# 14.461: Technological Change, Lecture 2
# 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 (the early literature is 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)

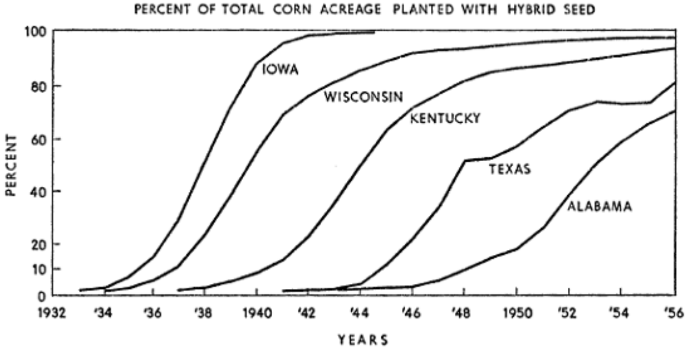


FIGURE 1.—Percentage of Total Corn Acreage Planted with Hybrid Seed.

# Patents

- A very useful source of data on the quantity, quality and nature of innovation comes from patents data.
- A significant fraction of new innovations are patented to protect the property rights of the inventor.

USPTO defines a patent as:

> *A patent is a property right granted by the Government of the United States of America to an inventor to exclude others from making, using, offering for sale, or selling the invention throughout the United States or importing the invention into the United States for a limited time in exchange for public disclosure of the invention when the patent is granted.*

# What Can Be Patented

- To be patented, an invention must be:
  - Novel,
  - Nonobvious,
  - Adequately described or enabled (for one of ordinary skill in the art to make and use the invention), and
  - Claimed by the inventor in clear and definite terms.
- Utility patents are provided for a novel, nonobvious and useful:
  - Process,
  - Machine,
  - Article of manufacture, or
  - Composition of matter.
- The Patent Act of 1790 was the first federal patent statute of the United States, and set the length of a patent as 14 years. Since 1995, it is 20 years.

# Some Examples: Watt's Steam Engine

A.D. 1769 . . . . . . . N° 913.

**Steam Engines, &c.**

WATT'S SPECIFICATION.

**TO ALL TO WHOM THESE PRESENTS SHALL COME,** I, JAMES WATT, of Glasgow, in Scotland, Merchant, send greeting.

**WHEREAS** His most Excellent Majesty King George the Third, by His Letters Patent under the Great Seal of Great Britain, bearing date the Fifth day of January, in the ninth year of His said Majesty's reign, did give and grant unto me, the said James Watt, His special licence, full power, sole priviledge and authority, that I, the said James Watt, my exors, admors, and assigns, should and lawfully might, during the term of years therein expressed, use, exercise, and vend, throughout that part of His Majesty's Kingdom of Great Britain called England, the Dominion of Wales, and Town of Berwick upon Tweed, and also in His Majesty's Colonies and Plantations abroad, my "NEW INVENTED METHOD OF LESSENING THE CONSUMPTION OF STEAM AND FUEL IN FIRE ENGINES;" in which said recited Letters Patent is contained a proviso obliging me, the said James Watt, by writing under my hand and seal, to cause a particular description of the nature of the said Invention to be inrolled in His Majesties High Court of Chancery within four calendar months after the date of the said recited Letters Patent, as in and by the said Letters Patent, and the Statute in that behalf made, relation being thereunto respectively had, may more at large appear.

**NOW KNOW YE,** that in compliance with the said provisoe, and in pursuance of the said Statute, I, the said James Watt, do hereby declare that the

# Some Examples: Watt's Steam Engine (continued)

A.D. 1769.—N° 913. 3

*Watt's Method of Lessening the Consumption of Steam & Fuel in Fire Engines.*

weights are pressed, but not in the contrary. As the steam vessel moves round it is supplied with steam from the boiler, and that which has performed its office may either be discharged by means of condensers, or into the open air.

Sixthly, I intend in some cases to apply a degree of cold not capable of reducing the steam to water, but of contracting it considerably, so that the engines shall be worked by the alternate expansion and constraction of the steam.

Lastly, instead of using water to render the piston or other parts of the engines air and steam tight, I employ oils, wax, rosinous bodies, fat of animals, quicksilver and other metalls, in their fluid state.

In witness whereof, I have hereunto set my hand and seal, this Twenty-fifth day of April, in the year of our Lord One thousand seven hundred and sixty-nine.

JAMES WATT. (L.S.)

Sealed and delivered in the presence of

Coll. Wilkie.
Geo. Jardine.
John Roebuck.

Be it remembered, that the said James Watt doth not intend that any thing in the fourth article shall be understood to extend to any engine where the water to be raised enters the steam vessell itself, or any vessell having an open communication with it.

James Watt.

Witnesses,
Coll. Wilkie.
Geo. Jardine.

**AND BE IT REMEMBERED**, that on the Twenty-fifth day of April, in the year of our Lord 1769, the aforesaid James Watt came before our said Lord the King in His Chancery, and acknowledged the Specification aforesaid, and all and every thing therein contained and specified, in form above written. And also the Specification aforesaid was stampt according to the tenor of the Statute made in the sixth year of the reign of the late King and Queen William and Mary of England, and so forth.

Wilkie, Ect.

Inrolled the Twenty-ninth day of April, in the year of our Lord One thousand seven hundred and sixty-nine.

LONDON:
Printed by George Edward Eyre and William Spottiswoode,
Printers to the Queen's most Excellent Majesty. 1855.

# Some Examples: Apple's Touchscreen

(12) **United States Patent**
**Ording**

(10) **Patent No.: US 8,209,606 B2**
(45) **Date of Patent: *Jun. 26, 2012**

(54) **DEVICE, METHOD, AND GRAPHICAL USER INTERFACE FOR LIST SCROLLING ON A TOUCH-SCREEN DISPLAY**

(75) Inventor: **Bas Ording**, San Francisco, CA (US)

(73) Assignee: **Apple Inc.**, Cupertino, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 763 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **12/270,807**

(22) Filed: **Nov. 13, 2008**

(65) **Prior Publication Data**

US 2009/0073194 A1 Mar. 19, 2009

**Related U.S. Application Data**

(63) Continuation of application No. 11/956,969, filed on Dec. 14, 2007, now Pat. No. 7,469,381.

(60) Provisional application No. 60/937,993, filed on Jun. 29, 2007, provisional application No. 60/946,971, filed on Jun. 28, 2007, provisional application No. 60/945,858, filed on Jun. 22, 2007, provisional application No. 60/879,469, filed on Jan. 8, 2007, provisional application No. 60/883,801, filed on Jan. 7, 2007, provisional application No. 60/879,253, filed on Jan. 7, 2007.

(51) **Int. Cl.**
***G06F 3/00*** (2006.01)
*G06F 3/01* (2006.01)

(52) **U.S. Cl.** ........ **715/700**; 715/786; 715/763; 715/784; 345/173; 345/156

(58) **Field of Classification Search** .................. 345/173, 345/180, 156; 715/784, 763, 786, 700
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,463,725 A 10/1995 Henckel et al. .............. 395/155
(Continued)

FOREIGN PATENT DOCUMENTS

AU 2007283771 A1 4/2008
(Continued)

OTHER PUBLICATIONS

Examiner's Amendment dated Oct. 29, 2008, to related U.S. Appl. No. 11/956,969.

(Continued)

*Primary Examiner* — Mark Rinehart
*Assistant Examiner* — Toan Vu
(74) *Attorney, Agent, or Firm* — Morgan, Lewis & Bockius LLP

(57) **ABSTRACT**

In accordance with some embodiments, a computer-implemented method for use in conjunction with a device with a touch screen display is disclosed. In the method, a movement of an object on or near the touch screen display is detected. In response to detecting the movement, a list of items displayed on the touch screen display is scrolled in a first direction. If a terminus of the list is reached while scrolling the list in the first direction while the object is still detected on or near the touch screen display, an area beyond the terminus of the list is displayed. In response to detecting that the object is no longer on or near the touch screen display, the list is scrolled in a second direction until the area beyond the terminus of the list is no longer displayed.

**21 Claims, 38 Drawing Sheets**

# Some Examples: Apple's Touchscreen (continued)

U.S. Patent Jun. 26, 2012 Sheet 2 of 38 US 8,209,606 B2

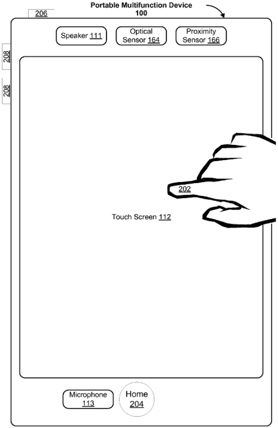


Figure 2

# Some Examples: Apple's Touchscreen (continued)

U.S. Patent Jun. 26, 2012 Sheet 3 of 38 US 8,209,606 B2

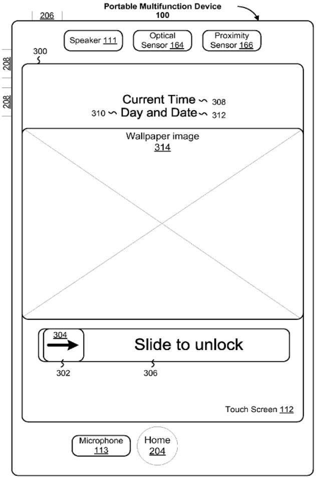


Figure 3

# Patent Citations

- What makes patents a particularly useful source of data for measuring and modeling innovation is the data on patent citations.
- We know essentially the entire universe of patent citations.
- 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.

# Patent Citations and Patent Value

- Considerable evidence suggests that patent value, and thus presumably patent quality, is correlated with patent citations, though there are many mitigating factors.
- For example:
  - Trajtenberg (1990): Individual patent specific social value for Computed Tomography Scanners related to citations
  - Hall, Jaffe and Trajtenberg (2005): Stock market value related to citations.
  - Bessen (2008): Patent renewals (decision to pay the annual renewal fee) related to citations

# Patent Citations and Spillovers

- Another prima fascia evidence in favor of the idea that innovation creates knowledge spillovers is that most patents "cite" other patents, indicating that they are "building" on them.
- 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 $\tau$. 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

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

  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 $\tau$, will affect behavior through knowledge capitals.

- Now substituting these into the profit function, we obtain

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

# 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 $\tau$ (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 $\tau$ 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 $\Pi_{12}$, i.e., whether competition between the two firms makes their output strategic complements or substitutes.

# Summarizing the predictions

TABLE VII

COMPARISON OF EMPIRICAL RESULTS TO MODEL WITH TECHNOLOGICAL SPILLOVERS AND PRODUCT MARKET RIVALRY

| (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 | 0.381** | 0.903** | 1.079*** | Yes |
| $\partial V_0/\partial r_m$ | Market value with *SPILLSIC* | Negative | −0.083** | −0.136** | −0.235** | Yes |
| $\partial k_0/\partial r_\tau$ | Patents with *SPILLTECH* | Positive | 0.417** | 0.530** | 0.407** | Yes |
| $\partial k_0/\partial r_m$ | Patents with *SPILLSIC* | Zero | 0.043 | 0.053 | 0.037 | Yes |
| $\partial y_0/\partial r_\tau$ | Productivity with *SPILLTECH* | Positive | 0.191** | 0.264** | 0.206** | Yes |
| $\partial y_0/\partial r_m$ | Productivity with *SPILLSIC* | Zero | −0.005 | −0.007 | 0.030 | Yes |
| $\partial r_0/\partial r_\tau$ | R&D with *SPILLTECH* | Ambiguous | 0.100 | −0.176* | 0.138 | |
| $\partial r_0/\partial r_m$ | R&D with *SPILLSIC* | Ambiguous | 0.083** | 0.224** | −0.022 | |

# 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)

- For technological relatedness, they also construct similar measures based on the Mahalanobis distance, which relaxes the assumption that knowledge spillovers are within technology classes and instead assumes that they are proportional to the likelihood of co-location of patents from different technology classes within firms.
- 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 for Market Value (Tobin's Q)

TABLE III

COEFFICIENT ESTIMATES FOR TOBIN'S Q EQUATION

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Specification: | OLS | OLS | OLS | OLS | OLS | IV 2nd Stage |
| Distance Measure: | Jaffe | Jaffe | Jaffe | Jaffe | Mahalanobis | Jaffe |
| $\ln(SPILLTECH_{t-1})$ | −0.064 | 0.381 | 0.305 | | 0.903 | 1.079 |
| | (0.013) | (0.113) | (0.109) | | (0.146) | (0.192) |
| $\ln(SPILLSIC_{t-1})$ | 0.053 | −0.083 | | −0.050 | −0.136 | −0.235 |
| | (0.007) | (0.032) | | (0.031) | (0.050) | (0.109) |
| $\ln(\text{R\&D Stock/Capital Stock})_{t-1}$ | 0.859 | 0.806 | 0.799 | 0.799 | 0.835 | 0.831 |
| | (0.154) | (0.197) | (0.198) | (0.198) | (0.198) | (0.197) |
| | | | | | | 1st Stage $F$-Tests |
| $\ln(SPILLTECH_{t-1})$ | | | | | | 112.5 |
| $\ln(SPILLSIC_{t-1})$ | | | | | | 42.8 |
| Firm fixed effects | No | Yes | Yes | Yes | Yes | Yes |
| No. observations | 9,944 | 9,944 | 9,944 | 9,944 | 9,944 | 9,944 |

# Regressions for Productivity

TABLE IV

COEFFICIENT ESTIMATES FOR THE CITE-WEIGHTED PATENT EQUATION

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Specification: | Neg. Bin. | Neg. Bin. | Neg. Bin. | Neg. Bin. | Neg. Bin. IV 2nd Stage |
| Distance Measure: | Jaffe | Jaffe | Jaffe | Mahalanobis | Jaffe |
| $\ln(SPILLTECH)_{t-1}$ | 0.518 | 0.468 | 0.417 | 0.530 | 0.407 |
| | (0.096) | (0.080) | (0.056) | (0.070) | (0.059) |
| $\ln(SPILLSIC)_{t-1}$ | 0.045 | 0.056 | 0.043 | 0.053 | 0.037 |
| | (0.042) | (0.037) | (0.026) | (0.037) | (0.028) |
| $\ln(\text{R\&D Stock})_{t-1}$ | 0.500 | 0.222 | 0.104 | 0.112 | 0.071 |
| | (0.048) | (0.053) | (0.039) | (0.039) | (0.020) |
| $\ln(\text{Patents})_{t-1}$ | | | 0.420 | 0.425 | 0.423 |
| | | | (0.020) | (0.020) | (0.020) |
| Pre-sample fixed effect | | 0.538 | 0.292 | 0.276 | 0.301 |
| | | (0.046) | (0.033) | (0.033) | (0.032) |
| | | | | | IV 1st Stage $F$-Tests |
| $\ln(SPILLTECH)_{t-1}$ | | | | | 74.6 |
| $\ln(SPILLSIC)_{t-1}$ | | | | | 15.0 |
| Firm fixed effects | No | Yes | Yes | Yes | Yes |
| No. observations | 9,023 | 9,023 | 9,023 | 9,023 | 9,023 |

# Regressions on Patents (citation weighted)

TABLE V

COEFFICIENT ESTIMATES FOR THE PRODUCTION FUNCTION

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Specification: | OLS | OLS | OLS | OLS | IV 2nd Stage |
| Distance Measure: | Jaffe | Jaffe | Jaffe | Mahalanobis | Jaffe |
| $\ln(SPILLTECH)_{t-1}$ | −0.022 | 0.191 | 0.186 | 0.264 | 0.206 |
| | (0.009) | (0.046) | (0.045) | (0.064) | (0.081) |
| $\ln(SPILLSIC)_{t-1}$ | −0.016 | −0.005 | | −0.007 | 0.030 |
| | (0.004) | (0.011) | | (0.021) | (0.054) |
| $\ln(\text{Capital})_{t-1}$ | 0.288 | 0.154 | 0.153 | 0.156 | 0.152 |
| | (0.009) | (0.012) | (0.012) | (0.012) | (0.012) |
| $\ln(\text{Labor})_{t-1}$ | 0.644 | 0.636 | 0.636 | 0.637 | 0.639 |
| | (0.012) | (0.015) | (0.015) | (0.015) | (0.016) |
| $\ln(\text{R\&D Stock})_{t-1}$ | 0.061 | 0.043 | 0.042 | 0.043 | 0.041 |
| | (0.005) | (0.007) | (0.007) | (0.007) | (0.007) |
| | | | | | 1st Stage $F$-Statistic |
| $\ln(SPILLTECH)_{t-1}$ | | | | | 112.4 |
| $\ln(SPILLSIC)_{t-1}$ | | | | | 51.2 |
| Firm fixed effects | No | Yes | Yes | Yes | Yes |
| No. observations | 9,935 | 9,935 | 9,935 | 9,935 | 9,935 |

# Regression on R&D (ln(R&D divided by sales))

TABLE VI

COEFFICIENT ESTIMATES FOR THE R&D EQUATION

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Specification: | OLS | OLS | OLS | OLS | IV 2nd Stage |
| Distance Measure: | Jaffe | Jaffe | Jaffe | Mahalanobis | Jaffe |
| $\ln(SPILLTECH)_{t-1}$ | 0.079 | 0.100 | −0.049 | −0.176 | 0.138 |
| | (0.018) | (0.076) | (0.042) | (0.101) | (0.122) |
| $\ln(SPILLSIC)_{t-1}$ | 0.374 | 0.083 | 0.034 | 0.224 | −0.022 |
| | (0.013) | (0.034) | (0.019) | (0.048) | (0.071) |
| $\ln(\text{R\&D/Sales})_{t-1}$ | | | 0.681 | | |
| | | | (0.015) | | |
| | | | | | IV 1st stage $F$-tests |
| $\ln(SPILLTECH)_{t-1}$ | | | | | 190.7 |
| $\ln(SPILLSIC)_{t-1}$ | | | | | 38.0 |
| Firm fixed effects | No | Yes | No | Yes | Yes |
| No. observations | 8,579 | 8,579 | 8,387 | 8,579 | 8,579 |

# Summary of Empirical Findings

TABLE VII

COMPARISON OF EMPIRICAL RESULTS TO MODEL WITH TECHNOLOGICAL SPILLOVERS AND PRODUCT MARKET RIVALRY

| (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 | 0.381** | 0.903** | 1.079*** | Yes |
| $\partial V_0/\partial r_m$ | Market value with *SPILLSIC* | Negative | −0.083** | −0.136** | −0.235** | Yes |
| $\partial k_0/\partial r_\tau$ | Patents with *SPILLTECH* | Positive | 0.417** | 0.530** | 0.407** | Yes |
| $\partial k_0/\partial r_m$ | Patents with *SPILLSIC* | Zero | 0.043 | 0.053 | 0.037 | Yes |
| $\partial y_0/\partial r_\tau$ | Productivity with *SPILLTECH* | Positive | 0.191** | 0.264** | 0.206** | Yes |
| $\partial y_0/\partial r_m$ | Productivity with *SPILLSIC* | Zero | −0.005 | −0.007 | 0.030 | Yes |
| $\partial r_0/\partial r_\tau$ | R&D with *SPILLTECH* | Ambiguous | 0.100 | −0.176* | 0.138 | |
| $\partial r_0/\partial r_m$ | R&D with *SPILLSIC* | Ambiguous | 0.083** | 0.224** | −0.022 | |

# Conclusions

- Knowledge spillovers are an important form of externality. Though they are not necessary for endogenous technological change, it is plausible that they are quite sizable.
- A variety of diverse evidence is consistent with the importance of these spillovers, but concerns related to the "reflection problem" plague many of the more formal attempts to draw inference on this.
- Patent data and patent citation data can be used to investigate this question, as well as more generally as a very useful source of data in empirical work on innovation and technological change.
- Estimates of the spillovers that attempt to deal with major endogeneity issues and also spillovers taking place through product market competition suggest that knowledge spillovers are very large.