Widgets and wodgets: Technology markets and R&D spillovers

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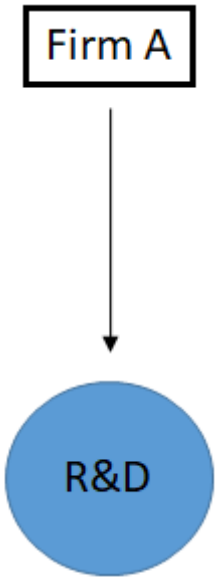
Motivation

The owner of a design has property rights over its use in the production of a new producer durable but not over its use in research. If an inventor has a patented design for widgets, no one can make or sell widgets without the agreement of the inventor. On the other hand, other inventors are free to spend time studying the patent application for the widget and learn knowledge that helps in the design of a wodget. Romer (1990), pp. 84.

Knowledge capital model: where are technology markets?



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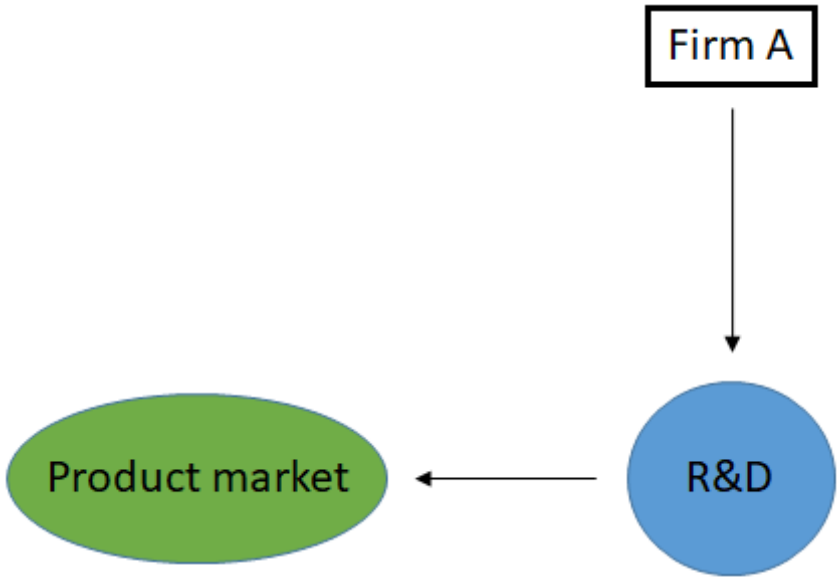

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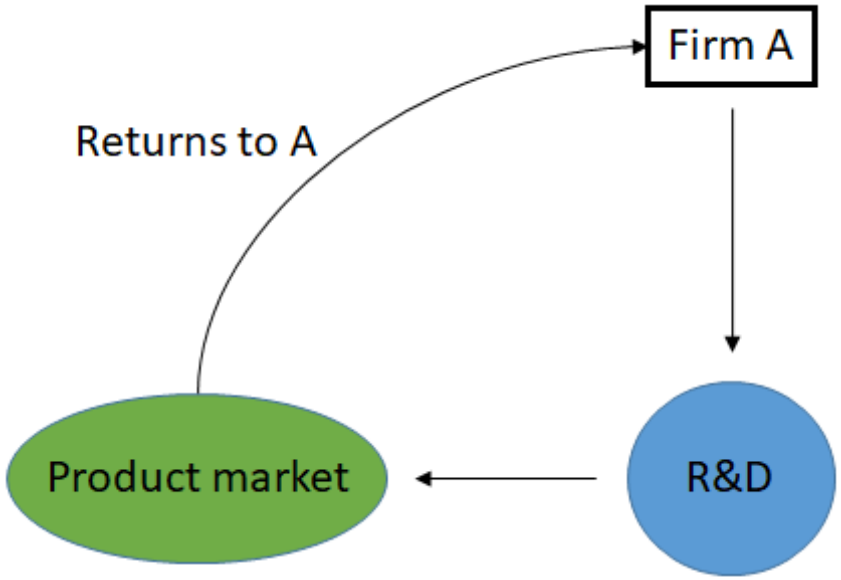

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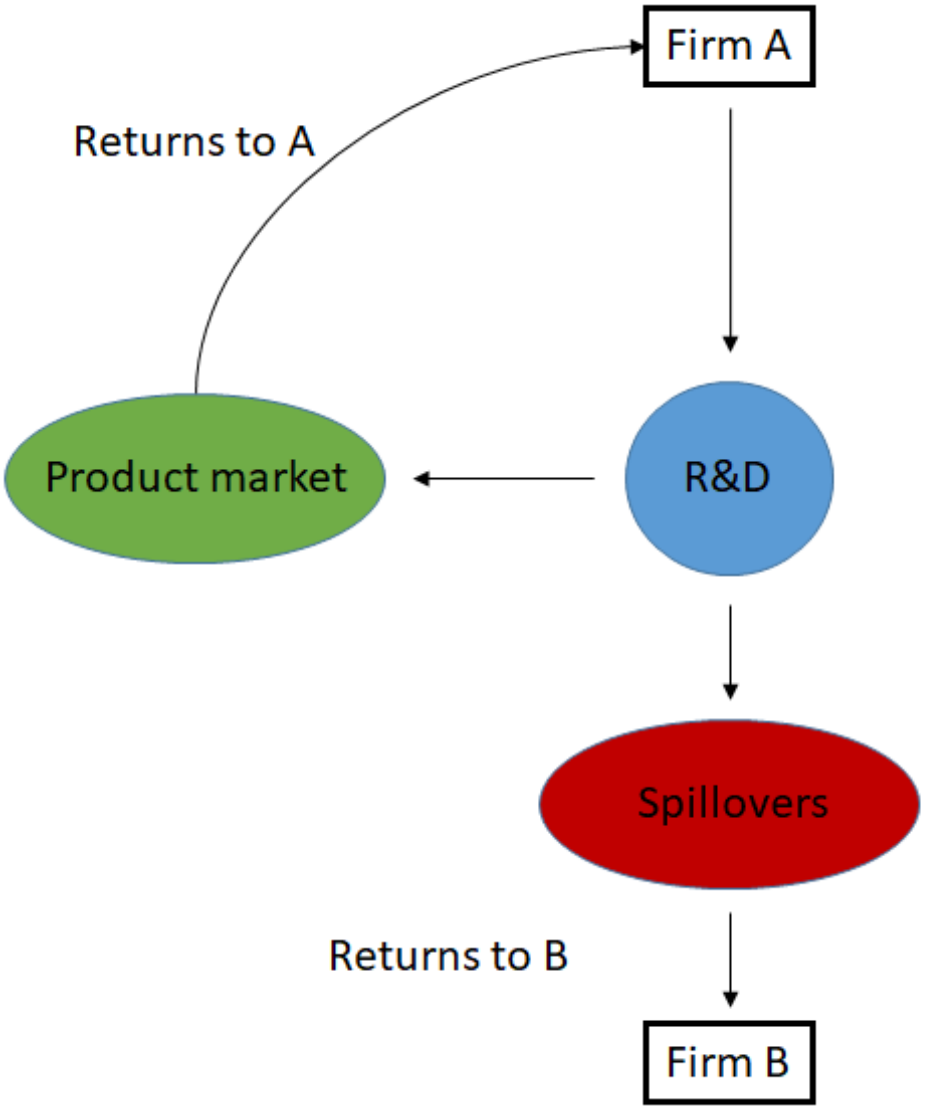

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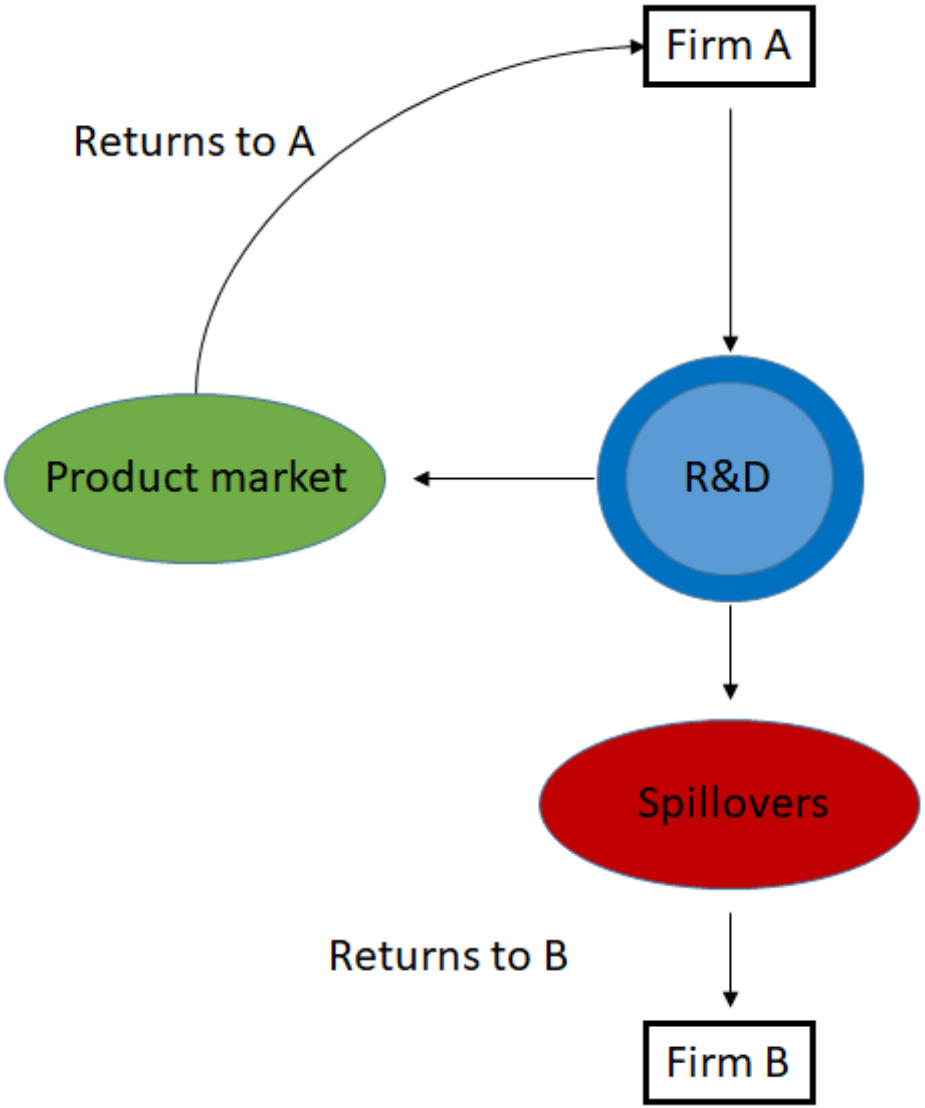

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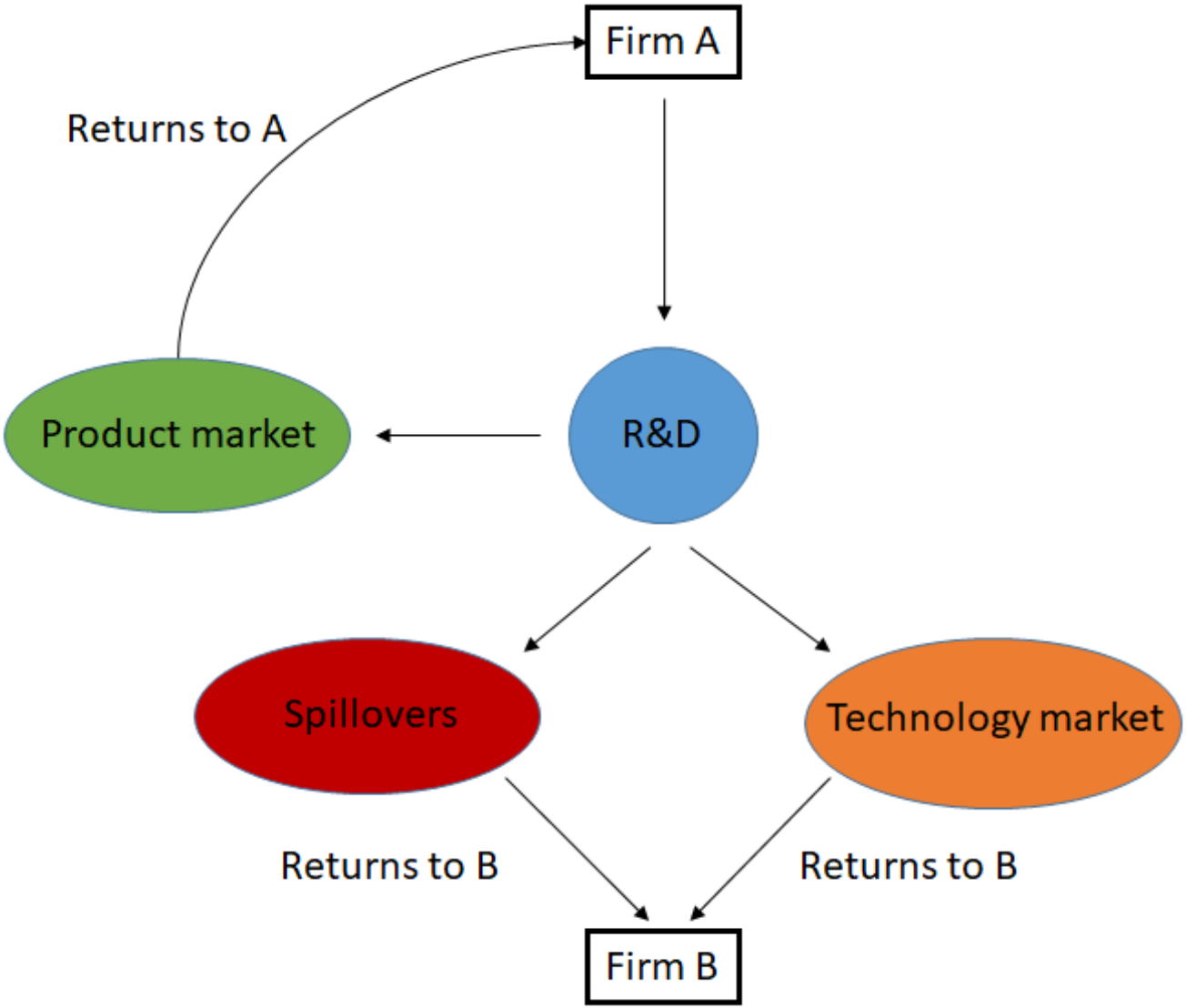

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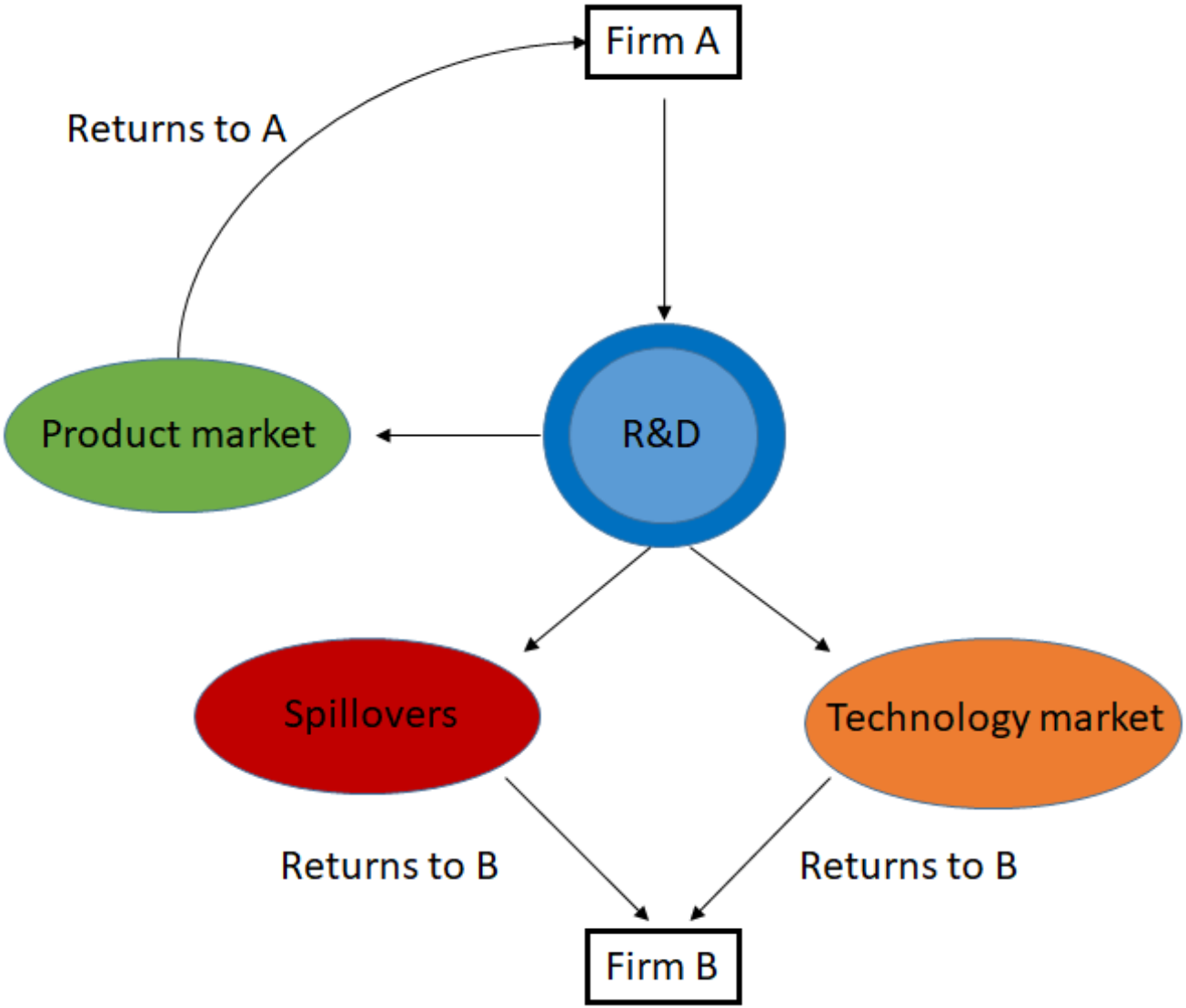

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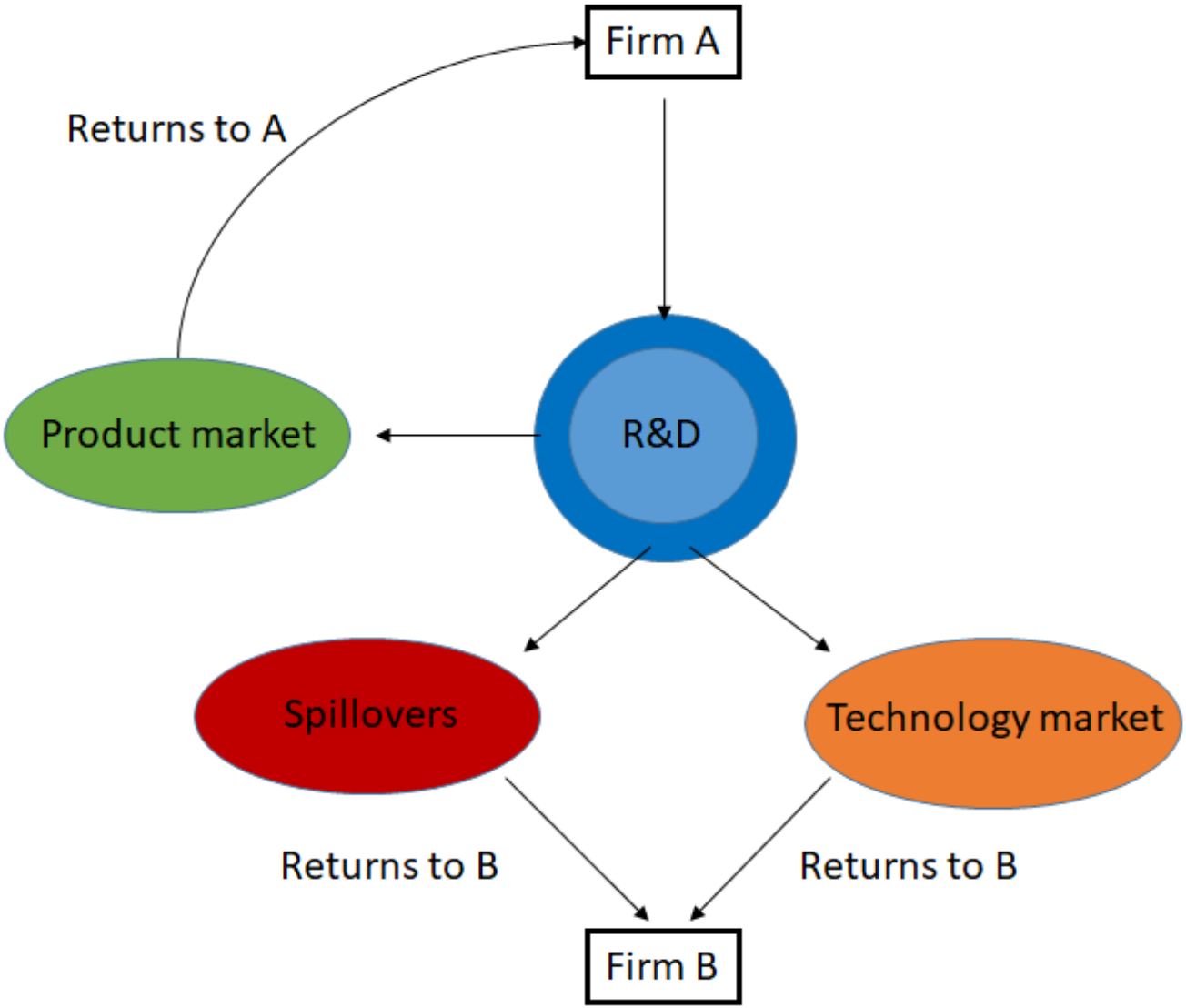

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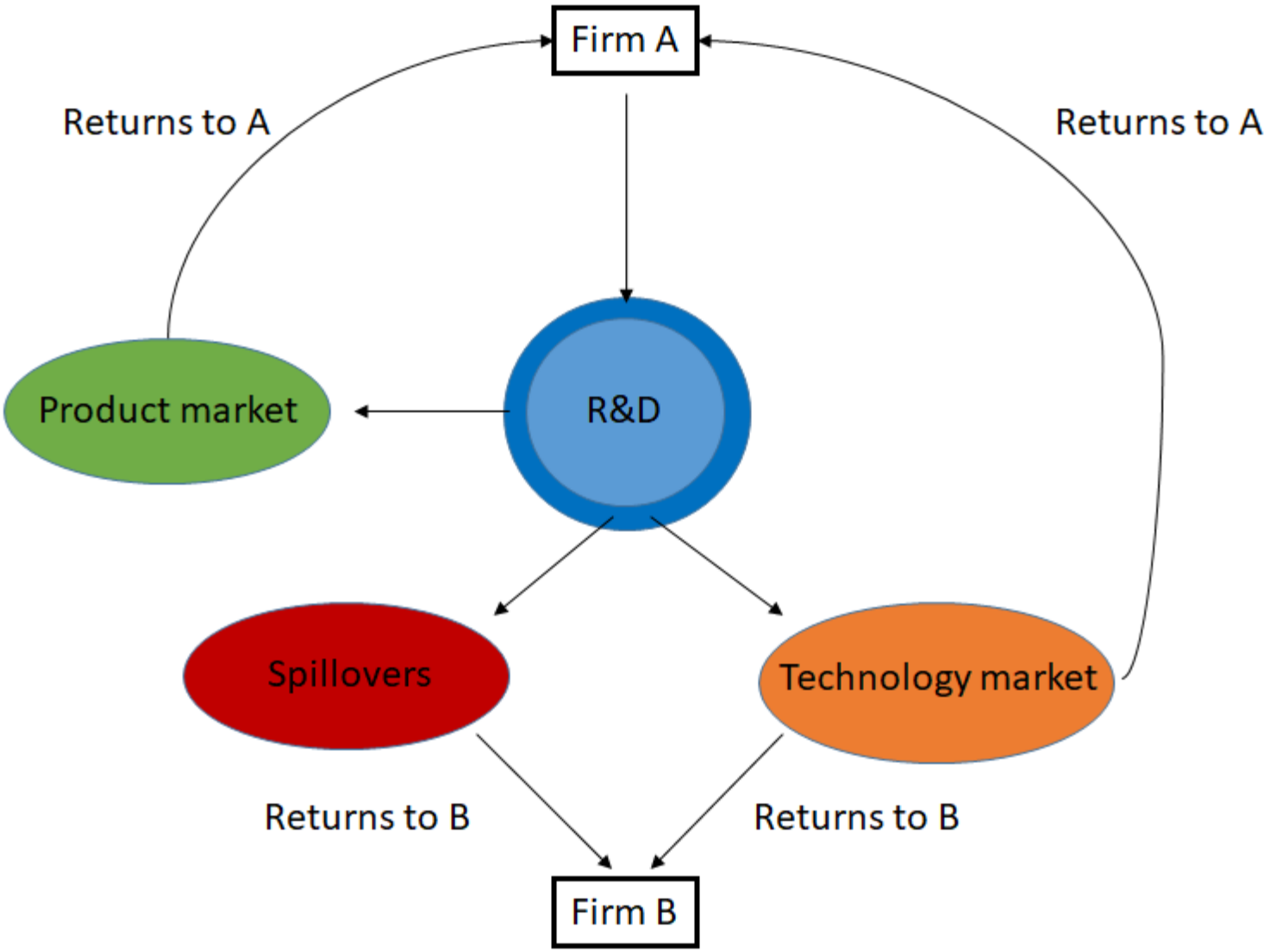

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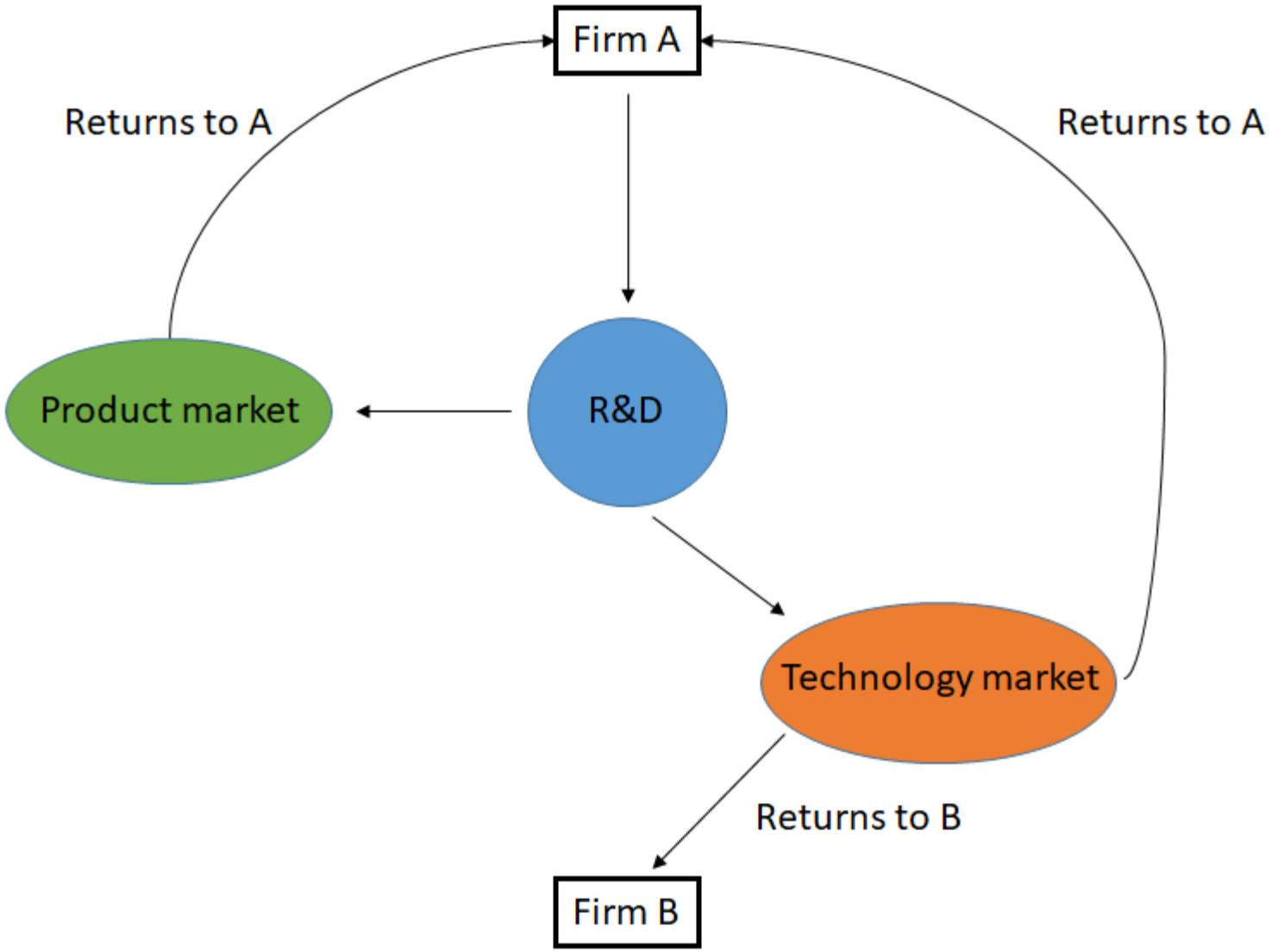


Contribution

- Create a new dataset on interactions in the market for technology between publicly held companies in North America over the period 1990-2014
- Estimate the *knowledge capital model* with spillovers and technology markets
- To identify causal effects we exploit variation in tax incentives to R&D holding technology space and the market for technology network constant over time
- Use estimates to calculate the private and social rates of return to R&D

Literature

- **Empirical spillover literature**
  - Distance weights: Bernstein and Nadiri (1988), Jaffe (1986), Bloom et al. (2013), Bottazzi and Peri (2003), Lychagin et al. (2016)
  - More sophisticated methods for calculating the spillover pool: Zacchia (2017), Colino (2016) and Manresa (2017)
- **Emirical literature on market for technology**
  - Supply: Arora and Gambardella (2010), Arora and Fosfuri (2003)
  - Demand: Ceccagnoli et al. (2010), Ali and Cockburn (2016)
  - Both: Arque-Castells and Spulber (2017), Figueroa and Serrano (2013) and Akcigit et al. (2016)
- **Strategic management literature on markets for technology**
  - Markets for technology enlarge the strategy space by allowing firms to decide between in-house development and acquisition: Arora et al. 2001, Cassiman and Veuglers, 2006.

Motivating framework

Total revenue of firm i in year t is given by:

$$Y_{it} = Y_{it}^{p} + Y_{it}^{t}$$

- Y_{it}^{p} is revenue obtained in the product market
- Y_{it}^{t} is revenue generated in the technology market

Motivating framework

Revenue generated in the product market

Revenue in the product market is generated with a Cobb-Douglas:

$$Y_{it}^{p} = G_{it}^{\beta_1} S_{it}^{\beta_2} M_{it}^{\beta_3} X_{it}^{\beta_4} e^{\varepsilon_{it}},$$

- G_{it} is the R&D stock
- $S_{it} = \sum_{j \neq i} \omega_{ij}^{S} G_{jt}$ is the spillover pool
  - ω_{ij}^{S} : Jaffe's cosine similarity metric between the technology classes of the patents of the two firms (θ_{ij}^{TEC})
- $M_{it} = \sum_{j \neq i} \omega_{ij}^{M} G_{jt}$ is the market for technology pool
  - ω_{ij}^{M} : dummy variable with value one if firm i adopts knowledge from j (d_{ij})
- X_{it} stands for conventional inputs and demand shifters

Motivating framework

Revenue generated in the technology market

Proportion of the aggregate increase in product market revenue that technology adopters enjoy thanks to accessing i's knowledge:

$$Y_{it}^{t} = \sum_{j \neq i} d_{ji} \varphi \left[Y_{jt}^{p}(d_{ji} = 1) - Y_{jt}^{p}(d_{ji} = 0) \right],$$

- d_{ji} indicator with value one if firm j adopts knowledge from i
- $\varphi \in [0, 1]$ is the percentage of firm j's increase in operating revenue that i appropriates through transfers.

Let $Y_t = \sum Y_{it}^p$ denote aggregate output. Then, the marginal private and social returns to R&D are given by:

$$MPR_{it} = \frac{\partial Y_{it}}{\partial G_{it}} = \frac{\partial Y_{it}^p}{\partial G_{it}} + \sum_{j \neq i} d_{ji} \varphi \left[\frac{\partial Y_{jt}^p (d_{ji} = 1)}{\partial G_{it}} - \frac{\partial Y_{jt}^p (d_{ji} = 0)}{\partial G_{it}} \right],$$

$$MSR_{it} = \frac{\partial Y_t}{\partial G_{it}} = \frac{\partial Y_{it}^p}{\partial G_{it}} + \sum_{j \neq i} \frac{\partial Y_{jt}^p}{\partial G_{it}}.$$

Data

Sources

- USPTO Patent Assignment Dataset
- Compustat
- Interactions in the market for technology
  - Patent trades (USPTO PAD)
  - Licensing (ktMINE, SEC)
  - Cross-licensing (own elaboration, SEC)
  - Licensing within joint ventures (SDC, SEC)
  - Cross-licensing within joint ventures (SDC, SEC)
  - R&D alliance (SDC, SEC)
- Tax data from Willson (2009) and Rao (2016)

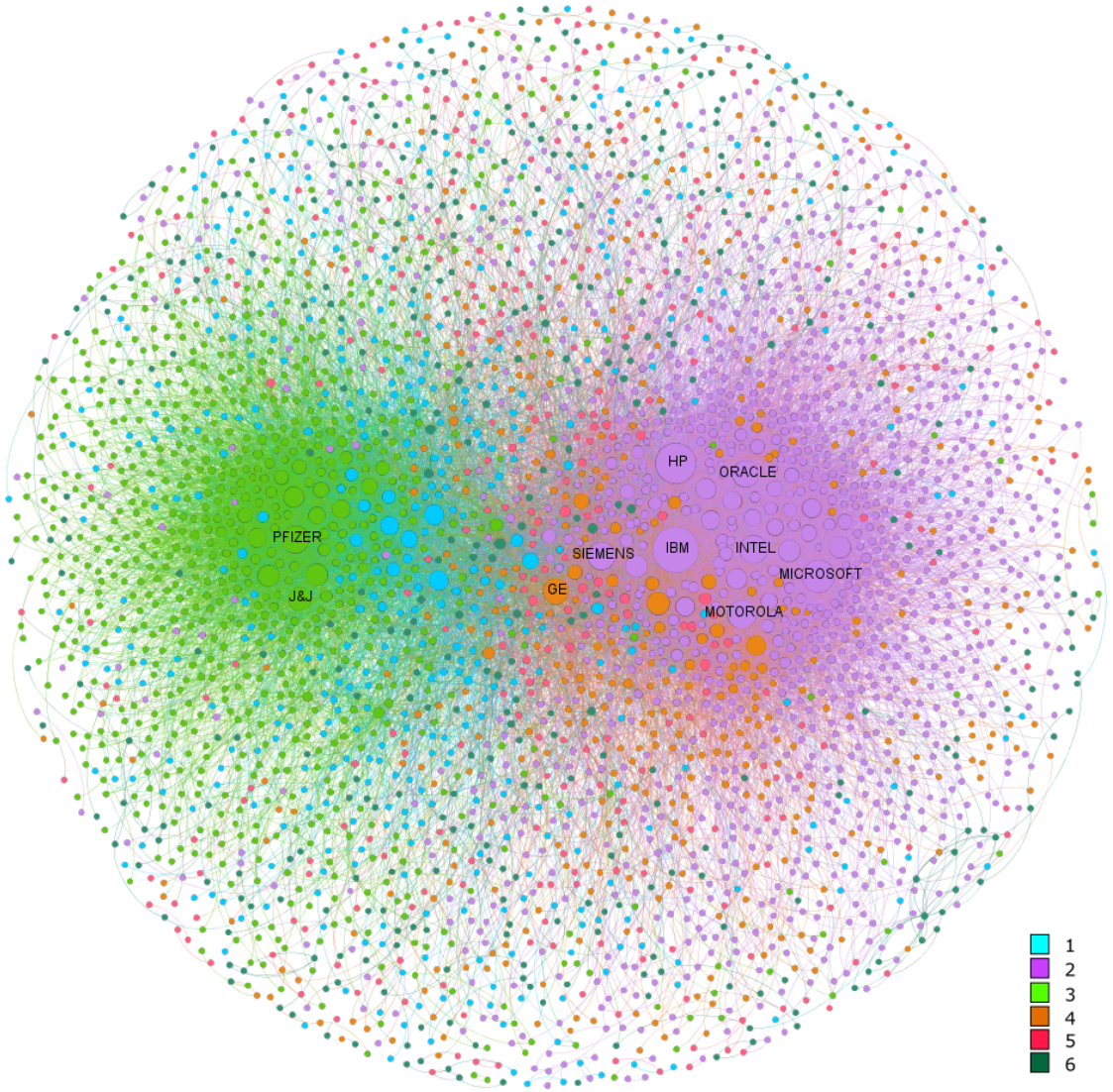
Data

Matched dataset

- $+$ 6,000 Compustat firms linked to at least one patent
- $+$ 3,000 firms interact in the market for technology
- $+$ 19,000 unique directed interactions

Data

Network of interactions by technology field (NBER6)



Data

Descriptive statistics spillover weights by distance in technology market

	Distance 1		Distance 2		Distances 3 and further	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Technological proximity	0.323	0.287	0.143	0.223	0.025	0.106
Geographical proximity	0.232	0.309	0.180	0.290	0.097	0.239
Market proximity	0.214	0.370	0.094	0.273	0.015	0.114
Percentage of citations	0.013	0.046	0.002	0.014	0.000	0.005
At least one citation	0.533	0.499	0.158	0.365	0.005	0.067
Number of observations	19,246		472,755		40,602,509	

Data

Panel dataset for regressions

- Longitudinal datasaet including 2,049 firms connected to the network as adopters during 1990-2014

- Sampling involves keeping firms with:
  - Four or more consecutive years
  - Non-missing observations for relevant variables
  - Positive R&D expenditures in all the years

Estimate specifications of the following form:

$$\ln Y_{it}^{p} = \beta_1 \ln G_{it-1} + \beta_2 \ln S_{it-1} + \beta_3 \ln M_{it-1} + \beta_4 X_{it-1} + \phi_t + \phi_i + u_{it}$$

where

- Y_{it}^{p} is sales (revenue in the product market)
- β_1, β_2 and β_3 are the parmeters of interest
- X_{it-1} is a vector of controls (changes across specifications)
- ϕ_t is a full set of year fixed effects
- ϕ_i is a firm fixed effect
- ε_{it} is the error term

- Identification challenges:
  - Common transitory shocks simultaneously affecting output and external R&D
  - Endogeneity of network formation and co-location in technology space

- Identification solution:
  - Instrument external R&D with tax credits
  - Set network of interactions and technology space constant

Results

Main results.

	OLS				IV			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ln(G)	0.029*	0.043***	0.028*	0.041***	0.028*	0.040***	0.027*	0.033**
	(0.016)	(0.015)	(0.016)	(0.016)	(0.016)	(0.015)	(0.016)	(0.016)
ln(S)	0.274***		0.257***	0.227***	0.239**		0.220**	0.364***
	(0.059)		(0.059)	(0.064)	(0.106)		(0.106)	(0.117)
ln(M)		0.028***	0.022**	0.021**		0.030***	0.030***	0.025**
		(0.009)	(0.009)	(0.009)		(0.010)	(0.010)	(0.010)
ln(Capital)	0.109***	0.111***	0.109***	0.099***	0.110***	0.111***	0.110***	0.099***
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
ln(Labor)	0.663***	0.657***	0.661***	0.671***	0.663***	0.658***	0.661***	0.673***
	(0.020)	(0.020)	(0.020)	(0.021)	(0.020)	(0.020)	(0.020)	(0.021)
Firm and year FE	Yes	Yes	Yes	No	Yes	Yes	Yes	No
Firm and year*SIC2 FE	No	No	No	Yes	No	No	No	Yes
Elasticity Yi wrt Gj, mean	0.0035	0.0032	0.0058	0.0053	0.0030	0.0035	0.0062	0.0075
Elasticity Yi wrt Gj, median	0.0007	0.0017	0.0020	0.0019	0.0006	0.0019	0.0024	0.0024
First stage F-test					433	3,936	217	214
Firms	2,049	2,049	2,049	2,049	2,049	2,049	2,049	2,049
Observations	24,596	24,596	24,596	24,596	24,596	24,596	24,596	24,596

Results

Pools from distant providers in the technology market

	OLS		IV	
	(1)	(2)	(3)	(4)
ln(G)	0.028*	0.041***	0.027*	0.033**
	(0.016)	(0.016)	(0.016)	(0.016)
ln(S)	0.254***	0.224***	0.218**	0.363***
	(0.059)	(0.064)	(0.106)	(0.117)
ln(M)	0.023***	0.022**	0.029***	0.025**
	(0.009)	(0.009)	(0.010)	(0.010)
ln(M distance 2)	0.003	0.005	-0.006	-0.002
	(0.019)	(0.019)	(0.020)	(0.018)
ln(M distance 3)	-0.055	-0.052	0.025	0.021
	(0.056)	(0.053)	(0.065)	(0.063)
ln(Capital)	0.109***	0.098***	0.110***	0.099***
	(0.013)	(0.013)	(0.013)	(0.013)
ln(Labor)	0.662***	0.672***	0.661***	0.673***
	(0.020)	(0.021)	(0.020)	(0.021)
Firm and year FE	Yes	No	Yes	No
Firm and year*SIC2 FE	No	Yes	No	Yes
Elasticity Yi wrt Gj, mean	0.0059	0.0054	0.0062	0.0075
Elasticity Yi wrt Gj, median	0.0020	0.0019	0.0023	0.0024
First stage F-test			108	108
Firms	2,049	2,049	2,049	2,049
Observations	24,596	24,596	24,596	24,596

Results

Additional splits of spillover and technology market weights

	Distance one vs. rest				Distances one and two vs. rest			
	OLS		IV		OLS		IV	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ln(G)	0.032**	0.044***	0.034**	0.039**	0.044***	0.051***	0.033**	0.040**
	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.017)	(0.017)
ln(S)	0.207***	0.193***	0.105	0.293***	-0.066	-0.011	-0.129**	-0.005
	(0.060)	(0.065)	(0.099)	(0.103)	(0.045)	(0.054)	(0.062)	(0.078)
ln(M)	0.025***	0.024***	0.028***	0.024**	0.063***	0.045**	0.187*	0.152
	(0.009)	(0.009)	(0.010)	(0.010)	(0.019)	(0.019)	(0.099)	(0.101)
ln(Capital)	0.110***	0.099***	0.111***	0.099***	0.110***	0.099***	0.111***	0.101***
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
ln(Labor)	0.659***	0.670***	0.659***	0.671***	0.660***	0.671***	0.663***	0.671***
	(0.020)	(0.021)	(0.020)	(0.021)	(0.020)	(0.021)	(0.020)	(0.021)
Firm and year FE	Yes	No	Yes	No	Yes	No	Yes	No
Firm and year*SIC2 FE	No	Yes	No	Yes	No	Yes	No	Yes
Elasticity Yi wrt Gj, mean	0.0058	0.0054	0.0046	0.0069	-0.0001	0.0002	0.0001	0.0008
Elasticity Yi wrt Gj, median	0.0037	0.0035	0.0038	0.0038	0.0000	0.0000	0.0001	0.0001
First stage F-test			283	451			9	9
Firms	2,049	2,049	2,049	2,049	2,049	2,049	2,049	2,049
Observations	24,596	24,596	24,596	24,596	24,596	24,596	24,596	24,596

Results

Alternative weights for the spillover pool

	Geo proximity		Market proximity		Forward citation (0,1)	
	OLS	IV	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)	(5)	(6)
ln(G)	0.043***	0.040***	0.046***	0.043***	0.042***	0.041***
	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)
ln(S)	0.006	-0.028	-0.026	-0.027	0.043	-0.047
	(0.063)	(0.082)	(0.021)	(0.024)	(0.037)	(0.046)
ln(M)	0.028***	0.031***	0.029***	0.031***	0.027***	0.031***
	(0.009)	(0.010)	(0.009)	(0.010)	(0.009)	(0.010)
ln(Capital)	0.111***	0.111***	0.111***	0.111***	0.110***	0.112***
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
ln(Labor)	0.657***	0.658***	0.656***	0.657***	0.658***	0.657***
	(0.020)	(0.020)	(0.020)	(0.020)	(0.020)	(0.020)
Firm and year FE	Yes	Yes	Yes	Yes	Yes	Yes
Elasticity Yi wrt Gj, mean	0.0032	0.0035	0.0033	0.0036	0.0031	0.0036
Elasticity Yi wrt Gj, median	0.0017	0.0019	0.0018	0.0019	0.0017	0.0019
First stage F-test		578		204		177
Firms	2,049	2,049	2,049	2,049	2,049	2,049
Observations	24,596	24,596	24,596	24,596	24,596	24,596

Results

Private and social returns (%) assuming a 50-50 split, main estimates

- Marginal private returns [smallest-largest providers]:
  - Canonical model without technology markets: [10-10]
  - Expanded model with technology markets: [10-16]
- Marginal social returns [smallest-largest providers]:
  - Canonical model without technology markets: [40-60]
  - Expanded model with technology markets: [40-66]

Conclusions

1. The metrics used to measure spillovers are correlated with connections in the market for technology.
2. The market for technology pool is a relevant input in the production function.
3. Spillovers and technology markets do not offset each other. But it is hard to find evidence of spillovers from distant providers in the market for technology network, the "cleanest" test for externalities.
4. The knowledge capital model without technology markets underestimates the private returns to R&D for prominent providers in the market for technology, which account for a disproportionately large share of R&D in the economy, but does not underestimate the social returns to R&D by much.