14.461: Technological Change, Lecture 3
Knowledge Spillovers and Diffusion

Daron Acemoglu

MIT

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Introduction

- A key issue in the analysis of technology is the extent to which investments in knowledge (for example by R&D) create positive knowledge spillovers from others.
- A related question concerns the patterns of diffusion of new technologies (as such diffusion often might result from copying, thus a form of knowledge spillovers).
- We have seen that endogenous growth could result both with and without such knowledge spillovers. Thus the presence and extent of such spillovers is an empirical question.
- There is a large literature on this topic (for example the early one surveyed by Griliches's Scandinavian Journal of Economics paper). However, it is plagued by lack of identification. At best, it documents correlations, sometimes difficult to interpret. The problem is that outside factors, both technological and otherwise, will affect firms that are likely to benefit from each other's R&D investments and knowledge.

Diffusion

- The basic facts about diffusion are well established.
- The classic paper by Griliches on the hybrid corn still tells the basic picture: there is slow diffusion of new technologies and the speed of diffusion depends on various factors, most notably on market conditions, human capital and various measures of "distance" or "similarity" between innovators/early adopters and late adopters.

Diffusion (continued)

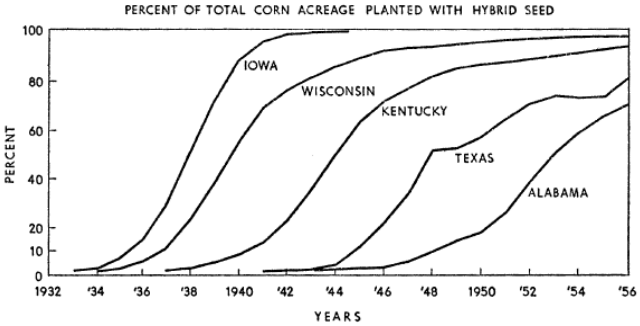

FIGURE 1.—Percentage of Total Corn Acreage Planted with Hybrid Seed.

Patent Citations

- Another prima fascia evidence is that most patents "cite" other patents, indicating that they are "building" on them.
- For example, between 1975 and 1990, a patent filed with the USPTO received about 8 cites (with a maximum of 631 cites) from other patents in the same time window. Only about 13-14% of this is self citation.
    - The number of cites naturally increases if we look at longer time windows.
- However, this is not conclusive, since the citation may be done purely for bureaucratic reasons and after the fact (and in fact, many of the citations are added by patent examiners).
- If so, we would not know exactly how much "building on the shoulders of giants" there is.
    - Nevertheless, this would be an interesting source of data to exploit for this purpose.

Geographic Concentration

- Another well-established fact is about geographic concentration of various innovative activities.
- The most famous paper here is Jaffe, Trajtenberg and Henderson (1993), which establishes geographic concentration of patent citations.
- They show that citations to patents registered in the United States by US innovators are more likely to be from other US patents (relative to non-US innovators) and more importantly, they are more likely to be from the same state and same SMSA as the cited patent.
- The question is how to interpret this fact: one interpretation is geographic localization of knowledge spillovers as the authors claim.
- Another interpretation would be localization of economic activity that a detailed sub-industry level due to other factors.

The Reflection Problem

- Estimating technology spillovers is hard due to the version of Manski's "reflection problem". This is what the interpretation of Jaffe, Trajtenberg and Henderson's findings suffered from.
- The reflection problem arises whenever we run a regression of the following form

$$y_j = \mathbf{X}_j' \boldsymbol{\beta} + \alpha \tilde{y}_j + \varepsilon_j$$

  where $\tilde{y}_j$ is some average or other moment of the y's of unit j. The most common version would be an average of unit j's neighbors or all units in some locality including unit j.
- To see this in the simplest possible way, reason like this: these firms are neighbors because they are somehow related (they have chosen to be neighbors or they are in the same locality for other reasons etc.). Any common shock to that locality or to the characteristic that has made them neighbors will create a correlation between y_j and $\tilde{y}_j$ that has likely to do nothing with the causal effect of the latter on the former.

Estimating Technology Spillovers

- Almost all papers estimating technology spillovers are subject to the reflection problem.
- Most of them ignore it.
- A few try to deal with it with some type of instrumental variables strategy, but often this is hard and not convincing.
- State-of-the-art paper that makes a good attempt to deal with it and also brings out certain additional economic issues is Bloom, Schankerman and Van Reenen, which I will now discuss.

Technology Spillovers and Product Market Rivalry

- Bloom, Schankerman and Van Reenen start with an important observation: one needs to distinguish knowledge (technology) spillovers from product market rivalry, since firms like you to share knowledge are often also product market rivals.
- Knowledge spillovers are positive externalities, while product market rivalry creates negative effects from (R&D) investments of one firm on the profits and value of another, so at the very least the presence of these two interactions need to be taken together; ignoring one of them can confound the other.

Simple Model

- Bloom, Schankerman and Van Reenen start with the following simple model to generate some qualitative predictions.
- To capture the possibility that some firms are "technology neighbors" and not product market rivals, and vice versa, they consider a world consisting of three firms.
- Firm 0 is a product market rival with firm m and is a technology neighbor with firm τ. The latter two firms do not interact.
- Let us focus on the interactions between firms 0 and m.
- Suppose that both firms have (net) profit function

$$\pi\left(x, x', k\right)$$

where x is their own output and x' is the output of their product market rival, and k is their own knowledge capital.

Simple Model (continued)

- After knowledge capitals are determined, the two firms compete (either in prices or quantities) and let us suppose that this is a unique (symmetric) equilibrium where

$$x_0^* = f(k_0, k_m) \text{ and } x_m^* = f(k_m, k_0).$$

  The fact that the same function determines the output level of both firms stems from the fact that there is a symmetric equilibrium and other potential heterogeneities, for example actions of technology neighbor firm τ, will affect behavior through knowledge capitals.
- Now substituting these into the profit function, we obtain

$$\Pi(k_0, k_m) = \pi(x_0^*, x_m^*, k_0).$$

Simple Model (continued)

- Suppose also that the knowledge capital of firm 0 is given by

$$k_0 = \phi\left(r_0, r_\tau\right),$$

where r denotes R&D investments, and by assumption, the knowledge of firm 0 depend only on its own investment than that of firm τ (non-trivially if there are indeed knowledge spillovers) but not on that of firm m.

- Now the R&D decision of firm 0 is a solution to the following simple maximization problem

$$V_0 = \max_{r_0} \Pi\left(\phi\left(r_0, r_\tau\right), k_m\right) - r_0.$$

- Clearly, the first-order condition

$$\Pi_1 \phi_1 - 1 = 0$$

gives the optimal R&D decision r_0^*, where subscripts denote derivatives and arguments are omitted.

Simple Model (continued)

- Now, the effect of R&D by technology neighbor and product market rival on knowledge stocks and firm value are given by:

$$\frac{\partial k_0}{\partial r_\tau} = \phi_2 \geq 0 \text{ and } \frac{\partial k_0}{\partial r_m} = 0,$$

  where the first of these is just the main effect, which is assumed to be nonnegative (whereas what we have looked at so far were the strategic responses, related to whether the R&D of one firm response positively or negatively to that of another).

- Then applying the envelope theorem gives how firm value reacts to R&D by technology neighbors and product market rivals:

$$\frac{\partial V_0}{\partial r_\tau} = \Pi_1 \frac{\partial k_0}{\partial r_\tau} \geq 0 \text{ and } \frac{\partial V_0}{\partial r_m} = \Pi_2 \frac{\partial k_0}{\partial r_m} \leq 0.$$

Simple Model (continued)

- The effect of R&D investment by firm τ on firm 0's behavior is given straightforwardly by applying the implicit function theorem as

$$\text{sign}\left\{\frac{\partial r_0^*}{\partial r_\tau}\right\} = \text{sign}\left\{\Pi_1\phi_{1\tau} + \Pi_{11}\phi_1\phi_\tau\right\}.$$

- Clearly, this will be positive only if $\phi_{1\tau} > 0$, i.e., if R&D by the technology neighbor increases the productivity of R&D by firm 0. Otherwise, because of diminishing returns in knowledge production, i.e., $\Pi_{11} < 0$, this will be negative. Intuitively, the more the other firm discovers, there is less for me to discover.
- The effect of the R&D of the rival on own R&D is

$$\text{sign}\left\{\frac{\partial r_0^*}{\partial r_m}\right\} = \text{sign}\left\{\Pi_{12}\phi_1\right\},$$

  which as expected depends on Π_{12}, i.e., whether competition between the two firms makes their output strategic complements or substitutes.

Summarizing

- Summarizing these "predictions":

(1)	(2) **Partial correlation**	(3) **Theory**	(4) **Empirics Jaffe**	(5) **Empirics Mahalanobis**	(6) **Empirics Jaffe, IV**	(7) **Consistency?**
$\partial V_0/\partial r_\tau$	Market value with SPILLTECH	Positive	0.242**	0.903**	0.579***	Yes
$\partial V_0/\partial r_m$	Market value with SPILLSIC	Negative	-0.072**	-0.136**	-0.087**	Yes
$\partial k_0/\partial r_\tau$	Patents with SPILLTECH	Positive	0.423**	0.583***	0.302**	Yes
$\partial k_0/\partial r_m$	Patents with SPILLSIC	Zero	0.053	0.078	0.076	Yes
$\partial y_0/\partial r_\tau$	Productivity with SPILLTECH	Positive	0.103**	0.212**	0.078**	Yes
$\partial y_0/\partial r_m$	Productivity with SPILLSIC	Zero	0.010	0.015	-0.017	Yes
$\partial r_0/\partial r_\tau$	R&D with SPILLTECH	Ambiguous	0.117	-0.176*	0.205**	-
$\partial r_0/\partial r_m$	R&D with SPILLSIC	Ambiguous	0.078**	0.224**	0.014	-

Empirical Strategy

- Bloom, Schankerman and Van Reenen estimate models related to these predictions on Compustat matched to the patents citation data.
- There are two major challenges:
  1. Constructing equivalents of technology neighbors and product market rivals.
  2. Worrying about the reflection problem.
- They are successful in the first, less so in the second.

Empirical Measures

- For technological relatedness, they look at the average share of patents of each firm in each of the technology classes between 1970 and 1999, with technology classes being constructed from the 426 USPTO categories.
- Technological relatedness of two firms i and j is then given by the unscented correlation between the share of patents in different technology classes of each firm (a measure originally suggested by Jaffe, 1986):

$$Tech_{ij} = \frac{T_i T_j'}{\sqrt{T_i T_i'}\sqrt{T_j T_j'}},$$

  where T_i is the vector of share of patents of firm i in different technology classes.

Empirical Measures (continued)

- Their measure of spillover for firm i in year t is then:

$$SpillTech_{it} = \sum_{j \neq i} Tech_{ij} \cdot K_{jt},$$

where K_{jt} is the R&D stock of firm j at time t, obtained from their past R&D investments.

Empirical Measures (continued)

- Measures of product market rivalry are created similarly, by using the vector of sales of each firm in different four digit industries. Denoting these vectors by S_i, this is

$$SIC_{ij} = \frac{S_i S_j'}{\sqrt{S_i S_i'}\sqrt{S_j S_j'}},$$

and they also define

$$SpillSIC_{it} = \sum_{j \neq i} SIC_{ij} \cdot K_{jt}.$$

Example

- Are these measures distinct?

	Correlation	*IBM*	*Apple*	*Motorola*	*Intel*
IBM	SIC Compustat	1	0.65	0.01	0.01
	SIC BVD	1	0.55	0.02	0.07
	TECH	***1***	***0.64***	***0.46***	***0.76***
Apple	SIC Compustat		1	0.02	0.00
	SIC BVD		1	0.01	0.03
	TECH		***1***	***0.17***	***0.47***
Motorola	SIC Compustat			1	0.34
	SIC BVD			1	0.47
	TECH			***1***	***0.46***
Intel	SIC Compustat				1
	SIC BVD				1
	TECH				***1***

Regression Specifications

- Then, their main empirical specifications regress firm value divided by assets (Tobin's average Q), future citation-weighted patents, R&D and productivity on SpillTech and SpillSIC as well as controls and own R&D stock
- Their models include firm fixed effects and also sometimes instrument for R&D using tax credits (as a function of the state and industry of the firm).
- While one may argue about whether it is instrumented to valid or not (though likely not...), it would not solve the endogeneity problems unless one also instrumented the spillover variables properly (see Acemoglu and Angrist, 2000, for the econometric point in the context of human capital externalities).
- Here the same tax credit variable used as instrument for spillovers, but this raises a variety of issues (in particular, correlation in the instrument between firms located in the same area)

Regressions on Tobin's Q

Dependent variable: Ln (V/A)	(1)	(2)	(3)
	All	Only SPILLTEC	Only SPILLSIC
Ln(SPILLTECH$_{t-1}$)	**0.242** **(0.105)**	**0.186** **(0.100)**	
Ln(SPILLSIC$_{t-1}$)	**-0.072** **(0.032)**		**-0.050** **(0.031)**

Regressions on Productivity

Dep Var: Ln(Sales)	(1)	(2)
	Fixed effects	Fixed effects
Ln(SPILLTECH) $_{t-1}$	**0.103*** (0.046)**	**0.111*** (0.045)**
Ln(SPILLSIC) $_{t-1}$	**0.010 (0.012)**	
Ln(Capital) $_{t-1}$	0.179*** (0.010)	0.179*** (0.010)
Ln(Labour) $_{t-1}$	0.634*** (0.013)	0.634*** (0.013)
Ln(R&D Stock) $_{t-1}$	0.041*** (0.006)	0.041*** (0.006)

Regressions on Patents

Dependent var: Patent Count	(1)	(2)
	Initial conditions, static	Initial conditions, dynamic
Ln(SPILLTECH) $_{t-1}$	**0.423*** (0.071)**	**0.375*** (0.050)**
Ln(SPILLSIC) $_{t-1}$	**0.053 (0.036)**	**0.041 (0.026)**
Ln(R&D Stock) $_{t-1}$	0.221*** (0.053)	0.104*** (0.039)
Ln(Patents) $_{t-1}$		0.420*** (0.020)

Regression on R&D

Dep Var: ln(R&D)	(1)	(2)
	Fixed Effects, Dynamics	Fixed Effects, Dynamics
Ln(SPILLTECH) $_{t-1}$	**-0.036** **(0.040)**	
Ln(SPILLSIC) $_{t-1}$	**0.033**** **(0.019)**	**0.037**** **(0.020)**

Instrumental Variable Regressions

	(1)	(2)	(3)	(2)
	Tobin's Q	Patents	Sales	R&D
Ln(SPILLTECH) $_{t-1}$	0.579*** (0.124)	0.302*** (0.071)	0.078** (0.033)	0.205* (0.093)
Ln(SPILLSIC) $_{t-1}$	-0.087* (0.047)	0.076 (0.049)	-0.017 (0.012)	0.014 (0.047)

Summary of Empirical Findings

(1)	(2) **Partial correlation**	(3) **Theory**	(4) **Empirics Jaffe**	(5) **Empirics Mahalanobis**	(6) **Empirics Jaffe, IV**	(7) **Consistency?**
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