Knowledge: Gift or Burden of Innovation?

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Research question

What is the Role of Knowledge directly and indirectly used in R & D?

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  - Large teams have fewer innovation findings, and too much reliance on literature could hinder free ideas (Lee et al., 2015).
- Knowledge: Ideas that not directly input but build the foundation of innovation
  - Knowledge and basic science foundation help to cut the unit cost of innovation (Arora et al.,2021)

Evidences from U.S. patents

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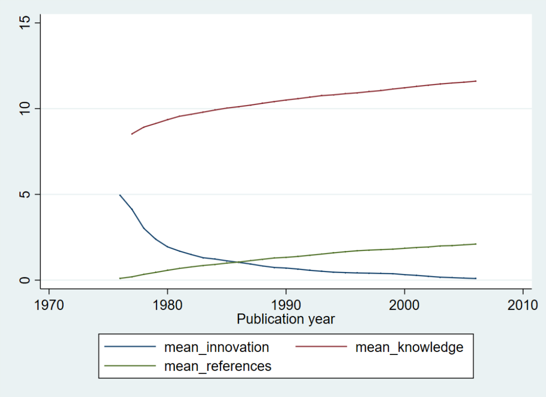
- Define **Innovation** of a patent as how many patents citing it without citing its references among all patents citing it.
- Define **References** of a patent as the total number of patents cited by it.
- Define **Knowledge** of each year in each (sub)field as the total number of patents published in the field before the year.

Total annual trend



As knowledge accumulates, the number of references on average increases, while the patents are becoming less disruptive overtime.

Guessing

Knowledge

References

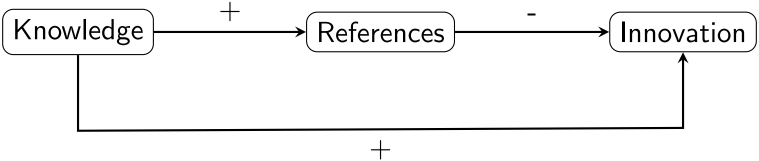
Innovation

Guessing

Guessing

$$\boxed{\text{Knowledge}} \xrightarrow{+} \boxed{\text{References}} \xrightarrow{-} \boxed{\text{Innovation}}$$

Guessing



Setting

- Two agents (firms' R&D teams) are choosing their research projects independently. Agent i chooses a research project (α_i, I_i), where α_i is the use of knowledge (References) and $\alpha_i \in [0, k]$, where k is the stock of public Knowledge. $I_i \geq 0$ measures the unique innovation developed by i.

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- The game has two stages. In the first stage, both agents choose (α_i, α_j) as how many references they are going to learn; in the second stage, agents choose (I_i, I_j) as how much innovation they will input into the project, and then the payoffs realize.

- Following Arora et al. (2021), the revenue of the project is determined by both agents' choice:

$$\Pi_i(I_i, I_j, \alpha_i) = I_i - \frac{c_1}{2} I_i^2 + c_2 I_i I_j + b\alpha_i$$

where $c_1 > 0$, and $b > 0$. c_2 measures the interaction between rivals. $c_2 > 0$ means there exists technical spillovers, while $c_2 < 0$ indicates competition.

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- Each agent pays two types of cost: (i) Innovation cost $\phi_i(\alpha_i; k) I_i$, where the unit cost of innovation is characterized by α_i and k with $\frac{\partial \phi}{\partial k} < 0$, ϕ_i convex in α_i, and $\frac{\partial^2 \phi}{\partial \alpha_i \partial k} < 0$; (ii) Education cost $C(\alpha_i) = \gamma \alpha_i$.

Agent i is maximizing the following payoff:

$$v_i = I_i - \frac{c_1}{2} I_i^2 + c_2 I_i I_j + b\alpha_i - \phi_i(\alpha_i; k) I_i - \gamma\alpha_i$$

We assume a stable Nash Equilibrium. This requires that $D = c_1^2 - c_2^2 > 0$, or $|c_1| > |c_2|$.

Equilibrium

In the second stage, write $\phi(\alpha_i; k)$ as ϕ_i, and $\phi(\alpha_j; k)$ as ϕ_j, the agents' optimal choice of innovation is given as

$$I_i^* = \frac{c_1(1-\phi_i) + c_2(1-\phi_j)}{D}$$

$$I_j^* = \frac{c_1(1-\phi_j) + c_2(1-\phi_i)}{D}$$

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To assure the existence of nonnegative results, it requires $\phi_i, \phi_j \leq 1$. From the equilibrium there is

$$\frac{\partial I_i^*}{\partial \alpha_i} = -\frac{c_1}{D}\frac{\partial \phi_i}{\partial \alpha_i} < 0$$

The relationship between innovation and the rival's references depends on sign of c_2:

$$\frac{\partial I_j^*}{\partial \alpha_i} = -\frac{c_2}{D}\frac{\partial \phi_i}{\partial \alpha_i}$$

Knowledge and innovation

The response of innovation input to public science is

$$\frac{\partial I_i^*}{\partial k} = -\frac{1}{D}(c_1\frac{\partial \phi_i}{\partial k} + c_2\frac{\partial \phi_j}{\partial k}) > 0$$

$$\frac{\partial I_j^*}{\partial k} = -\frac{1}{D}(c_1\frac{\partial \phi_j}{\partial k} + c_2\frac{\partial \phi_i}{\partial k})$$

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If there exists strategic complementarity between innovations, i.e., $c_2 > 0$, both firms innovate more in response to an increase in public science. Otherwise, if the innovations are strategic substitutes, then one (but not both) firm may reduce innovation. However, it always holds that

$$\frac{\partial I_i^*}{\partial k} + \frac{\partial I_j^*}{\partial k} = -\frac{1}{D}(c_1 + c_2)(\frac{\partial \phi_i}{\partial k} + \frac{\partial \phi_j}{\partial k}) > 0$$

Proposition I

In the equilibrium, the optimal choice for innovation is determined by the firm's innovation cost and its competition with the rival. And there is $\frac{\partial I_i^*}{\partial \alpha_i^*} < 0$, $\frac{\partial I_j^*}{\partial \alpha_i^*} < 0$, $\frac{\partial I_i^*}{\partial k} > 0$ and $\frac{\partial I_j^*}{\partial k} > 0$ under the assumptions on innovation cost functions and strategic complementarity, i.e., innovation decreases in both own and rival's references and increases in public knowledge.

References and knowledge

In the first stage, firm i' chooses α_i to maximize

$$v_i = I_i^* - \frac{c_1}{2} I_i^{*2} + c_2 I_i^* I_j^* + b\alpha_i - \phi_i(\alpha_i; k) I_i^* - \gamma\alpha_i$$

By envelope theorem, the optimal α_i satisfies that

$$\frac{\partial \phi_i}{\partial \alpha_i} I_i^* = \frac{(b-\gamma)D}{c_1^2}$$

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Proposition II

In the equilibrium, the optimal choice for references is determined by the firm's optimal innovation, education cost, and the firm's own innovation cost function. And there is $\frac{\partial \alpha_i^*}{\partial k} > 0$ under the assumptions on innovation cost functions, i.e., references increase in public knowledge.

Role of knowledge

The substitutability between references and public knowledge also leads to

$$\frac{\partial^2 I_i}{\partial \alpha_i \partial k} = -\frac{c_1}{D}\frac{\partial^2 \phi_i}{\partial \alpha_i \partial k} > 0$$

that accumulation of knowledge mitigates the negative effect of references on innovation.

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Proposition III

Knowledge mitigates the negative impact of references on innovation, and if $|\frac{\partial^2 I_i}{\partial \alpha_i \partial k}|$ is large enough, then there is

$$\frac{dI_i}{dk} = [\frac{\partial I_i}{\partial k}(>0) + \frac{\partial I_i}{\partial \alpha_i}(<0)\frac{d\alpha_i}{dk}(>0)] < 0$$

That the overall effect of knowledge on innovation is negative.

Empirical results

Variable Name	Variable Measurement
Innovation	CD-5/CD-10 index
Field Knowledge	Patents published before in the same subfield (in Logarithm)
Subfield Knowledge	Patents published in the same year and same subfield (in Logarithm)
References	Total backward cites from the patent
Originality	Fields of patents cited from the patent
Age	Mean age of work cited
Age Variance	Dispersion in age of work cited
Team Production	Mean number of prior works produced by team members (in Logarithm)
Diversity	Diversity of work cited
Competition	Average innovation in the same year and (sub)field

	Mean	SD	Min	Max	N
Innovation	0.13	0.30	-1.00	1.00	2.9e+06
Field Knowledge	10.62	1.08	0.69	12.50	3.1e+06
Subfield Knowledge	8.29	0.79	0.69	9.88	3.1e+06
References	1.61	0.97	0.00	6.67	2.8e+06
Originality	0.52	0.35	0.00	1.00	2.5e+06
Age	7.10	3.81	-36.00	30.00	2.8e+06
Age variance	3.08	2.35	0.00	19.00	2.8e+06
Team Productions	1.35	1.17	0.00	7.27	3.1e+06
Diversity	0.98	0.01	0.89	1.00	3.1e+06
Competition	0.14	0.16	-0.11	1.00	3.1e+06

$$Innovation_{ist} = \beta_0 + \beta_1 Knowledge_{st} + \beta_2 References_{ist} + \mathbf{X}_{ist}\delta + \epsilon_{st}$$

	Clustering NBER subfield		Clustering NBER field	
	Innovation	Alter Innovation	Innovation	Alter Innovatio
Knowledge	0.0120***	0.0120***	0.0330***	0.0309***
	(0.000)	(0.000)	(0.000)	(0.000)
References	-0.0451***	-0.0529***	-0.0448***	-0.0528***
	(0.000)	(0.000)	(0.000)	(0.000)
Competition	0.158***	0.171***	0.167***	0.188***
	(0.000)	(0.000)	(0.000)	(0.000)
Obs	2454595	2465161	2454595	2465161

	(1) Chemical	(2) omputers & Communications	(3) Drugs & Medical	(4) Electrical & Electronic	(5) Mechanical
Patents published before in the same subfield (in Logarithm)	-0.0586***	0.00335*	0.0125***	-0.0144***	-0.00271
	(0.000)	(0.049)	(0.000)	(0.000)	(0.252)
Patents published in the same year and same subfield (in Logarithm)	0.0593***	-0.00403*	-0.00902**	0.0165***	-0.0125***
	(0.000)	(0.043)	(0.001)	(0.000)	(0.000)
Total backward cites from the patent	-0.0458***	-0.0427***	-0.0247***	-0.0536***	-0.0512***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Discussions

- The researcher makes use of two types of existing ideas: references and public, general knowledge.
- Knowledge could encourage innovation by cutting costs of innovation directly.
- References could hinder innovation by making it harder to innovate.
- Knowledge will also encourage references and mitigate the negative impact of references on innovation.
- While knowledge makes both innovating and referring easier, the overall effect of knowledge accumulation on innovation is negative. This is because references have a larger negative effect.

Thank you!