassiman and Veugelers, 2006)

Theoretical Background

- Third: $\frac{\partial TFP_{it}}{\partial S_{it,in}} < \frac{\partial TFP_{it}}{\partial S_{it,ex}}$

- External R&D often produces knowledge that is more codified, standardized, and explicitly documented, which facilitates diffusion across firms and industries (Knott, 2008)
- Internal R&D creates a larger share of tacit and firm-specific knowledge, embedded in routines and organizational practices, which is less transferable and thus less likely to generate measurable spillover effects (Nelson and Winter, 1982)

Theoretical Background

- Fourth: Effects of internal and external R&D investment are greater for firms operating in low-markup segments (i.e., highly competitive environments), whereas they are smaller for firms in high-markup segments (i.e., less competitive environments)

$$\frac{\partial^2 TFP_{it}}{\partial IRD_{it}\partial M_{it}} = \underbrace{\Phi_{in}'(M_{it})\theta_{in} IRD_{it}^{\theta_{in}-1}}_{Competition\ \ Chanel<0} + \underbrace{\Phi_{in}(M_{it})\theta_{in}(\theta_{in}-1) IRD_{it}^{\theta_{in}-2}}_{Di\min ishing\ \ M\arg inal\ \ \mathrm{Re}turns<0} \times \underbrace{\frac{dIRD_{it}}{dM_{it}}}_{>0} < 0$$

$$\frac{\partial^2 TFP_{it}}{\partial ERD_{it}\partial M_{it}} = \underbrace{\Phi_{ex}'(M_{it})\theta_{ex} ERD_{it}^{\theta_{ex}-1}}_{Competition\ \ Chanel<0} + \underbrace{\Phi_{ex}(M_{it})\theta_{ex}(\theta_{ex}-1) ERD_{it}^{\theta_{ex}-2}}_{Di\min ishing\ \ M\arg inal\ \ \mathrm{Re}turns<0} \times \underbrace{\frac{dERD_{it}}{dM_{it}}}_{>0} < 0$$

Theoretical Background

- Fifth: Effect of R&D spillovers will increase as the markup rises

$$\frac{\partial^2 TFP_{it}}{\partial S_{it,in}\partial M_{it}} = \underbrace{\Psi_{in}'(M_{it})\gamma_{in}S_{it,in}^{\gamma_{in}-1}}_{Competition\ Chanel>0} + \underbrace{\Psi_{in}(M_{it})\gamma_{in}(\gamma_{in}-1)S_{it,in}^{\gamma_{in}-2}}_{Di\min ishing\ M\arg inal\ Re turns<0} \times \underbrace{\frac{dS_{it,in}}{dM_{it}}}_{>0}$$

$$\frac{\partial^2 TFP_{it}}{\partial S_{it,ex}\partial M_{it}} = \underbrace{\Psi_{ex}'(M_{it})\gamma_{ex}S_{it,ex}^{\gamma_{ex}-1}}_{Competition\ Chanel>0} + \underbrace{\Psi_{ex}(M_{it})\gamma_{ex}(\gamma_{ex}-1)S_{it,ex}^{\gamma_{ex}-2}}_{Di\min ishing\ M\arg inal\ Re turns<0} \times \underbrace{\frac{dS_{it,ex}}{dM_{it}}}_{>0}$$

  - Under weak competition, firms possess greater slack and absorptive capacity, enabling them to better internalize external knowledge and thereby amplify the productivity impact of R&D spillovers

Data

- Use the data from the South Korea's Statistical Office's Firm Activity Survey from 2006 to 2018

Table 1. Summary Statistics for Key Variables

	mean	median	standard deviation
Total Wage Bill	17,816	4,848	151,693
Fixed Tangible Asset	71,541	11,831	743,810
Material Costs	113,718	18,025	1,005,742
Sales Revenue	193,869	36,195	1,875,612
Internal R&D	4,697	241	133,494
External R&D	303	0	9,038
Equity	12,571	2.214	76,306

Notes: The unit is million Korean won (KRW), and the total number of observations is 75,537.

Internal and External R&D

Table 2. Allocation of Internal and External R&D Investment (%)

		External R&D		
		Yes	No	Total
Internal R&D	Yes	7.18	64.39	71.56
	No	1.05	27.39	28.44
	Total	8.22	91.78	100.00

Note: Each cell reports the percentage of firms falling into the corresponding category of internal and external R&D investment status.

Table 3. Classification of Firms by Internal and External R&D Investment Persistence

	Internal R&D		External R&D	
	Count	Share (%)	Count	Share (%)
Always	4,025	44.80	68	0.76
Switcher	3,408	37.93	1,966	21.88
Non-investor	1,551	17.26	6,950	77.36

Notes: The sample includes firms observed in more than two periods. "Always" refers to firms that invest in R&D in every period, "Switcher" refers to firms that move in and out of investment, and "Non-investor" refers to firms that never invest. Table format follows Mañez and Love (2020).

Internal and External R&D

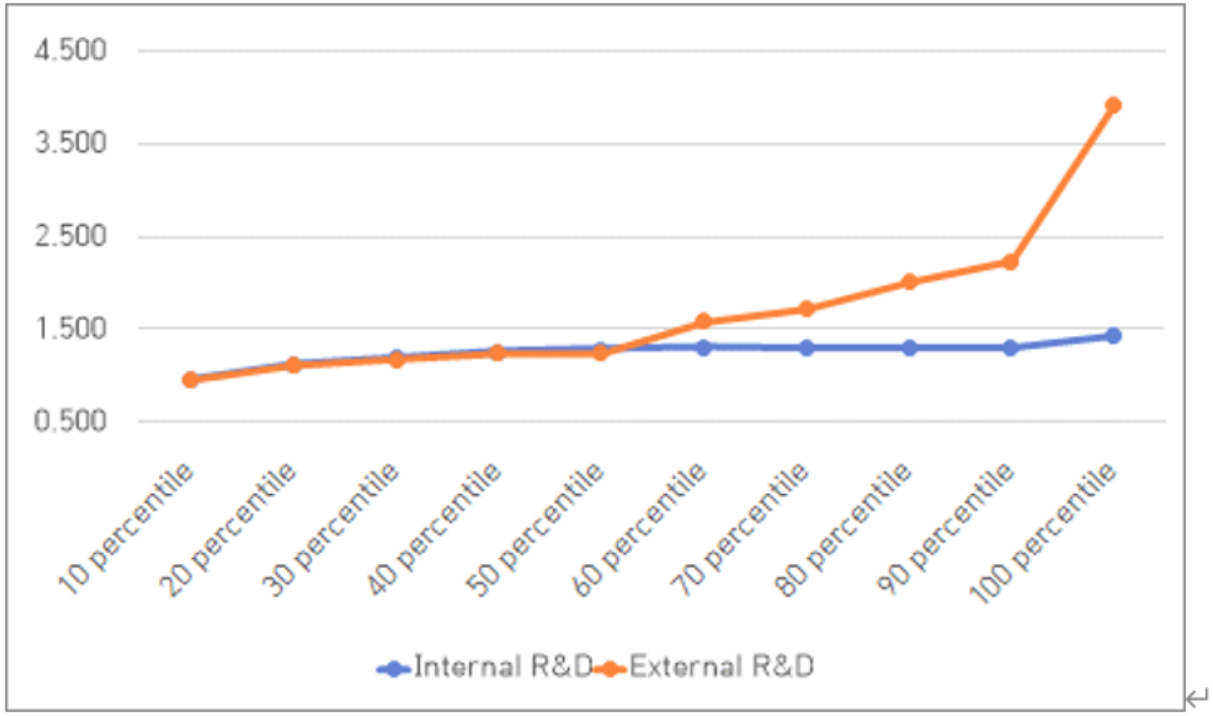


Figure 2. Share of Firms Engaging in Internal and External R&D by Sales Revenue Percentile

Note: The figure displays the proportion of firms investing in internal or external R&D within each decile of the sales revenue distribution. Internal R&D participation rises steadily across deciles, while external R&D is more concentrated among firms in the top percentiles.

Internal and External R&D

Table 4. Year-to-Year Transitions in R&D Investment Status

Status in year t	Status in year t+1			
	Neither	Internal R&D Only	External R&D Only	Both
Neither	73.91	23.88	0.75	1.46
Internal R&D only	10.34	84.89	0.45	4.33
External R&D only	17.81	26.71	45.55	9.94
Both	5.13	39.83	1.01	54.03
All firms	27.28	64.49	1.04	7.19

Notes: The table shows the percentage of firms transitioning between R&D investment categories from year t to year t+1. Structure follows Aw, Roberts, and Xu (2011) on R&D and export dynamics.

- Firms that make internal R&D investments tend to be more persistent compared to those that make external R&D investments

Internal and External R&D

- From <Table 3 & 4>: Internal R&D investments tend to be **more persistent** External R&D investments
  - Irreversibility of internal R&D investments: Czarnitzki and Toole (2011, 2013), Cho and Lee (2021)
  - Sunk cost: Manez et al. (2009), Manez and Love (2020) . Lee and Kim (2022)
  - Friction and adjustment for internal R&D: Schankerman and Nadiri (1984), Bloom (2007), Doraszelski and Jaumandreu (2013), Aysun (2020), Aysun et al. (2025)
  - Uncertainty or risk for internal R&D: Bloom (2007), Czarnitzki and Toole (2011, 2013), Doraszelski and Jaumandreu (2013), Lee and Kim (2022)

Production Function Estimation and TFP

- Use C-D production function using Olley and Pakes (1996) and Levinsohn and Petrin (2003) and construct TFP

$$y_{it} = \beta_l l_{it} + \beta_k k_{it} + \beta_m m_{it} + \Gamma YD_t + IRD_t + OSIC_i + \omega_{it} + u_{it} \quad (1)$$

Table 5. Production Function Estimation Results

Input	Coefficient Estimates	Standard Errors
Labor	0.412***	0.007
Capital	0.092***	0.005
Material	0.221***	0.007

Notes: Standard errors are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Estimates are based on 75,537 observations from 10,180 firms. Year, region, and two-digit industry fixed effects are included.

Firm Level Markups

- Measure of Competition: Markup=P/MC
- Follow De Loecker (2011) and De Loecker and Warzynski (2012)

$$markup\ (\mu_{it}) = \frac{\beta_m}{\alpha_{it}^m} \quad (3)$$

- where β_m is the output elasticity of material costs or the coefficient estimate in production function and α_m is the proportion of material costs to sales revenue

R&D Spillover Variables

- Define two proxy variables of the spillover effects following Knott (2008)

- *Leader Distance* : $S_{ijt} = \max(R\&D_{ijt}) - R\&D_{ijt}$

- *Sum Above* : $S_{ijt} = \sum_{i \neq f} R\&D_{ijt}, R\&D_{ijt} > R\&D_{fjt}$

TFP, Spillovers, and Markups

Table 6. Summary Statistics for Firm-Level TFP, Markup, and Spillover Effect Variables of Internal and External R&D Investment

	Mean	Median	Standard Deviation
TFP	70	56	77
Markup	1.315	0.414	39.873
Internal R&D leader distance	1,344,510	128,675	3,019,915
External R&D leader distance	92,457	9,340	177,624
Internal R&D sum above	2,722,920	555,977	5,220,807
External R&D sum above	154,591	27,534	274,326

Notes: TFP is calculated as the exponentiated predicted output from equation (1), effectively converting log TFP estimates into monetary units (million Korean won, KRW). The variables of Internal and External R&D investment spillover effect variables are also measured in monetary units, specifically in million KRW.

Empirical Model and Estimation Method

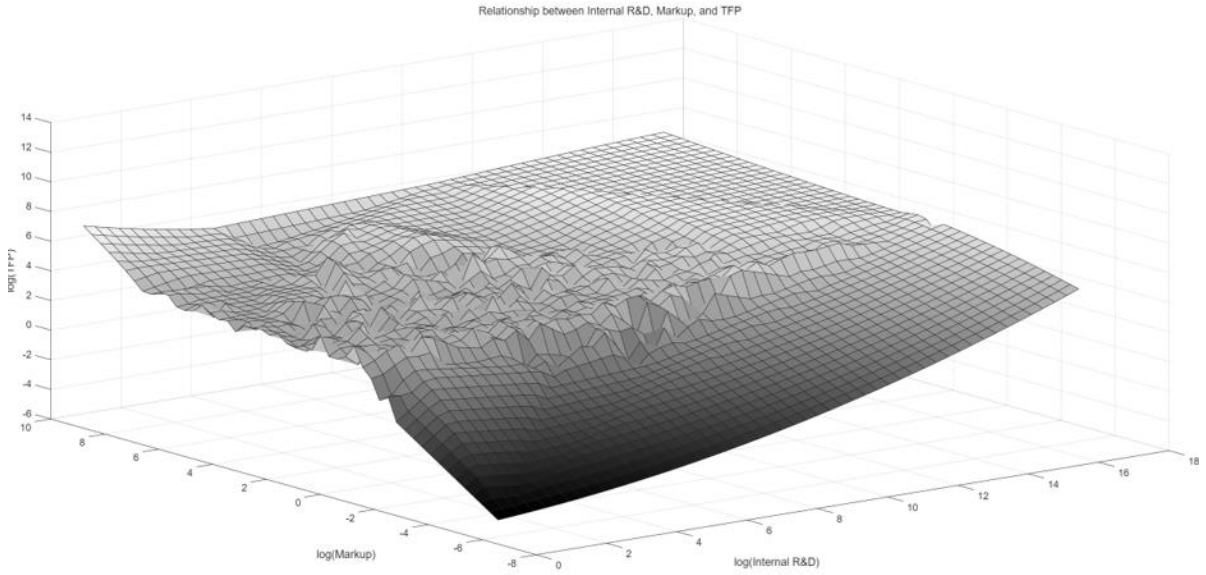
- Empirical Estimation Model

$$tfp_{it} = \beta_0 + \beta_1 ird_{it} + \beta_2 erd_{it} + \beta_3 equity_{it} + \beta_4 ird\_so_{it} + \beta_5 erd\_so_{it}$$

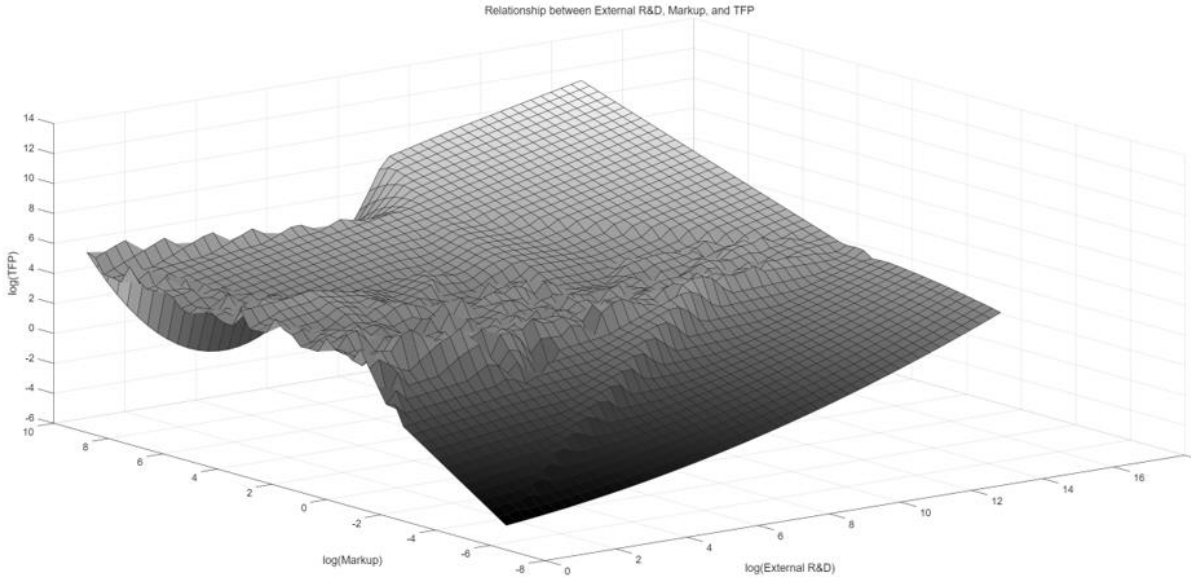
$$+ \Gamma YD_t + \mathrm{I}RD_i + \mathrm{O}SIC_i + a_i + v_{it}$$

- Estimation Method: Fixed Effects Instrumental Variable(FEIV) Estimation Method

R&D, Markups, and TFP



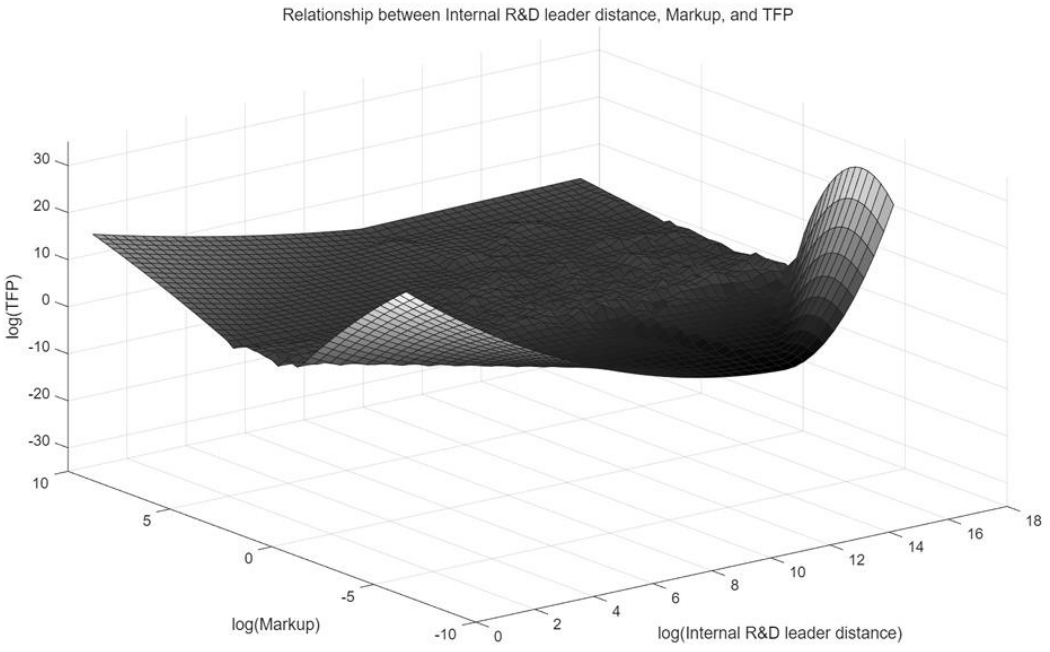
Panel A. Internal R&D, Markup, and TFP



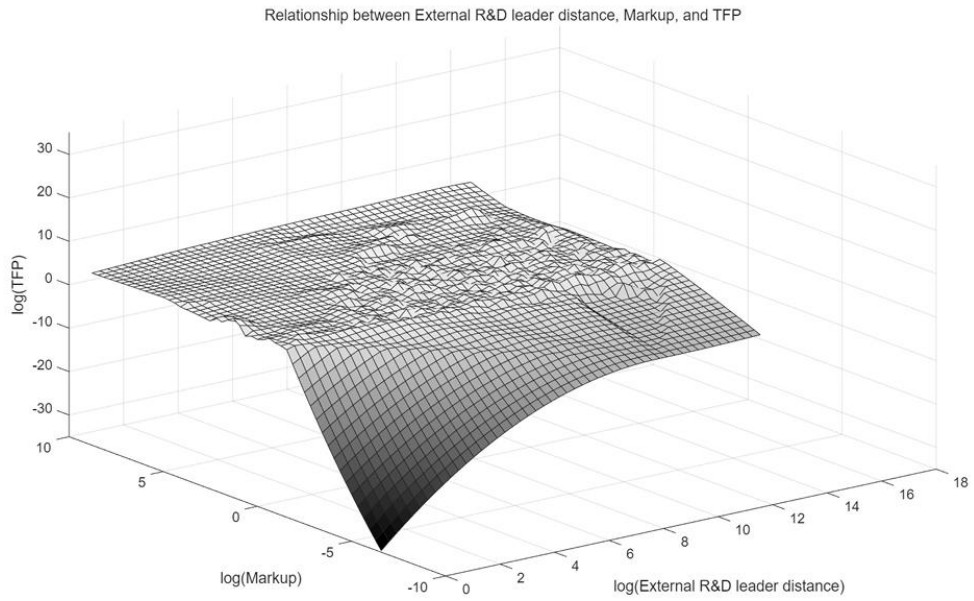
Panel B. External R&D, Markup, and TFP

<Figure 3> Relationship between Internal and External R&D Investments, Markup, and TFP

R&D Spillover, Markups, and TFP



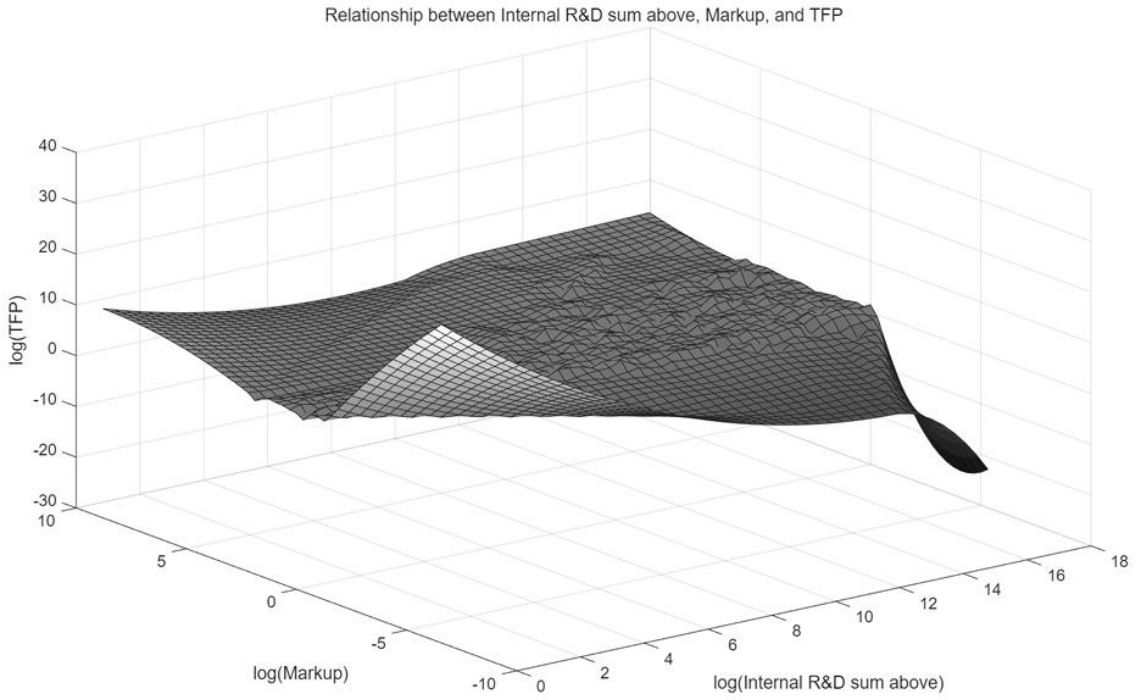
Panel A: Internal R&D *Leader Distance*, Markup, and TFP



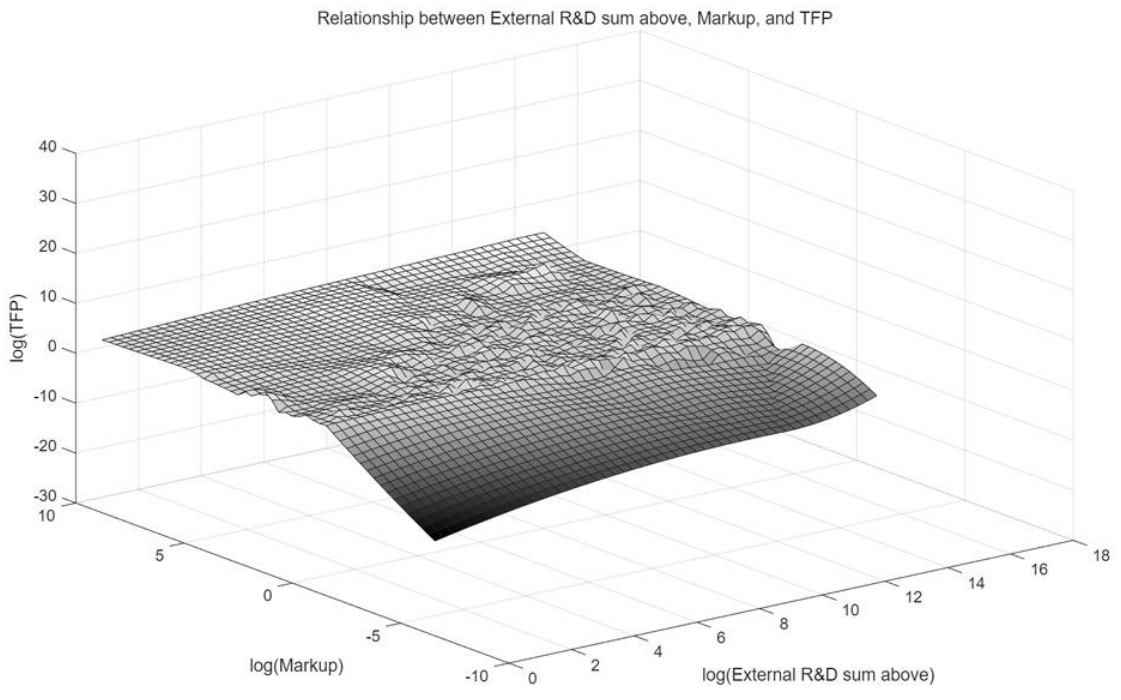
Panel B: External R&D *Leader Distance*, Markup, and TFP

<Figure 4> Relationship between Internal and External R&D *Leader Distance*, Markup, and TFP

R&D Spillover, Markups, and TFP



Panel A: Internal R&D *Sum Above*, Markup, and TFP



Panel B: External R&D *Sum Above*, Markup, and TFP

<Figure 5> Relationship between Internal and External R&D *Sum Above*, Markup, and TFP

Effects of Internal and External R&D

Table 8. Effects of Internal and External R&D on TFP by Markup Quartile Using FEIV

	Leader Distance					*Sum Above*				
	25%	25-50%	50-75%	Above 75%	Total	25%	25-50%	50-75%	Above 75%	Total
Internal R&D	0.021***	0.022***	0.018***	0.014**	0.018***	0.021***	0.022***	0.018***	0.017***	0.018***
	(0.005)	(0.004)	(0.004)	(0.006)	(0.002)	(0.005)	(0.004)	(0.004)	(0.006)	(0.002)
External R&D	0.018***	0.006	0.010**	0.004	0.009***	0.019***	0.007	0.012**	0.009	0.011***
	(0.005)	(0.004)	(0.005)	(0.007)	(0.002)	(0.005)	(0.004)	(0.005)	(0.008)	(0.003)
Equity	0.045***	0.034***	0.027***	0.038***	0.042***	0.044***	0.033***	0.027***	0.039***	0.042***
	(0.006)	(0.006)	(0.006)	(0.010)	(0.003)	(0.006)	(0.006)	(0.006)	(0.010)	(0.003)
Internal R&D Spillover	0.007	-0.012	0.005	0.030***	0.008*	0.012	-0.015	0.004	0.026*	0.006
	(0.009)	(0.009)	(0.008)	(0.011)	(0.004)	(0.012)	(0.013)	(0.009)	(0.014)	(0.005)
External R&D Spillover	0.006*	0.006	0.009*	0.024**	0.009***	0.009**	0.010	0.016*	0.044***	0.015***
	(0.004)	(0.004)	(0.006)	(0.009)	(0.002)	(0.004)	(0.006)	(0.009)	(0.016)	(0.003)
Weak IV Test	170.92***	144.09***	179.60***	189.89***	1126.97***	171.65***	143.92***	179.68***	189.93***	1127.40***
	292.46***	261.46***	213.73***	293.84***	1603.63***	292.83***	261.50***	213.99***	296.62***	1604.26***
	177.59***	118.69***	190.71***	239.57***	1020.78***	147.53***	88.98***	223.71***	216.58***	999.81***
	481.04***	233.09***	141.01***	128.82***	1441.30***	470.49***	178.62***	79.94***	71.88***	1073.64***
Endogeneity Test	16.509***	15.024***	12.821***	7.613	26.250***	18.111***	14.847***	13.046**	8.656*	31.271***
Number of Observations	15,099	14,833	14,593	15,201	63,266	15,099	14,833	14,593	15,201	63,266

Notes: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. All variables are log-transformed. Fixed effects for year, region, and industry are included in all specifications.

Effects of Internal and External R&D

- Effects of Internal and External R&D on TFP are significantly positive
- Effects of both internal and external R&D investment on Total Factor Productivity (TFP) are higher when markups are low, indicating stronger competition
- Effect of internal R&D investment on TFP is greater than that of external R&D investment
- However, as competition intensifies (markups decrease), the gap between the effects of internal and external R&D investments narrows

Effects of Internal and External R&D

- Spillover effect of external R&D investment om TFP is greater than that of internal R&D investment

- Effects of both internal and external R&D Spillovers tend to be larger when competition is weak (i.e., when markups are high)

Concluding Remarks

- Try to address the policy implications!

- Try to link empirical results with real-world cases!

Suggestions

- We encourage you to suggest an idea!

- Thank you for your attention!