The Economics of Innovation

Prof. Dr. Ulrich Kaiser

Department of Business Administration

University of Zurich

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1. The Arrival of Innovation
1.4 Technology adoption

Some slides adopted from Manuel Trajtenberg!
1. The Arrival of Innovation

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The Impact of Innovations: “first hand” evidence

What do we mean by “first hand”? Lots on indirect evidence, primarily on productivity growth, at various levels:

- Macro (economy-wide)
- Sectors (various levels of aggregation)
- Firms

Extensive literature, measurement issues, is it “really” tech change?
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The Impact of Innovations: “first hand” evidence

- Diffusion of innovations
- Rates of return on process and product innovation (Griliches, Mansfield)
- Hedonic Prices
- Welfare analysis of product innovations
- Valuation of new goods
- Impact on wages, inequality
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Tree of Zvi
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Diffusion of major innovations in the US (from Hall 2002)
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Diffusion of major innovations in the US (from Klenow)
Table 8

The Impact of Selected New Goods on Consumer Spending

<table>
<thead>
<tr>
<th></th>
<th>Spending Share*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1980</td>
</tr>
<tr>
<td><strong>As % of All Spending on Recreation</strong></td>
<td></td>
</tr>
<tr>
<td>Television Sets</td>
<td>4.9</td>
</tr>
<tr>
<td>Cable Television Service</td>
<td>1.8</td>
</tr>
<tr>
<td>All Television</td>
<td>6.7</td>
</tr>
<tr>
<td>Movies</td>
<td>1.9</td>
</tr>
<tr>
<td>VCRs and Movie Rentals</td>
<td>1.0</td>
</tr>
<tr>
<td>Movies, VCRs, and Rentals</td>
<td>2.9</td>
</tr>
<tr>
<td>Audio and Video (except computers)</td>
<td>14.9</td>
</tr>
<tr>
<td>Computers</td>
<td>.1</td>
</tr>
<tr>
<td>All Audio and Video</td>
<td>15.0</td>
</tr>
</tbody>
</table>

**As % of All Spending on Services**

<table>
<thead>
<tr>
<th></th>
<th>Spending Share*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1980</td>
</tr>
<tr>
<td>Telephone Charges (except cellular)</td>
<td>3.2</td>
</tr>
<tr>
<td>Cellular Telephone Charges</td>
<td>.0</td>
</tr>
<tr>
<td>All Telephone Charges</td>
<td>3.2</td>
</tr>
</tbody>
</table>

*The underlying data are nominal consumer expenditures from the U.S. national income and product accounts. Recreation = spending on recreation and on audio and video products; computers = spending on hardware, software, and Internet connections; telephone = charges for local, long distance, and cellular services. Source: U.S. Department of Commerce, Bureau of Economic Analysis.
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Innovation and Diffusion in Agriculture

- The overlooked sector...
  - Continuous and dramatic innovation in agriculture freed resources that allowed for the growth of the others sectors: first manufacturing, then services.

- Still continuing...
  - Focus on Hybrid Corn – could not sustain 6+ billion people without it!
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Innovation and Diffusion in Agriculture

Chart 2-20 Employment and Real Output in Agriculture
Agricultural employment declined dramatically from 1940 to 1970, while real agricultural output increased substantially.

Sources: Department of Commerce (Bureau of the Census and Bureau of Economic Analysis) and Council of Economic Advisers.
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Innovation and Diffusion in Agriculture

Chart 2-21 Agricultural Productivity
Agricultural productivity on farms surged in the mid-20th century

Index, 1996=100

Sources: Department of Commerce (Bureau of the Census) and Council of Economic Advisers.
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What is hybrid corn?

- In the 1920-30’s corn breeders in the USA developed a practical way to make hybrid corn. Farmers could take advantage of the benefits of inbreeding followed by directed cross breeding of corn inbred lines that resulted in an increase in vigor and yield of the hybrid offspring.

- The technology was introduced even though corn breeders and other scientists did not (and still don't) understand the genetic principles of hybrid vigor, one of the major reasons for increased yield of hybrid corn.
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Hybrid Seed (from Wikipedia)

In agriculture and gardening, hybrid seed is seed produced by artificially cross-pollinated plants. Hybrids are bred to improve the characteristics of the resulting plants, such as better yield, greater uniformity, improved color, disease resistance, and so forth. Today, hybrid seed is predominant in agriculture and home gardening, and is one of the main contributing factors to the dramatic rise in agricultural output during the last half of the 20th century. In the US, the commercial market was launched in the 1920s, with the first hybrid corn. Hybrid seed cannot be saved, as the seed from the first generation of hybrid plants does not reliably produce true copies, therefore, new seed must be purchased for each planting.
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Hybrid Seed (from Wikipedia)

- The introduction of hybrids also allowed, for the first time, a cost effective protection of intellectual property in corn breeding. Farmers buying the seed could not maintain or recreate the hybrid themselves and thus needed to buy seed from the seed corn companies each year if they wanted to maintain the yield advantage the corn hybrids provided.

- “Seed corn companies" soon were responsible for virtually all of the sales of hybrid corn in the USA. The farmers in the Corn Belt readily adopted this new technology and the majority of the acreage was planted to corn hybrids in just a few years. Corn yields immediately started to rise and are still rising, due in large part to annual improvements in hybrid genetics.
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Hybrid Seed (from Wikipedia)

- Hybrid corn was and is a huge scientific and commercial success. There were, however, unforeseen consequences of this technology. Existing open-pollinated varieties throughout the Corn Belt quickly disappeared and consequently uniformity in the cornfields greatly increased.

- This increased the potential for genetic vulnerability as was demonstrated by the outbreak of Southern Corn Leaf Blight Race T, a fungal disease, in 1970. It was virulent to most hybrid cultivars at the time because of the genetic uniformity. The yield losses in the southern and central parts of the Corn Belt were disastrous.
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Apomixis: the new frontier

- For more than 50 years, one of the most cherished dreams of plant breeders has been to find a way to transform corn and other cereal grains into super-plants able to reproduce by themselves without losing hybrid vigor, desirable agronomic traits, or useful disease- or insect-resistance. The term for this type of vegetative miracle is "apomixis."

- Apomixis is an asexual type of reproduction in which the plant embryos grow from egg cells without being fertilized by pollen--the male part of the plant.
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Apomixis: the new frontier

“This year [1998], Agricultural Research Service scientists took a giant leap toward realizing their dream. They obtained the first patent on an apomictic plant--Patent No. 5,710,367, "Apomictic Maize"--from the U.S. Patent and Trademark Office. Their next goal: to pinpoint and patent the specific gene or genes responsible for this trait in corn.”
Apomictic maize/Tripsacum hybrids having a ratio of maize chromosomes: Tripsacum chromosomes of at least 30:9 have been developed. These hybrids are useful for introgressing diplosporous apomictic reproduction into a maize background toward the ultimate goal of establishing immortalized commercial lines of apomictic maize having stably inherited characteristics without the need for continuously producing hybrid seed by repeated crossings of selected parental lines. DNA primers for use in assaying maize/Tripsacum hybrids for apomictic reproduction behavior are provided.

Inventors: Kindiger; Bryan K. (Woodward, OK); Sokolov; Victor (Novosibirsk, RU)

Assignee: The United States of America as represented by the Secretary of (Washington, DC)

Appl. No.: 532904 Filed: September 22, 1995

Current U.S. Class: 800/266; 47/DIG1; 536/24.3; 800/269; 800/275; 800/320.1
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Zvi Griliches’ Hybrid Corn Paper

HYBRID CORN: AN EXPLORATION IN THE ECONOMICS OF TECHNOLOGICAL CHANGE

BY ZVI GRILICHES

(see Figure 1). Hybrid corn was the invention of a method of inventing, a method of breeding superior corn for specific localities. It was not a single invention immediately adaptable everywhere. The actual breeding of adaptable hybrids had to be done separately for each area. Hence, besides the differences in the
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Hybrid corn across states
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The simple logistic diffusion model

\[ P(t) = \frac{K}{1+e^{-(a+bt)}}, \quad K \leq 1 \]

\[ K - P(t) = K \frac{e^{-(a+bt)}}{1+e^{-(a+bt)}} \]

\[ \log \left[ \frac{P(t)}{K-P(t)} \right] = a + bt \]

Griliches estimated it for every state, then explained differences in parameters \( a, b \) across states.
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The diffusion parameters and what accounts for them

- Time is measured from 1940 (e.g. 1936: –4).

- “Origin”: time elapsed till 10% adopted – computed as (-2.2-a)/b

- Parameter a: related to the lag in the development of adaptable hybrids for particular areas and in the entry of seed producers into those areas.
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The diffusion parameters and what accounts for them

- Differences across regions in $a$ explained as function of market density, innovation and marketing costs.

- Differences in parameter $b$ (speed of adoption) and $K$ (ceiling) across regions: explained by differences in the profitability of shift from open pollinated to hybrid varieties.
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Findings

- It is possible to account for a large share of the spatial and chronological differences in the use of hybrid corn with the help of "economic" variables.

- The lag in the development of adaptable hybrids for particular areas and the lag in the entry of seed producers into these areas can be explained on the basis of varying profitability of entry.

- Also, differences in both the long-run equilibrium use of hybrids and in the rate of approach to that equilibrium level are explainable, at least in part, by differences in the profitability of the shift from open pollinated to hybrid varieties.
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Findings

- Given a limited set of resources, the hybrid seed industry expanded according to a pattern which made sense, allocating its resources first to the areas of highest returns.
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The diffusion parameters and what accounts for them

- Differences across regions explained as function of market density, innovation and marketing costs.

- Differences in parameter b (speed of adoption) and K (ceiling) across regions: explained by differences in the profitability of shift from open pollinated to hybrid varieties.
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Welfare effects of process innovation

\[ V_s = \frac{\pi_t}{r} \]

Griliches: social return from hybrid corn - 700%
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Other diffusion models

- Start from heterogeneity of users/adopters in relevant dimensions (related to benefits / cost of adoption), postulate distribution, dynamic process that e.g. reduces costs over time, hence sweeping increasing portions of the distribution.

- This can feed back because of demonstration effects, etc.
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1.1 Science, invention and innovation
Gort and Klepper (1982)

- Surveyed 46 innovations
- Study adoption/imitation of these innovations
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1.1 Science, invention and innovation

Gort and Klepper (1982)

Figure 2. New Products and Number of Producers

Source: Gort and Klepper (1982), based on a sample of 46 product innovations.
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1.1 Science, invention and innovation

Gort and Klepper (1982)

... there is no equilibrium number of firms in an industry”; “... [the] ultimate number of producers and the number at each preceding point in time depends upon the sequence of events to that point”; “... technical change (innovations) plays a critical role in determining both entry rates and the eventual number of firms in the market”; “... the number of firms in product markets technologically adjacent to those of a new product—that is, the number of potential entrants—influence the entry rates”; “... the onset of Stage III [flattening net entry rates] and the ensu-
1. The Arrival of Innovation
1.1 Science, invention and innovation
Gort and Klepper (1982)

...ing net exit in Stage IV is not associated with the maturity of the market as measured by market size or the growth rate in demand”; “rather it corresponds to a decrease in the rate of innovations external to the industry, a compression of profit rates, and the accumulation of valuable experience by incumbent producers” (p. 634). Of course, there is no gen-
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Trajtenberg’s paper - framework

The “magnitude” of product innovation between two periods: the increment in consumer surplus associated with having the latest choice set \( (S_t) \) rather the previous one \( (S_{t-1}) \):

\[
S_t = (s_{1t}, s_{2t}, \ldots, s_{nt}), \quad s_{it} = \{p_{it}, z_{it}\}
\]

\[
\Delta W = W(S_t) - W(S_{t-1})
\]

If just one product \( x \) and one quality dimension \( z \),

\[
\Delta W = \int_{p}^{\infty} [x(v, z_t) - x(v, z_{t-1})] \, dv
\]

i.e. additional area under demand function, brought about by \( \Delta z \).
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Trajtenberg’s paper – MNL and surplus function

\[ V_i^c = V(z_i, y - p_i) + \varepsilon_i \equiv v_i + \varepsilon_i \]

\[ \Rightarrow \pi_i = \frac{e^{v_i}}{\sum_{j}^{n} e^{v_j}} \]

The surplus function (exponent: for linear utility):

\[ W(S) = \left[ \left( \ln \sum_{j=1}^{n} e^{-\alpha p_j 1 \phi(z_j)} \right) / \alpha \right] + y \]
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Trajtenberg’s paper – MNL and surplus function

- Estimate MNL for differentiated products in the market. Issues: IIA, and:

- Serious problem: endogeneity of price, i.e. price (positively) correlated with unobserved quality (which goes into the error term), hence upward bias in estimation of $\alpha$ – critical (see surplus function)!

- In study of CT Scanners, finding of upward slopping demand curve, for that reason; correction using residuals from hedonic price function. But later on whole literature on how to cope with the problem – BLP etc.
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Trajtenberg’s paper – CT scanners

- Key issue in Medicine: ability to visualize internal organs. X-rays (~1900), ultrasound (1950s), gamma camera (1960s). All of these: rather crude. Otherwise: cut open!

- Hounsfield began work on CT at EMI, in 1967. First installation: 1973. First only head, then also body scanners.

- Godfrey Hounsfield and Allan M. Cormack (Tufts University) got the Nobel Prize in Medicine in 1979.

- Since then: MRI, fMRI, PET, angio CT, etc.
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Trajtenberg’s paper – first generation CT scanners
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Trajtenberg’s paper – second generation CT scanners
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(c) Third-generation scanners

X-ray source

Detector array
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Trajtenberg’s paper – CT scanner characteristics

- CT Scanners: highly complex systems, yet main attributes:

  - Scan time: how long it takes to scan one thin cross-sectional “slice” (minutes at first, down to 1 sec)
  
  - Spatial Resolution – size of smallest object that can be just visualized in best of conditions (but there is more to image quality)
  
  - Reconstruction time: from end of scan to image display
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Trajtenberg’s paper – CT scanner characteristics

Figure 2.2 Diffusion of CT Scanners by Hospital Size (number of beds)
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Trajtenberg’s paper – CT scanner characteristics

<table>
<thead>
<tr>
<th>Year</th>
<th># of firms</th>
<th>Net entry*</th>
<th>Herfindahl index</th>
<th># of modelsb</th>
<th># of new modelsb</th>
<th>Herfindahl for patents c</th>
</tr>
</thead>
<tbody>
<tr>
<td>1973</td>
<td>1</td>
<td>1</td>
<td>1.00</td>
<td>1</td>
<td>1</td>
<td>1.00</td>
</tr>
<tr>
<td>1974</td>
<td>1</td>
<td>0</td>
<td>1.00</td>
<td>1</td>
<td>1</td>
<td>0.77</td>
</tr>
<tr>
<td>1975</td>
<td>5</td>
<td>4</td>
<td>0.42</td>
<td>5</td>
<td>4</td>
<td>0.21</td>
</tr>
<tr>
<td>1976</td>
<td>9</td>
<td>4</td>
<td>0.36</td>
<td>14</td>
<td>11</td>
<td>0.32</td>
</tr>
<tr>
<td>1977</td>
<td>13</td>
<td>4</td>
<td>0.22</td>
<td>23</td>
<td>14</td>
<td>0.22</td>
</tr>
<tr>
<td>1978</td>
<td>11</td>
<td>-2</td>
<td>0.27</td>
<td>23</td>
<td>6</td>
<td>0.15</td>
</tr>
<tr>
<td>1979</td>
<td>10</td>
<td>-1</td>
<td>0.22</td>
<td>22</td>
<td>5</td>
<td>0.15</td>
</tr>
<tr>
<td>1980</td>
<td>9</td>
<td>-1</td>
<td>0.26</td>
<td>17</td>
<td>2</td>
<td>0.29</td>
</tr>
<tr>
<td>1981</td>
<td>8</td>
<td>-1</td>
<td>0.25</td>
<td>14</td>
<td>3</td>
<td>0.27</td>
</tr>
<tr>
<td>1982</td>
<td>9</td>
<td>1</td>
<td>n.a.</td>
<td>16</td>
<td>8</td>
<td>0.37</td>
</tr>
</tbody>
</table>

*Number of entries minus number of exits.

bPhilips’s scanners are not included.

cIndex of concentration of patents by year of application.
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Trajtenberg’s paper – firms in CT

<table>
<thead>
<tr>
<th>Firm</th>
<th>Entry</th>
<th>Exit</th>
<th>Total units sold</th>
<th>Max. market share (year)</th>
<th>Patent in Cl</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMI</td>
<td>1973</td>
<td>1980</td>
<td>596</td>
<td>100.0 (75)</td>
<td>123</td>
</tr>
<tr>
<td>Artronix</td>
<td>1975</td>
<td>1979</td>
<td>34</td>
<td>3.7 (76)</td>
<td>4</td>
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<tr>
<td>G.E.</td>
<td>1975</td>
<td>—</td>
<td>466</td>
<td>40.6 (81)</td>
<td>59</td>
</tr>
<tr>
<td>Pfizer</td>
<td>1975</td>
<td>1981</td>
<td>118</td>
<td>11.5 (75)</td>
<td>5</td>
</tr>
<tr>
<td>Technicare</td>
<td>1975</td>
<td>1986</td>
<td>534</td>
<td>39.0 (78)</td>
<td>16</td>
</tr>
<tr>
<td>AS&amp;E</td>
<td>1976</td>
<td>1978</td>
<td>13</td>
<td>2.9 (77)</td>
<td>5</td>
</tr>
<tr>
<td>Picker</td>
<td>1976</td>
<td>—</td>
<td>82</td>
<td>10.7 (80)</td>
<td>11</td>
</tr>
<tr>
<td>Syntex</td>
<td>1976</td>
<td>1978</td>
<td>51</td>
<td>5.9 (76)</td>
<td>5</td>
</tr>
<tr>
<td>Varian</td>
<td>1976</td>
<td>1978</td>
<td>15</td>
<td>2.1 (76)</td>
<td>7</td>
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<tr>
<td>Elscint</td>
<td>1977</td>
<td>—</td>
<td>56</td>
<td>8.5 (80)</td>
<td>3</td>
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<tr>
<td>Philips</td>
<td>1977</td>
<td>—</td>
<td>—</td>
<td>n.a.</td>
<td>50</td>
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<tr>
<td>Searle</td>
<td>1977</td>
<td>1978</td>
<td>6</td>
<td>1.3 (77)</td>
<td>1</td>
</tr>
<tr>
<td>Siemens</td>
<td>1977</td>
<td>—</td>
<td>54</td>
<td>14.6 (81)</td>
<td>51</td>
</tr>
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<td>CGK</td>
<td>1978</td>
<td>1979</td>
<td>1</td>
<td>0.3 (78)</td>
<td>6</td>
</tr>
<tr>
<td>Omnimedical</td>
<td>1978</td>
<td>—</td>
<td>45</td>
<td>7.1 (80)</td>
<td>0</td>
</tr>
<tr>
<td>Toshiba</td>
<td>1979</td>
<td>—</td>
<td>7</td>
<td>3.3 (81)</td>
<td>18</td>
</tr>
<tr>
<td>Interad</td>
<td>1982</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0</td>
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<tr>
<td>Imatron</td>
<td>1984</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>4</td>
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</table>
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Trajtenberg’s paper – prices and characteristics

<table>
<thead>
<tr>
<th>Year</th>
<th>Price ($ thousand)</th>
<th>Speed (seconds)</th>
<th>Resolution (millimeters)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Head</td>
<td>Body</td>
<td>Head</td>
</tr>
<tr>
<td>1973</td>
<td>310</td>
<td>—</td>
<td>300</td>
</tr>
<tr>
<td>1974</td>
<td>370</td>
<td>—</td>
<td>300</td>
</tr>
<tr>
<td>1975</td>
<td>379</td>
<td>365</td>
<td>285</td>
</tr>
<tr>
<td>1976</td>
<td>374</td>
<td>471</td>
<td>105</td>
</tr>
<tr>
<td>1977</td>
<td>354</td>
<td>573</td>
<td>95</td>
</tr>
<tr>
<td>1978</td>
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<td>620</td>
<td>96</td>
</tr>
<tr>
<td>1979</td>
<td>154</td>
<td>667</td>
<td>150</td>
</tr>
<tr>
<td>1980</td>
<td>154</td>
<td>739</td>
<td>115</td>
</tr>
<tr>
<td>1981</td>
<td>150</td>
<td>827</td>
<td>115</td>
</tr>
<tr>
<td>1982</td>
<td>150</td>
<td>850</td>
<td>115</td>
</tr>
</tbody>
</table>

*Weighted average of all scanners in the market (annual sales as weights).

Minimum scan time, simple average.

Spatial resolution, simple average.
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Trajtenberg’s paper – sales, firms, and R&D

<table>
<thead>
<tr>
<th>Year</th>
<th>Unit Sales</th>
<th>Body (Percentage of Sales)</th>
<th>Number of Firms</th>
<th>R &amp; D $^$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1973</td>
<td>16</td>
<td>0</td>
<td>1</td>
<td>1.0</td>
</tr>
<tr>
<td>1974</td>
<td>74</td>
<td>0</td>
<td>1</td>
<td>7.8</td>
</tr>
<tr>
<td>1975</td>
<td>221</td>
<td>.45</td>
<td>4</td>
<td>28.6</td>
</tr>
<tr>
<td>1976</td>
<td>374</td>
<td>.76</td>
<td>9</td>
<td>58.2</td>
</tr>
<tr>
<td>1977</td>
<td>385</td>
<td>.85</td>
<td>12</td>
<td>46.6</td>
</tr>
<tr>
<td>1978</td>
<td>248</td>
<td>.72</td>
<td>10</td>
<td>37.0</td>
</tr>
<tr>
<td>1979</td>
<td>273</td>
<td>.70</td>
<td>9</td>
<td>33.7</td>
</tr>
<tr>
<td>1980</td>
<td>270</td>
<td>.80</td>
<td>8</td>
<td>29.6</td>
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<td>1981</td>
<td>392</td>
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<td>1982</td>
<td>428</td>
<td>.94</td>
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<td>n.a.</td>
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</table>
1. The Arrival of Innovation

1.4 Technology adoption

Trajtenberg’s paper – framework cont’d

\[ S_t = (s_{1t}, s_{2t}, \ldots, s_{nt}), \quad s_{it} = \{p_{it}, z_{it}\} \]
\[ \Delta W = W(S_t) - W(S_{t-1}) \]
\[ W(S) = \left[ \left( \ln \sum_{j=1}^{n} e^{-\alpha p_j 1_{\phi(z_j)}} \right) / \alpha \right] + y \]

\[ \pi_i = \frac{e^{vi}}{\sum_{j} e^{v_j}} \]
1. The Arrival of Innovation

1.4 Technology adoption

Trajtenberg’s paper – estimates

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<td>SPEED</td>
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<td>RESOL</td>
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<td>-5.565</td>
<td>-7.756</td>
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<td>RTIME</td>
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<td>-.366</td>
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<td>(-2.2)</td>
<td>(-1.2)</td>
<td>(2.7)</td>
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<td>$\rho^2 = 1 - \frac{L(\mathbf{\beta}^*)}{L(\mathbf{\beta}^0)}$</td>
<td>.131</td>
<td>.116</td>
<td>.42</td>
<td>.455</td>
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<td>Corr($\pi^*$, $\pi$)</td>
<td>.99</td>
<td>.910</td>
<td>.993</td>
<td>.998</td>
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<td></td>
<td>(.0001)</td>
<td>(.012)</td>
<td>(.0001)</td>
<td>(.0016)</td>
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Number of scanners: 6, 6, 8, 4
Number of observations: 89, 56, 69, 80

NOTE.—Asymptotic t-values are in parentheses.
1. The Arrival of Innovation

1.4 Technology adoption

Trajtenberg’s paper – results, welfare gains

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1. Time profile of incremental gains (yearly figures and 3-year moving averages)
1. The Arrival of Innovation

1.4 Technology adoption

Trajtenberg’s paper – total gains and R&D

Social rate of return: 270%