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ZVI GRILICHES'S CONTRIBUTIONS TO THE ECONOMICS OF TECHNOLOGY AND GROWTH*

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Zvi Griliches's contributions to the economics of technology and growth are identified. Included is a discussion of his contributions on: the determinants of differences in speed of adoption of innovations; the use of patents to measure technology; the private and social returns to R&D; and spillover effects from R&D. Griliches's own evaluation of his research contribution is compared to the evaluation of others in the field, using as evidence citation counts of his works collected from the *Social Science Citation Index*. Griliches's most important contribution is his 1957 *Econometrica* hybrid corn paper that is a foundation of the economics of technological innovation. Remarkably, the trend in annual citations to the paper has continued to increase for over 40 years. Finally, we summarize Griliches's most recent views on the practice of economics and on the most important unanswered questions in the economics of technology and growth.

Keywords: Technology; R&D; Growth; Productivity; Patents; Griliches

JEL codes: O30 – Technological change, General; O47 – Measurement of economic growth; Aggregate productivity.

INTRODUCTION

With Griliches's passing on November 4, 1999, it is appropriate to honor his contributions by reviewing them. In part we are following Griliches's own example, because he often gave credit for important contributions to his teachers, his colleagues and his students. He believed that knowledge in science was cumulative and he did not want the discoveries of past economists to be lost. Griliches expressed this belief, not just in words, but also in action, most notably after Jacob Schmookler's untimely death. So that Schmookler's important patent data would remain readily available to a wide audience, Griliches (and his co-editor Hurwicz) invested considerable time and care editing the final volume of Schmookler's work.[1]

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[1] Rosenberg (1974) and others saluted him for this effort.

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The cumulative character of scientific progress was still on Griliches's mind during one of his final presentations, when he suggested that the next generation of researchers should not despair at what remains to be done:

> There is still a long way to go, but the previous generation has provided them with good shoulders on which to stand. (Griliches 2001, p. 612)

If Griliches is right to emphasize the cumulative nature of science, then summarizing his contributions turns out to be no mere exercise in hagiography. Because he dealt with issues crucial to the continued growth of the economy, reminding ourselves of what he learned, and how he learned it, may prove beneficial to the effort toward continued progress in this field.

In the pages that follow, we focus on Griliches's contribution through his publications. But we should note that a fuller account of his contributions would also emphasize two other aspects of his total contribution to economic knowledge. One of these consists of his considerable efforts to construct and improve important databases on patents and other measures of R&D. Another major area of contribution consists of the students, co- authors, and colleagues who he influenced over the years, in terms of methods, values, and research questions. This contribution is most obviously seen in his students, but he also influenced a much broader group of scholars through his extensive comments at the National Bureau of Economic Research (NBER) productivity conferences that he organized and participated in, as well as in a host of other conferences, and venues.

GRILICHES'S CONTRIBUTION

Many trace the founding of the Economics of Technology to the work of Joseph Schumpeter.[2] But the field achieved prominence, definition and depth with the work of a more recent generation of "founding fathers." Who to identify in this way might be a matter of discussion, but on anyone's short list would be Zvi Griliches. Although the profession probably focuses too much on the Nobel Prize as a validation for an economist's career, it may be worth noting that while he lived, many predicted he would receive the award, and now that he is no longer with us, many still believe he should have received it.[3]

[2]Mansfield credits Schumpeter with founding the field (1995, I, p. ix) Rosenberg has gone so far as to say: " . . . the study of technological innovation . . . still consists of a series of footnotes upon Schumpeter." (Rosenberg, 1982, p. 106) Griliches (R&D, . . . , 2000, p. 45) lists Schumpeter with four other "major" early economists who recognized the importance of technological innovation.

[3]Warsh (1994) suggested that Griliches and Jorgenson might receive the Nobel together. Gary Becker was quoted (in Warsh 1999) as saying: "He was a serious contender for a Nobel Prize. I was hoping, on sentimental grounds, that he might get it this year." A 1996 *Wall Street Journal* article that polled 39 "top economists" concluded that Griliches was one of five leading contenders for the Prize (Phillips). In his 1990 predictions, Garfield found that Griliches ranked 23rd in lifetime citations. Of the 22 economists ranked ahead of him in citations, 11 had already received the Nobel Prize, and two had deceased without receiving it (Keynes and Robinson). Of the remaining nine economists ranked above Griliches three received the Nobel Prize since 1990 (Becker, Lucas and Sen). Milton Friedman has worried whether the Nobel Prize is good for the progress of economics: " . . . is it desirable in any discipline that a few scholars who have made their mark in that discipline should have the power to decide the kind of work that is prestigious, on which other scholars ought to concentrate if they want their work to be recognized as important? Is it desirable to have that much centralization of power effectively directing the course of research in basic fields?" (Friedman and Friedman, p. 443).

Griliches made important contributions in many areas of economics, most notably labor economics, econometrics and the economics of technology and growth. He has been called the fox who knows many things in contrast to Dale Jorgenson's hedgehog, who knows one big thing.[4] But Griliches too had his "hedgehog" side: although at first glance working in several areas, much of Griliches's work arose from his attempts to answer one or two "important questions," that he asked early, and returned to often. In particular, much of his work in labor economics, econometrics, and the economics of technology, was tied to the question: what does the evidence tell us are the important determinants of economic growth and productivity?[5]

Nerlove suggests that instead of being remembered as a pure econometric theorist, Griliches should be remembered as "... an empirical economist in the best sense, perhaps the best his generation of economists produced." (p. F424) Levin (1986), in placing Griliches among the four founding giants of the economics of technology, identifies his comparative advantage as being respect for the data, and systematic analysis of it.[6] Griliches himself, in a 1999 interview, suggests that he developed econometric techniques to solve important empirical issues, as opposed to developing a technique and then looking around for an application. (in Krueger and Taylor, p. 178)

In the interview, Griliches argues that the fundamental topic of most of his research involves trying to explain the "residual": what of economic productivity growth is left to explain after the standard variables are properly measured. He began work on this issue in the later 1950's and says that: "One can think of almost everything that I've done since as trying to fill in pieces of this larger puzzle." (in Krueger and Taylor, p. 182.)

In this paper, the main aim will be to discuss Griliches's most important contributions to the economics of technology and growth. In judging "importance" we will make use of Griliches's own judgments about what was important in his work, the judgments of other distinguished scholars in the field and the judgments implied by citation counts of Griliches's publications.

One of the key sources of Griliches's own revealed judgments of what is most important in his work consists of what he chose to include in the three collections of his articles: 15 articles in *Technology*, *Education*, and *Productivity* [**TEP**]. 1988; 13 articles in *R&D* and *Productivity*: *the Econometric Evidence* [**RDP**], 1998; and 26 articles in *Practicing Econometrics* [**PE**], 1998.[7] Other important sources include his final book, R&D, *Education and Productivity*: *A Retrospective*, and his interview with Krueger and Taylor.

Evidence of the profession's judgment of Griliches's contributions takes several forms. The most direct are essays aiming mainly to summarize and access Griliches's work. One of the most useful to appear so far is Nerlove's recently published (2001) appreciation and professional assessment. Fraumeni (2000), Mairesse (2003), and Pakes (2000) also provide briefer, and less-critical, evaluations of Griliches's contributions.

[4]Berlin quotes the Greek poet Archilochus as saying: 'The fox knows many things, but the hedgehog knows one big thing'. Berlin applies this to intellectuals by contrasting the hedgehogs who "..., who relate everything to a single central vision, ..." and the foxes "...who pursue many ends, often unrelated and even contradictory, connected, if at all, only in some *de facto* way ..." This contrast was applied to Jorgenson and Griliches by Warsh (1994). Griliches provides some support for the view that he was a "fox" in his *JEP* interview, when he notes that early on he was strongly influenced by a Popperian professor at Hebrew University (Krueger and Taylor, p. 175) where "Popperian" is used in the broad sense of skepticism toward uncritical ideology, as opposed to "Popperian" in the sense of Popper's specific methodology of science, as taken up, say, in Friedman's famous article (1953).

[5]Nerlove identifies the "central core of his contribution" as being "... a fuller and more quantitative understanding of the process of economic growth." (p. F424).

[6]Levin identifies the other three founding giants as being Mansfield, Nelson, and Scherer.

[7]Besides the three compilations of his own articles, the rest of the books he edited were mainly collections of articles by other economists. One exception is the volume of Schmookler's patent work that Griliches co-edited with Hurwicz. A second exception is the volume with Ringstad on *Economies of Scale and the Form of the Production Function*. This book analyzes a Norwegian data set, finding that in general there were small increasing returns to Norwegian manufacturing.

Citations to Griliches's publications may provide an additional, broader, and perhaps more objective measure of professional attention that is likely to be correlated with the scientific importance of various parts of Griliches's life opus. Rankings based on citations can only be viewed as rough measures of relative importance to the profession for a variety of well-known reasons that do not need to be fully rehearsed here. The interpretation, and limitations, of citations have been discussed in a variety of settings (see, *e.g.*, Nederoff's review, passim). One limitation arises because the comparison of citations received during different periods of time, assumes that there is a sufficient degree of stationarity in the process that generates citations. The assumption might not be fully justified for a variety of reasons. One is that Griliches's general growth in reputation might make it more likely for an article later in his career to be more highly cited than an equal-quality article that had been published before his reputation was established (see: David 1994). However the fact that Griliches established his reputation early in his career (he received the Clark Medal in 1965) may reduce the seriousness of concerns about the stationarity of the citation generating process.

With appropriate qualifications and caveats, citations often have been found to be a useful measure of academic productivity, proving, for example, to be a robust and important determinant of academic salaries, when estimated in a variety of econometric specifications (see, *e.g.*, Diamond, 1986). Levin and Stephan express (p. 63) the consensus view that "heavily cited articles are generally better and have made a more significant contribution to science than have less heavily cited articles." Griliches himself believed that citations were a useful measure of academic productivity and intellectual influence. In his note on ranking journals with Einav, the co-authors suggest (p. 233) that citations " . . . represent a reasonable measure of scientific output; . . . " Similarly, in one of his articles with Adams, the co-authors state that: "Citations are themselves an uncertain metric of the impact of an article, *though they are the best measure that we have*." (Adams and Griliches, 1998, p. 129, italics added)

Our source for citations is primarily the "Web of Science" database published by the Institute for Scientific Information (ISI), incorporating citations in the sciences, social sciences, arts, and humanities. The online Web of Science was occasionally supplemented with the *Social Science Citation Index* (*SSCI*), which is the book version of the part of the ISI database most relevant to Griliches's work. For the present research, the primary advantage of the Web of Science version of the database is that it has been extended back through 1956 for the social sciences, in contrast to the 1966 starting date for the *SSCI*. Citation counts were available through the year 2001, and part of the year 2002.

Griliches's total publications, including books, articles, notes, comments, reviews, and congressional testimony, total approximately 221. Of these 110 were identified as having received at least one citation over the period from date of publication through August 2002. Table I classifies these 110 publications by period of publication, and by whether they deal mainly with technology, or mainly with some other field of economics (mainly econometrics or labor). Table II lists the number of citations for 110 articles and notes of

TABLE I Time-path of Griliches Articles.*

	Year range of publication					
	57–59	*60–69*	*70–79*	*80–89*	*90–99*	*2000*
Technology articles	3	16	6	16	21	2
Nontechnology articles	4	15	10	10	7	0
Total	7	31	16	26	29	2

*The articles classified are from the set of those cited articles listed in Table II.

TABLE II Citation Ranking of Griliches Articles.*

Tec 10 yr rnk	*Tec tot rnk*	*All 10 yr rnk*	*All tot rnk*	*Cmp*	*"Article title abbrev." journal abbrev. (co-authors, if any)*	*Yr*	*10 yr cites*	*Total cites*
1	7	1	8		"Changes in the Demand for Skilled Labor within U.S. . . ." *QJE* (Berman, Bound)	94	226.8	202.3
–	–	2	2	PE	"Distributed Lags: A Survey." *Econometrica*	67	214.0	416.0
2	5	3	6	RDP	"Patent Statistics as Economic Indicators: A Survey." *JEL*	90	183.0	250.7
3	9	4	14	RDP	"The Search for R&D Spillovers." *Scandinavian J Econ*	92	141.9	141.9
–	–	5	10	TEP	"Education, Income, and Ability." *JPE* (Mason)	72	115.0	185.2
4	3	6	4		"Econometric Models for Count Data & with Ap . . ." Econometrica (Hausman, Hall)	84	109.0	299.2
5	12	7	20	RDP	"Productivity. R&D and the Data Constraint." *AER*	94	106.2	102.3
6	2	8	3	TEP	"The Explanation of Productivity Change." *REStud* (Jorgenson)	67	106.0	375.9
7	28	9	44		"R&D & Productivity: Econometric Res. & Meas. issues." In *Hdb Ec Innov & T.C.*	95	83.2	38.0
8	4	10	5	RDP	"Issues in Assessing the Contribution of R&D to Productivity Growth." *Bell J Econ*	79	70.0	252.0
9	10	11	17	PE	"Production Funct. in Manuf.: Some Prel. Res." *Theory & Empir. Analysis of Prod.*	67	70.0	116.0
–	–	12	13	PE	"Errors in Variables in Panel Data." *J Econometrics* (Hausman)	86	69.0	143.5
–	–	13	9	PE	"Estimating the Returns to Schooling: Some Econometric Probl." *Econometrica*	77	62.0	200.5

TABLE II *(Continued).*

Tec 10 yr rnk	*Tec tot rnk*	*All 10 yr rnk*	*All tot rnk*	*Cmp*	*"Article title abbrev." journal abbrev. (co-authors, if any)*	*Yr*	*10 yr cites*	*Total cites*
10	15	14	23	RDP	"Productivity, R&D, and Basic Research at the Firm Level in the 1970s." *AER*	86	58.0	93.8
11	17	15	25		"Productivity Puzzles and R&D: Another Nonexplanation." *J Econ Pers*	88	57.0	75.6
12	8	16	11	TEP	"Research Expenditures, Education, & the Aggregate Agricul. Prod. Funct." *AER*	64	56.0	164.0
13	16	17	24	TEP	"Notes on the Role of Educ. In Prod. Funct . . ." *Educ, Inc. and Hum Cap, Stud Inc*	70	53.0	80.0
14	34	18	51		"Econometric Est. of Price Ind. for P.C.s . . ." *J Econometrics* (Berndt, Rappaport)	95	48.6	31.2
–	–	19	16	PE	"A Note on Serial Correlation Bias in Estimates of Distributed Lags." *Econometrica*	61	48.0	118.0
–	–	20	15	PE	"Sibling Models and Data in Economics: Beginnings of a Survey." *JPE*	79	42.0	133.8
15	33	21	50		"Generics and New Goods in Pharmaceutical Price Indexes." *AER* (Cockbum)	94	38.6	31.6
16	13	22	21	TEP	"The Sources of Measured Productivity Growth: U.S. Agricul., 1940–1960." *JPE*	63	38.0	97.2
17	21	23	32	RDP	"Returns to Res. & Dev. Expen. in the Priv. Sec." *New Dev in Prod Meas, Stud in*	80	37.0	53.0
18	1	24	1	TEP	"Hybrid Corn: An Exploration in the Econ. of Techno. Change." *Econometrica*	57	35.0	548.8

19	6	25	7	TEP	"Research Cost and Social Returns: Hybrid Com and Related Innovations." *JPE*	58	33.0	225.6
–	–	26	28	PE	"Errors in Variables and Other Unobservables." *Econometrica*	74	32.0	61.6
20	20	27	30		"R&D and the Productivity Slowdown." *AER Papers*	80	32.0	54.2
–	–	28	31	PE	"Missing Data & Self-Sel. in Large Panels." *Annales do L'INSEE* (Hall, Hausman)	78	32.0	53.6
–	–	29	39	PE	"Wages of Very Young Men." *JPE*	76	32.0	43.0
21	36	30	54		"Price Indexes for Microcomputers: An Exploratory Study." *Price Meas.* (Berndt)	93	29.6	28.0
–	–	31	19	PE	"Specification Bias in Estimates of Production Functions." *J Farm Econ*	57	29.0	104.6
22	22	32	33	PE	"Cost Allocation in Railroad Regulation." *Bell J Econ*	72	29.0	53.0
23	11	33	18	TEP	"Capital-Skill Complementarity." *REStat*	69	28.0	112.4
–	–	34	37		"More on Brothers." *Kinometrics* (Chamberlain)	77	26.0	44.0
24	18	35	27		"Patents and R&D: Is There a Lag?" *IER* (Hall, Hausman)	86	24.0	63.5
–	–	36	52	PE	"The Determinants of Investment Revisited." *IER* (Wallace)	65	24.0	30.0
–	–	37	34	PE	"Unobservables with a Var.-Comp. Struct.: Abil. . . . Brothers." *IER* (Chamberlain)	75	22.0	53.0
25	19	38	29		"The Demand for Fertilizer: An Econometric Interp. of a Technic. . . ." *J Farm Econ*	58	21.0	58.0
26	29	39	45	TEP	"Research Expenditures and Growth Accounting." *Sci & Tech in Econ Growth*	73	20.0	36.0
27	32	40	48		"Industry Effects & Appropria. Measures in the Stock Market's . . ." *AER* (Cockbum)	88	20.0	33.8

TABLE II *(Continued).*

Tec 10 yr rnk	*Tec tot rnk*	*All 10 yr rnk*	*All tot rnk*	*Cmp*	*"Article title abbrev." journal abbrev. (co-authors, if any)*	*Yr*	*10 yr cites*	*Total cites*
28	23	41	35		"Estimates of the Aggr. Agric. Prod. Func. from Cross-Sec. Data." *J Farm Econ*	63	19.0	44.6
29	44	42	76		"Firm Productivity In Israeli Industry: 1979–1988." *J of Econometrics* (Regev)	95	18.8	13.6
–		43	26		"Small-Sam. Prop. of Sev. Two-Stage Reg. Meth. . . . of Auto-C . . . " *JASA* (Rao)	69	18.0	71.0
30	25	44	41	RDP	"Interindustry Technology Flows & Productivity Growth: . . . " *REStat* (Lichtenberg)	84	18.0	42.2
31	38	45	57	PE	"Automobile Prices & Quality: Did the Gas. Price Incre. . . . ?" *J Bus Ec Stat* (Ohta)	86	18.0	26.2
–	–	46	73		"Auditing the Producer Price-Index—Microevid. . . . " *J Bus Ec Stat* (Bemdt, Rosett)	93	17.0	15.6
–	–	47	12	PE	"Is Aggregation Necessarily Bad?" *REStat* (Grunfeld)	60	16.0	151.6
–	–	48	36		"Specification Error in Probit Models." *REStat* (Yatchew)	85	16.0	44.2
32	30	49	46		"Patents and R&D at the Firm Level: A First Report." *Econ Letters* (Pakes)	80	15.0	35.2
–		50	64		"Errors of Measurement in Output Deflators." *J Bus Ec Stat* (Lichtenberg)	89	15.0	21.2
33	14	51	22	TEP	"Hedonic Price Indexes for Auto.: An Econometric Anal. of Qual. Change." *NBER*	61	14.0	95.8

–		52	49		"Notes on Est. Agg. Qua. Cons. Func." *Econometrica* (Maddala, Lucas, Wallace)	62	14.0	33.0
34	40	53	60		"The Value of Patents as Indic. of Inve. . . ." *Economic Pol. & Techn.* (Pakes, Hall)	87	13.0	23.2
35	31	54	47		"Market Value, R&D, and Patents." *Econ Letters*	81	12.0	34.2
36	35	55	53	TEP	"issues in Growth Acc.: Rep. to Denison" & "Final . . ." *Sur Cur Bus* (Jorgenson)	72	12.0	30.0
–	–	56	55		"On an Index of Quality Change." *JASA* (Adelman)	61	12.0	28.0
–	–	57	66	PE	"Distrib. Lags, Disaggreg., & Regional Demand Funct. for Fertilizer." *J Farm Econ*	59	12.0	19.0
–	–	58	67	PE	"Wages, Schooling & IQ of Brothers & Sisters: Do the . . . ?" *IER* (Bound, Hall)	86	12.0	19.0
37	37	59	56		"Sources of Measured Productivity Change: Capital Input." *AER* (Jorgenson)	66	11.0	28.0
–	–	60	62		"Notes on the Measure. of Price & Quality Changes." *Models Income NBER*	64	11.0	22.0
38	41	61	70	RDP	"Comparing Product. Growth—Expl. of French & U.S. . . ." *Eur Ec Rev* (Mairesse)	83	11.0	17.0
39	43	62	72		"Patents—Recent Trends and Puzzles." *Brook Papers*	89	11.0	16.6
40	51	63	89		"Aggregate Price Indexes, New Goods, and Generics." *QJE* (Fisher)	95	10.4	8.0
41	26	64	42	TEP	"Measuring Inputs in Agriculture: A Critical Survey." *J Farm Econ*	60	10.0	42.0
42	39	65	58	TEP	"Capital Stock in Inves. Funct.: Some Prob. . . . Meas.?" *Measure. in Econ., Studies*	63	10.0	25.0

TABLE II *(Continued).*

Tec 10 yr rnk	*Tec tot rnk*	*All 10 yr rnk*	*All tot rnk*	*Cmp*	*"Article title abbrev." journal abbrev. (co-authors, if any)*	*Yr*	*10 yr cites*	*Total cites*
–	–	66	74		"Brookings Model Volume—Review Article." *REStat*	68	10.0	15.0
–	–	67	68	PE	"Estimating Distr. Lags in Short Panels with an Applic. to the . . . " REStud (Pakes)	84	9.0	19.0
–	–	68	69		"Estimates of the Aggregate United States Farm Supply Function." *J Farm Econ*	60	9.0	18.0
–	–	69	78		"Household & Econ.—Toward a New Theory of Pop. & Econ. Grow.—Com." *JPE*	74	9.0	12.0
43	46	70	79		"R&D and Productivity: Measurement Issues and Econometric Results." *Science*	87	9.0	12.0
–	–	71	85		"Data and Econometricians—The Uneasy Alliance." *AER, Papers*	85	9.0	9.0
–	–	72	40		"The Demand for a Dur. Input: U.S. Farm Tractors, 1929–1957." *Dem Our Goods*	60	8.0	43.0
44	27	73	43		"The Costs of Automobile Model Changes Since 1949." *JPE* (Fisher, Kaysen)	62	8.0	42.0
–	–	74	59		"The Demand for Inputs in Agricult. & a Derived Supply Elasticity." *J Farm Econ*	59	8.0	24.0
45	49	75	83		"Production Functions in Manufacturing—Some Additional Results." *SEJ*	68	8.0	10.0
–	–	76	61		"Profitability Versus Interaction: Another False Dichotomy." *Rural Sociology*	62	7.0	23.0
46	47	77	81	PE	"Auto. Prices Revisited . . . Hedonic Hypoth." *House. Prod Cons, St Inc W* (Ohta)	76	5.0	11.0

–	–	78	93	PE	"Heterog. in Panel Data: . . . Stable Prod. Func.?" *Es. in Hon. of E. Mal.* (Mairesse)	89	5.0	6.6
47	59	79	99		"Product., Mark. Power, & Capac. Utiliz. When Spot Mark. Are Inc." *AER* (Eden)	93	4.2	4.0
–	–	80	63	PE	"Errors-in-the-Variables Bias in Nonlinear Contexts." *Econometrica* (Ringstad)	70	4.0	22.0
–	–	81	84	PE	"More on CES Production Functions." *REStat*	67	4.0	10.0
48	56	82	96		"The Costs of Auto. Model Cha. . . . " *AER* [abst. of *JPE* version] (Fisher, Kaysen)	62	4.0	6.0
49	57	83	97	RDP	"R&D & Productiv. Gr.: Com. Japan & U.S. . . . ." *In Prod Growth NBER* (Mairesse)	90	4.0	6.0
50	24	84	38		"Hybrid Com and the Economics of Innovation." *Science*	60	3.0	44.0
–	–	85	86		"Schooling Interrup., Work While in School & the Ret. from School." *Scand J Ec*	80	3.0	9.0
51	60	86	103		"Technological Change and Economic Theory: Discussion." *AER*	65	3.0	3.0
–	–	87	80	TEP	"Congruence Versus Profitability: A False Dichotomy." *Rural Sociology*	60	2.0	12.0
52	52	88	90		"Hybrid Com Revisited—A Reply." *Econometrica*	80	2.0	8.0
–	–	89	100		"Are Farmers Irrational?" *JPE*	60	2.0	4.0
–	–	90	101		"Samp. Sel. Bias & End. in the Est. of a Wage . . . " *Annales de L'INSEE* (Yatchew)	81	2.0	4.0
–	–	91	106		"Birth-Order, Schooling, and Earnings—Comment." *J Labor Econ*	86	2.0	2.0
53	62	92	107		"Sources of Agricul. Economic Growth and Productivity—Discus." *Am J Agric Ec*	92	2.0	2.0

TABLE II *(Continued).*

Tec 10 yr rnk	*Tec tot rnk*	*All 10 yr rnk*	*All tot rnk*	*Cmp*	*"Article title abbrev." journal abbrev. (co-authors, if any)*	*Yr*	*10 yr cites*	*Total cites*
54	63	93	109		"Hedonic Price Indexes for Pers. Comp.—.Intertem . . . " *Econ Letters* (Hamermesh)	94	1.9	1.0
55	64	94	110		"National-Science-Foundation Grants for Economics—Reply." *J Econ Pers*	94	1.6	1.0
56	54	95	92		"Inventing and Maximizing." *AER* (Schmookler)	63	1.0	7.0
–	–	96	102		"The Demand for Fertilizer in 1954—An Inter-State Study." *JASA*	59	1.0	4.0
*	–	*	65		"Cons. Prices, the C.P.I. . . . " *J Econ Pers* (Boskin, Dulberger, Gordon, Jorgenson)	98	*	20.6
*	42	*	71		"Do Subs. to Commer.: R&D Reduce Market Failures?. . . . " *Res Pol* (Klette, Moen)	00	*	16.9
*	–	*	75		"The CPI Commis.: Find. & Reco." *AER* (Boskin, Dulberger, Gordon, Jorgenson)	97	*	14.8
*	45	*	77		"The Discovery of the Residual: A Historical Note." *JEL*	96	*	13.0
*	48	*	82	PE	"Production Funct.: The Search for Identifi." *Econometrics & Ec Theo* (Mairesse)	98	*	10.0

*	–	*	87	"The Inconsisten. of Common Scale Est. When . . . " *J Appl Econometrics* (Klette)	96	*	8.2
*	50	*	88	"Characteristics of Dem. for Pharm. . . . " *Rand J Ec* (Ellison, Cockbum, Hausman)	97	*	8.0
*	53	*	91	"Quality Change and New Products." *AER* (Gordon, RJ)	97	*	7.0
*	55	*	94	"Pharm. Innov. & Market Dyn.: Track. Effe. . . . " *Brook Papers* (Berndt, Cockbum)	96	*	6.6
*	–	*	95	"Education, Human Capital, and Growth: A Personal Perspective." *J Labor Econ*	97	*	6.6
*	58	*	98	"Measuring Science: An Exploration." *Proc Nat Acad Sciences* (Adams)	96	*	5.6
*	–	*	104	"Presc. Drug Prl. for the Eld." *Mon Lab Rev* (Berndt, Cockbum, Cocks, Epstein)	98	*	2.0
*	61	*	105	"Emp. Patterns of Firm Growth & R&D Inv: A Quality Ladder . . . " *Econ J* (Klette)	00	*	2.0
*		*	108	"Ranking Economics Departments." *J Econ Pers* (Einav)	98	*	1.0

*Co-authors' last names are listed in parentheses at the end of the journal abbreviation. If a co-author's name is underlined, that co-author was the first-author of the article; otherwise, Griliches was the first-author. "Cmp" stands for "Compilation." The three compilations of previously published articles by Griliches are: *Technology, Education, and Productivity* [TEP], 1988; *R&D and Productivity: the Econometric Evidence* [RDP], 1998; *Practicing Econometrics* [PE], 1998. "10 year" was the actual 10 year count for articles published before 1992. For later articles, it was the estimated number of articles that the article will receive in the ten years after publication, based on the number received so far. The "10 yr rank" was based on the 10 year citation counts. In cases of ties in the "10 year" citation counts, the rank was based on the total citations. (Fractional citation counts sometimes result because full-year-2002 counts were estimated based on data through August.)

TABLE III Citation Ranking of Books Authored, Co-authored, or Edited by Griliches.*

10 yr	*Tot rnk*	*Book title*	*Yr*	*10 yr cites*	*Total cites*	*# Gril chs*
1	2	R&D, Patents, & Productivity, NBER	84	121	219	6 of 21
2	1	Price Indexes and Quality Change	71	107	255	2 or 8
3	4	Economics of Scale and the Form of the Production F.	71	82	98	All
4	3	Handbook of Econometrics, vols. 1–3	83	66	130	1 of 35
5	5	Output Measurement ... NBER Studies Income	92	34	34	1 of 14
6	6	Technology, Education, & Productivity [TEP]	88	17	21	All
7	8	Income Distribution & Economic Inequality	78	8	6	1 of 19
*	7	R&D and Productivity: Econometric Evidence [RDP]	98	*	9	All
*	9	Practicing Econometrics [PE]	98	*	5	All
*	10	R&D, Education and Productivity: A Retrospective	00	*	4	All

*Citation data in Table III were obtained from manual counts of the hard-copy version of the *SSCI* through the Jan.–Apr. 2002 installment.

Griliches that had received citations through August 2002. Table III lists citations to all of Griliches's monographs. Figure 1 reproduces the most famous graph, from Griliches's most-cited paper. Figure 2 shows the time path of total citations to the 110 publications in Table II. Figure 3 displays the time path of citations to each of the six most-highly cited pre-1971 Griliches articles. Figure 4 displays the time path of citations to each of the next six most highly cited pre-1971 Griliches articles. (Following the tables in the paper is an appendix that discusses some details of the citation counts in the paper.)

Since Griliches's older publications have had more years in which to accumulate citations than his more recent writings, citations were counted for a ten year period immediately

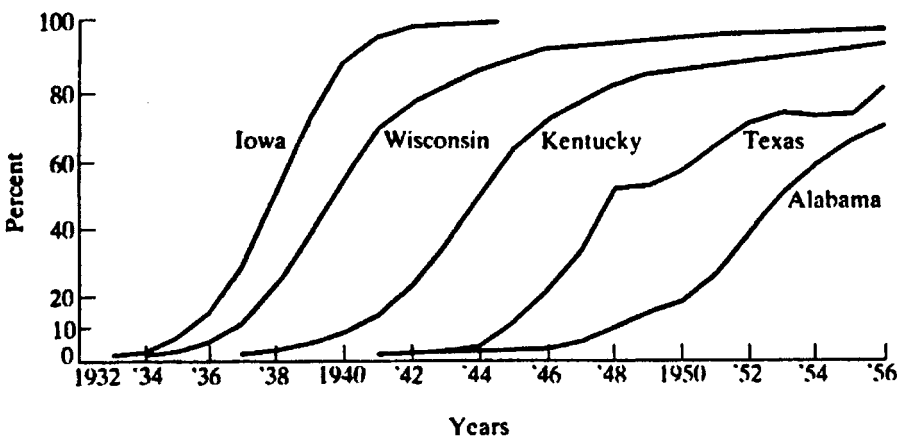

FIGURE 1 Percentage of total corn acreage planted with hybrid seed. (Source: USDA, agricultural statistics, various years.) {Reprinted from Griliches 1957, p. 28 in [**TEP**].}

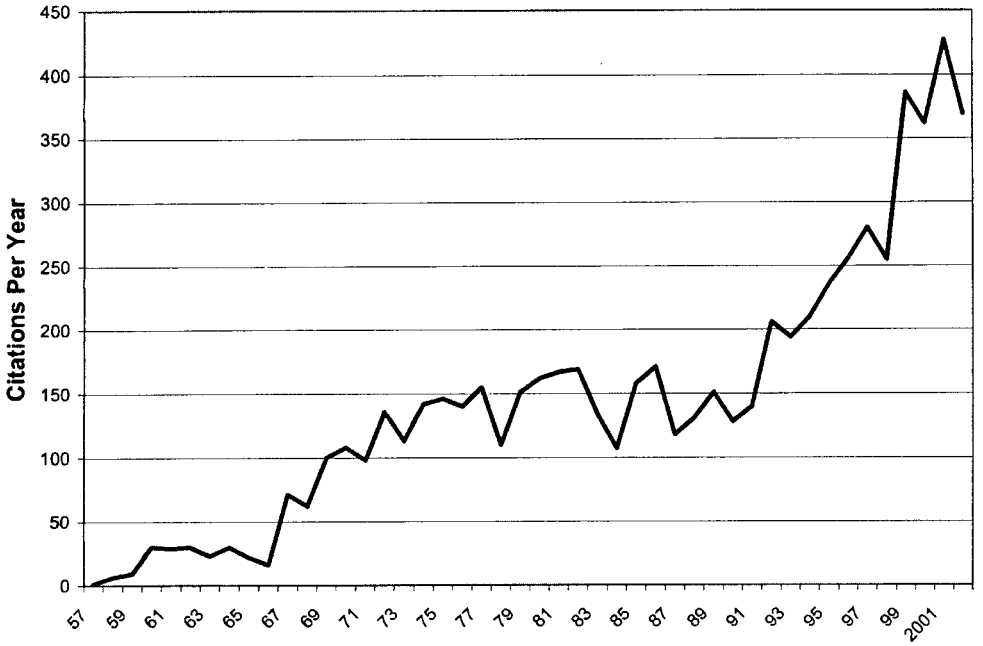

FIGURE 2 Total citations per year to all of Griliches articles listed in table II.

following the publication date of an article or monograph. This "10 year" citation count was used to rank publications in Tables II and III, although the "total" ranking is also presented.

We will begin by addressing a general issue: Griliches's self-assessment of his own work. From there we proceed to sketch some of his most important findings on economics of technology and growth. Finally, we conclude with Griliches's advice for future researchers.

GRILICHES'S SELF-ASSESSMENT OF HIS WORK COMPARED TO THE PROFESSION'S ASSESSMENT

Some influential economists (*e.g.*, Joan Robinson and Sir John Hicks) in later years prominently disputed the profession's assessment of what was most important and valuable in their life work. So it may be useful to note how much Griliches's assessment of his own work corresponds to the profession's.

The citation rankings in Tables II and III provide some important evidence of the profession's assessment. For Griliches's self-assessment, we may find evidence in which articles he chose to include in compilations later in life.

If we focus on the 96 articles ranked by 10-year citation counts in Table II, we can calculate that of the 48 most highly-cited on the list, Griliches reprinted about 65% in compilations, while of the 48 least highly-cited on the list, Griliches reprinted about 31%. Such evidence suggests that Griliches's own assessment of the significance of his own work was not greatly at odds with the profession's.

Of the 20 most-highly-cited Griliches articles listed in column three of Table II of this paper, all but five (col. 3, #s 1, 6, 9, 15, 18) were reprinted in one of Griliches's compilation volumes. Of these five, four (col. 3, #s 1, 6, 9, 18) were not first-authored by Griliches; and these four articles each had two co-authors in addition to Griliches. Regarding these articles,

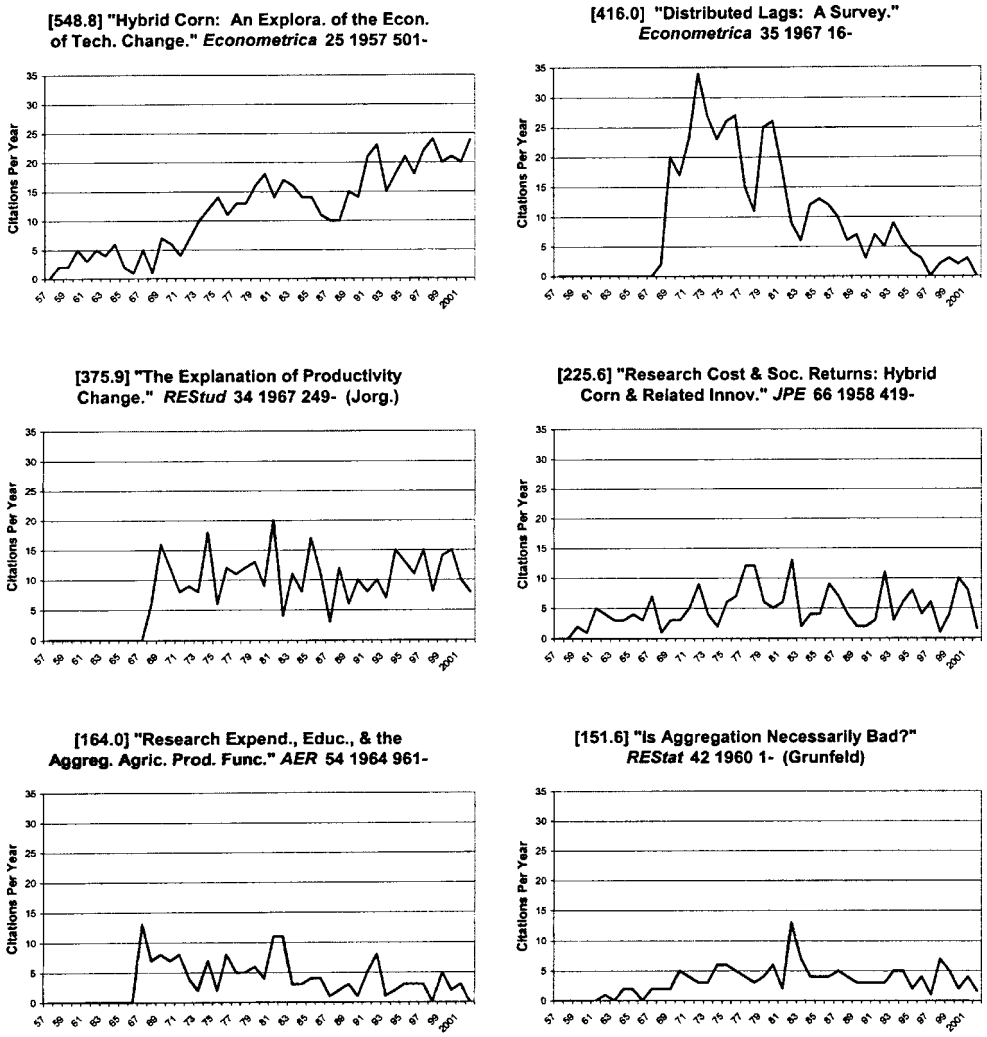

FIGURE 3 Six most-highly cited pre-1971 Griliches articles [total citations in brackets].

Griliches may have believed that the proportion of his contribution to the total article, was not large enough to justify including the article in his compilation volumes. In addition, of the five non-compiled articles, three (col. 3, #s 1, 3, 18) appeared as recently as the mid-1990's and so, unlike articles from decades earlier, would not need reprinting to keep them accessible. Not in either of these groups is (col. 3, #15), "Productivity Puzzles and R&D: Another Nonexplanation," which was published in 1988. One explanation for not reprinting this article is that Griliches believed that most of the issues it treated were dealt with later, and better, in other papers, such as his AEA presidential address (col. 3, #7), which he *did* include in **RDP**.

The highest ranked (col. 3, #1) article not included in a compilation is the *QJE* article co-authored with Berman and Bound on changes in demand for skilled labor, in which the authors find that the increase in demand for skilled labor is due to labor-saving technology rather than due to an increase in free-trade. Most notably they find that the increase is highly

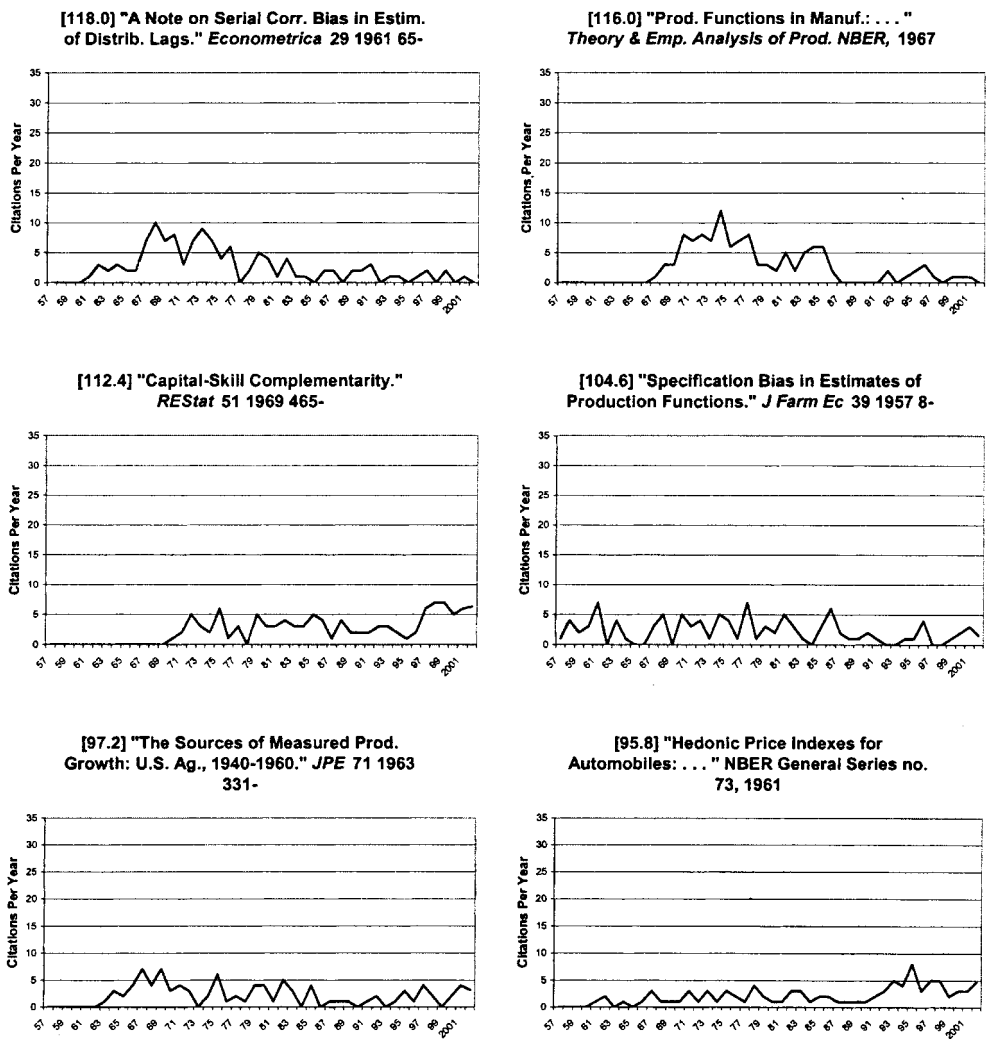

FIGURE 4 Next six most-highly cited pre-1971 Griliches articles [total citations in brackets].

correlated with computer and R&D investment. Griliches mentions this paper briefly in *Retrospective* (p. 40). The direct reference to it is for evidence of the weakness of the capital accumulation account of the increase in the education premium. Immediately following this reference, he briefly discusses attempts to defend the alternative "technical-skill hypothesis" which he describes as asserting " . . . that education becomes more valuable in periods of rapid technological change, and that it takes more education to cope with the ensuing upheavals and to figure out what is the right thing to do." (p. 40) In a footnote (p. 96, note 7), he includes his paper with Berman and Bound as one of those that "attempts" to defend the technical skill hypothesis, while in the main text he skeptically appraises the support for the technical-skill hypothesis, saying: "The actual empirical work on this topic is not all that convincing, primarily because it is so difficult to get an independent and relevant measure of technological change." (p. 40) So one might suppose that he did not include the paper in **RDP** because he had concerns about problems with the data. But on those grounds, he would have also excluded several other papers that were actually included. It remains likely

that the reason for not including this paper in a compilation is as sketched more generally above – it had appeared recently enough to be readily accessible, and Griliches may have believed that to include the paper in one of the compilations would be to claim too high a share of credit for the paper.

The 18th ranked article (col. 3, #18) was the third among the top 20 that Griliches did not choose to include in a compilation. The 1995 article in the handbook edited by Stoneman, surveys empirical results on the relationship between R&D and productivity. In *Retrospective* Griliches comments (p. 46) that this literature "has grown enormously" and he briefly summarizes (pp. 46 and 52) some of the main conclusions of the 1995 paper. In the footnote referring to this literature (p. 96, note 1) he cites three survey articles that are later than his 1995 article. It may be that our procedure (see the appendix to this paper) for estimating this article's eventual 10-year citation count, overestimates the count, because the information in the article may be depreciating at a fast rate, due to the increasing volume of the literature, and other articles reviewing it. For the same reasons, Griliches may have concluded that the article did not have sufficient continuing value to warrant reprinting.

We may look at the 20 most-highly-cited articles to evaluate the profession's view of the relative importance of Griliches's contributions in two very broad categories: "economics of technology, R&D, and growth" *vs.* "econometric methods and/or labor economics." By my count, about 13 of the top 20 articles fall mainly in the "technology" area and about six (col. 3, #s 2, 5, 12, 13, 19, 20) fall mainly in the "methods/labor" area, with two articles (col. 3, #s 1, 18) countable in both, implying that roughly 70% of Griliches's most influential articles were in the area of "economics of technology, R&D, and growth." This conclusion corresponds to Griliches's own view of what mattered most in his work, since his final *Retrospective* focuses much more on issues technology and growth than on issues of econometric method or pure labor economics.

So we may conclude that Griliches and the profession are in fairly close agreement on which of his articles mattered most and on which area of economics he most contributed to progress.

GRILICHES'S MAJOR CONTRIBUTIONS TO THE ECONOMICS OF TECHNOLOGY AND GROWTH

In this section, we summarize several of Griliches's most important contributions to the economics of technology and growth. We focus our discussion on those articles on technology and growth that ranked among the top 10 technology articles either in terms of 10 year citation count (the first column of Tab. II) or among the top 10 technology articles in terms of total citation count (the second column of Tab. II). We have already discussed Griliches's highest ranked (col. 1, #1) technology article, which is the *QJE* article co-authored with Berman and Bound on changes in demand for skilled labor. We will discuss the remaining articles roughly in the order of citation ranking, but will group closely related articles together.

Griliches's second and fourth most-highly cited articles in technology/growth deal with different aspects of patent data. The main substantive conclusion of the 1984, fourth-ranked paper, is that more recent vintages of firm R&D were yielding fewer patents than had earlier vintages. First-authored by Jerry Hausman, and second-authored by Bronwyn Hall, this *Econometrica* paper builds on a 1980 Griliches and Pakes paper, and is framed by the authors as providing improved, broadly applicable, methods for handling count data. The second-ranked paper is Griliches's 1990 *JEL* survey article on patents. Substantively, the paper

finds a high correlation between R&D expenditures and the number of patents. Another important finding was to show that much of the decline in patents issued in the 1970s was attributable to delays in patent-processing by the U.S. Patent Office. The 1990 paper also suggests a more optimistic interpretation of the main result of the 1984 paper. Specifically, it suggests that the average quality of patents had been rising, so that the earlier paper's finding of a declining patent yield from R&D, did not necessarily imply a declining yield in terms of innovations.

Griliches's third, seventh and eighth most-highly-cited technology/growth articles are important because of their discussion of spillover effects in R&D. Eighth-ranked "Issues in Assessing the Contribution of R&D to Productivity" (1979) lays out the conceptual framework for much later work on R&D and productivity. In addition to providing an early discussion of the importance of spillover effects of R&D, the paper focuses on the need for better data, especially in regard to the output of R&D intensive industries, and the stock of R&D capital. Griliches viewed his third-ranked, 1992 paper on spillovers partially as an opportunity to bring the 1979 paper to the attention of the "New Growth Theory" practitioners, who he thought were unaware of it (**RDP**, p. 7). The 1992 paper also reviewed the recent empirical evidence on spillovers, and tentatively concluded that spillover effects may be substantial. Griliches's seventh most highly cited work, on "R&D and Productivity . . .," includes an extended discussion of the evidence on R&D spillover and externality issues. The 1995 paper was written fairly quickly, focused mainly on a summary of the research of others, and was intended mainly for pedagogical purposes.[8] Similar discussions occur more briefly in several of Griliches's other publications in the mid to late 1990's (*e.g.*, in his 1994 AEA presidential address, and in *Retrospective*).

His fifth most cited article on technology/growth was his AEA presidential address (1994) on "Productivity, R&D and the Data Constraint." The paper is rich and subtle, with many caveats and qualifications. But the central message that many readers have taken from it is that the perceived decline in the growth rate may be mainly due to the growing importance of the service sector in the economy, and the extreme difficulty in measuring productivity in services.

In the decade from the mid-1950's through the mid-1960's, Griliches focused most of his research toward issues of productivity in agriculture. Griliches's 13th most cited article on technology/growth (and eighth most highly cited in total citations) was his 1964 *AER* paper on agricultural research expenditures. He indicates (**TEP**, p. 21) that this paper, along with the 1963 *JPE* paper, " . . . represent my most successful attempts to . . . check the validity of the attribution of productivity growth to its various suggested 'sources'." Of the two papers, the 1964 paper was more comprehensive in the sources examined, including a variable for government investment in R&D and agricultural extension activities. The result was that all of the productivity growth between 1949 and 1959 could be accounted for. Perhaps most notably, about one-third of the growth was attributed to government investment in R&D and agricultural extension services. By Griliches's account, the paper proved important in shaping his views about what mattered: "This work left me with the conviction that education, investment in research, and economies of scale (both at the level of the firm and at the level of the market) were the important sources of productivity growth in the long run." (**TEP**, p. 21) Elsewhere, (*Retrospective*, p. 22) Griliches says that the 1963 and 1964 papers "overexplained" the residual, but soundly verified the "proximate sources of measured productivity growth." In Griliches's view, the work in these papers culminated in his 1967 paper with Jorgenson.

[8] I am indebted to an anonymous referee for much of the substance of this paragraph on Griliches's survey in the 1995 Stoneman volume.

A different 1967 paper, his ninth most highly cited paper on technology/growth, marked the beginning of Griliches's switch from a focus on productivity in agriculture to a focus on productivity in manufacturing. Working within a Cobb-Douglas production function framework, he concluded (pp. 316–317) that accounting for improved labor quality reduces the size of the "residual" from about 60% of the rate of growth to about 20% of the rate of growth. This work, and especially his concurrent work with Jorgenson, was an important step in the development of Griliches's thinking on the role of technology in explaining productivity growth. The centerpiece of the work with Jorgenson is the sixth-ranked 1967 *Review of Economic Studies* article, but also includes the 1966 (col. 1, #37) *AER* paper, and the 1972 (col. 1, #36) reply to Denison published in a special issue of the *Survey of Current Business*. The 1967 paper boldly concludes that when inputs are measured properly, and the estimation is done properly, all of productivity growth is accounted for, leaving no room for the "residual" that many had associated with technological improvement. In *Retrospective*, Griliches suggests (p. 23) that the strong claims of the paper embody "a certain youthful recklessness." With the passage of time, he came to believe that the paper carried the then conventional approach as far as it could go. "Conventional approach" here refers to an approach using "... constant returns, competitive output and factor markets, and no externalities..." With time, Griliches came to believe that such a framework could not offer a full explanation of productivity growth, and that a better explanation would require taking account of "... increasing returns to scale, R&D spillovers, and other externalities and disequilibria." Having lost the hubris of youth, in later years he was not certain that such a fuller account will be feasible, or, if feasible, that such an account would explain the slowdown in productivity growth in the 1970s and 1980s.

Griliches's 10th most highly cited paper on technology/growth was his 1986 *AER* paper on "Productivity, R&D, and Basic Research at the Firm Level in the 1970s." In it, he reached three important conclusions. The first, consistent with earlier studies, was that R&D had a positive and high impact on firm productivity. The second was that basic research had a greater impact than other forms of R&D. In his concluding discussion he finds this result puzzling since if the firm is successfully profit-maximizing, the return should be equal in all activities. He suggests that basic research may be riskier, and that it may take a long while to reach long-run equilibrium. The third important result of the paper was that firm level research that is financed by the firm itself, has a larger impact on firm productivity than firm level research that is financed by the federal government. He argues that this finding is not so surprising, since most federally-financed R&D is undertaken by the firm as contract work to produce a specific output that is sold back to the government, not in order to increase the firm's productivity.

His 19th most cited article on technology/growth (and *most* cited in terms of total lifetime citations) is his early dissertation-based *Econometrica* paper on "Hybrid Corn: An Exploration in the Economics of Technological Change." The graph reproduced below is perhaps the most famous from this paper, showing the s-shaped adoption curves of hybrid corn in different geographical locations. Most notably, Griliches goes on to explain much of the variation in the speed of adoption on the basis of rational, profit-maximizing behavior on the part of the seed-producers and the farmers.

Griliches's 20th most cited article on technology/growth (and sixth most highly cited in total citations) was his second paper to be based on his dissertation research on hybrid corn R&D. This 1958 *JPE* paper was one of the first to calculate the social rate of return from investment in R&D, which was estimated to be 40 percent per annum. The methods in this paper have been widely applied and extended (see, *e.g.*, Evenson's 1990 account of the number of replications in agricultural economics alone). It is perhaps puzzling that this paper, which has been so widely applied, is cited less than the 1957 *Econometrica* hybrid

corn paper on technical change. Perhaps the 1957 paper represents a more fundamental challenge to what the profession views as appropriate problems and methods. (We will return to this issue in the final two sections of the paper.)

GRILICHES'S POST-1995 ARTICLES ON TECHNOLOGY

In the article-ranking presented in Table II, we did not rank articles published from 1996 through 2000, on the grounds that too little time had passed to have much confidence in their ultimate reception. Several of these papers are informative, however; partly for their substantive conclusions, and partly for the evidence they provide of Griliches's final views of what the important questions are in the economics of technology.

Much of Griliches's productive time during the last few years of his life was devoted to editing and writing introductions for two edited volumes of his works: *R&D and Productivity* (1998) and *Practicing Econometrics* (1998). He especially devoted substantial time and effort to *R&D, Education, and Productivity: A Retrospective*, which was completed during the final months of his life. Based on his October 1997 Simon Kuznets Memorial Lectures given at Yale, this book presents a final summary of what Griliches thought was most important in his past work on technology, and his advice for future researchers on what are the interesting questions and fruitful methods. (Some of this advice will be summarized in the final section of this paper.)

Of the 14 articles listed in Table II that Griliches published from 1996 through 2000, all but two are co-authored, and of the co-authored papers, Griliches is the first-author of only one of them. We may infer that Griliches's contribution to most of these co-authored papers was not the dominant contribution.

Both of the two single-authored articles among the 14 (*JEL*, 1996; *J Labor Ec* 1997) represent retrospective surveys of Griliches's mature views on topics to which he had made major contributions. The remaining papers are at least of interest, however, in showing the sort of work that Griliches viewed as promising and useful at the end of his career.

Griliches's paper with Adams is a preliminary discussion of the quality of data measuring scientific productivity, and a teasing out of what the data imply, at face value, about the extent of diminishing returns, and spillovers, of scientific research.

The quality ladder paper with Klette represents Griliches's most ambitious final contribution to the theory of R&D and economic growth. Their model (of a type which has sometimes been loosely identified as 'Schumpeterian') attempts to explain three stylized facts about firm size, firm growth and R&D.

A second paper with Klette, though primarily a contribution to econometrics, makes a point highly relevant to the economics of technology, *viz.*, that standard estimates of firm economies of scale are biased downwards, because they actually represent a mixture of scale and demand-side parameters.

During the final decade of his life, Griliches devoted considerable attention to understanding pricing and innovation in prescription drugs; a crucially important, paradigmatic, and controversial example of the economics of technological change. In the 1996 *Brookings* article, Griliches and co-authors find that the Bureau of Labor Statistics (BLS) estimates for their index of antidepressant drug prices are double what they should be. The main problems with BLS estimates relate to inadequately dealing with the introduction of new drugs.

In the 1997 *Rand Journal* article, Griliches and co-authors find that price elasticities of demand are higher at the dispensing stage of the purchasing process than at the prescribing

stage of the process. They suggest that this may be due to physicians having limited information on prices when they write prescriptions.

The three co-authored articles on improving the accuracy of the CPI, represent Grilches's final contribution to his long-standing efforts to improve the quality of important, policy-relevant data series.

GRILICHES'S WORK ON POLICY

Griliches's attitude toward the role of the economist was ambiguous. On the one hand, he was always careful in his academic work to present the qualifications in his conclusions, and the weaknesses of his data. On the other hand, he defined important problems in part on the basis of their relevance to important public policy issues, and believed that economists could benefit early in their careers from brief stints working for the government, in order for them to do more relevant work later on. He even thought that it was beneficial to sound economic policies if good economists occasionally stayed in government beyond their early years. The reason is not optimism that they will hew firmly to their intellectual principles in the face of political exigencies – he recognizes that they will likely be "co-opted." Rather, what is important is that "they must raise the level of discussion." (in Krueger and Taylor, p. 186).

Griliches himself was willing to present a simplified "bottom-line" for policy makers on occasion. Although the effects of R&D on growth are always qualified in his academic writings, he was on occasion willing to eschew qualification for the press: "The slack growth of the past seven years in research and development spending will come home to roost." ("Silent Crisis . . .," 1976). He also was part of the controversial "Boskin Commission" that argued that government cost of living adjustments based on the CPI were too high, since the CPI overstates inflation. (Bunker, 1996; Gallagher, 1996).

Most vehemently, and with the least qualification, Griliches testified before Congress when the Reagan administration proposed to cut NSF funding of economics by 75%. He is reported to have told Congress that the cuts could be attributed "only to vindictiveness, ignorance and arrogance." (Silk, 1981).

THE OUTLIER: GRILICHES'S MOST IMPORTANT CONTRIBUTION

Since the knowledge presented in an article is expected to depreciate over time, the common expected citation pattern for most articles is that citations to them will peak within a few years after publication and then gradually decline. If the rate of citation inflation is sufficiently high, the effect of the inflation might counteract the effect of depreciation, and a more monotonic pattern of citations might be observed.

If we examine in Figures 3 and 4, the citation patterns of Griliches's 12 most highly cited articles published before 1971, we find that most articles are cited at a fairly steady rate. Some (such as 416.0, 375.9 and 164.0) start out strongly cited. Others (such as 225.6 and 151.6) build more gradually to their peak citation rate. Some (such as 416.0 and 116.0) decline substantially from their peak citation rate. Others (such as 375.9 and 225.6) maintain a fairly constant rate of citations after reaching the peak level.

Of Griliches's articles, one stands as an outlier: confounding both reasonable expectations, and the observed citation patterns of Griliches's other articles. The outlier is the 1957 *Econometrica* article on hybrid corn. Alone among the 12 articles, this article has a rate of citations that strongly trends upward over time. Alone among the 12 articles, the first

15 years of citation data provide no clue of the eventual citation success of the article. The peak rate of citations, so far, for this article (24 in 1998) occurred 42 years after the article's publication.

One may speculate on the reason. Perhaps a growing number of economists, gradually over the decades, came increasingly to appreciate the role of technological progress in economic growth. And perhaps a growing number began to believe that studying the sources of innovation, and the determinants of the speed of adoption of innovation, might be a more important topic than studying systems at or near equilibrium. Growing numbers do not mean a majority. If such research was the dominant research program in the profession, then Griliches's paper might have been so fully assimilated into the profession's methods that it would no longer be much-cited. (No one cites Marshall when they report an elasticity.[9]) As for Griliches himself, we shall see that one of his main hopes for future research is in the further development of his research on the development and adoption of technological innovations.

The citation evidence on the importance of Griliches's 1957 paper is generally supported by the comments of those scholars who have closely observed, or carefully studied Griliches's career. When Griliches's colleague and early co-author, Dale Jorgenson summarized Griliches's main contribution for the *New York Times* (as quoted in Weinstein, 1999), he stated the standard view for which there is much agreement: Griliches's early work measuring the high return to R&D in developing hybrid corn, and on measuring and explaining the differences in the rate of acceptance of hybrid corn, represent his best known, and most-mentioned contribution. It is this work that Pakes (2000, p. 443) also identifies as "seminal."

THE RESIDUAL: GRILICHES'S ADVICE ON WHAT REMAINS TO BE DONE AND HOW BEST TO DO IT

One source of Griliches's final advice is Krueger and Taylor's interview of him during his final illness. A second major source of Griliches's advice for the future is his small final book *R&D, Education and Productivity: A Retrospective* (which we have been abbreviating as *Retrospective*), especially the final chapter entitled "Reminders for Traveling the Research Road Ahead." Nerlove calls this small book, Griliches' "most definitive statement" (p. F425) on the process of economic growth.

Griliches in *Retrospective* emphasizes several observations[10] about the economic world that "sometimes get lost in our rush toward modeling." (p. 87) The first is that productivity growth is not simply a matter of technological change, but also depends on " . . . the efficiency with which existing industrial enterprises and other social institutions are operated." (p. 87) The second is that technical change is not simply a matter of R&D, it also involves learning by doing and other "informal R&D". On this important topic, Griliches reminds us that " . . . we have relatively little systematic evidence about it or understanding of how best to promote it." (p. 88).

His third and fourth observations are closely interrelated. The assumption that knowledge is free and perfect is not only "wildly optimistic" (p. 88), but also assumes away some of the most important issues of how to speed the development and diffusion of knowledge. Quoting Hayek's classic paper, he also notes that much important knowledge is tacit, or is "knowledge of the particular circumstances of time and place." (Hayek, 1945, p. 521) The normal state of

[9]For a discussion of this point, see: Stigler, George J. and Claire Friedland. 1982, pp. 182 & 184.

[10]I summarize in the body of the paper, five of his six main observations. The sixth observation is that increases in productivity do not necessarily imply increases in social welfare if social welfare depends, in part, on the equality of income and wealth.

the world is transition, not equilibrium, both because individuals are gaining information and because they are striving to improve their situation. Griliches concludes that: "The study of growth will require embracing more seriously a view of the economy where decentralized information and incentives in a constantly evolving world make all the difference." (p. 89).

The fifth observation is that understanding the components of productivity growth does not answer the more fundamental questions of what determines the growth in these inputs. Here Griliches suggests that economists will need to study history:

> Real explanations will come from understanding the sources of scientific and technological advances and from identifying the incentives and circumstances that brought them about and that facilitated their implementation and diffusion. Explanation must come from comprehending the historical detail from finding ways of generalizing (modeling?) the patterns that may be discernible in the welter in it. This leads us back to the study of the history of science and technology and the diffusion of their products, a topic that we have left largely to others. But if we want to understand better what we are talking about, where technical change is actually coming from, we will need to study history. There is no free lunch in economic research either. (pp. 89–90).

In his final years, Griliches was focusing his attention on some of these deeper determinants of economic growth. In his 1998 paper with Adams he was looking at the effectiveness of different academic institutions at increasing our knowledge of science. His spillover article showed the importance of academic science, research that Jaffe and others have extended. His work with Lichtenberg undercut the view that science had been depleted as a deep source of economic growth. Arguably, his final advice to the profession is most self-consciously expressed in the final chapter of *Retrospective*. And in the final footnote to that final chapter he adds an extension: "I have said too little in this book about the role of science in generating productivity growth. Saying something quantitative about it is even more difficult." (p. 99).

In the Krueger and Taylor interview, Griliches suggests that one problem with economics lies in the application of equilibrium models:

> We never have had a good theory of transitions. And the field, by and large, moved toward an interpretation where everything was in equilibrium, all the time. So the diffusion story, as such, didn't seem like the model people wanted to develop. (p. 181).

For this reason he believes that, apart from a couple of papers by Mansfield, and by David, that the profession did not develop his model of the adoption of hybrid corn. He elaborates that

> . . . most of the economy is quite far away from the boundaries of the current state of knowledge. Some of it is because it is an equilibrium – it's not profitable at the existing cost structure. But some it is because it's new and it hasn't been fully developed yet. It's in the process of being adopted. (p. 181).

He also identified a more general problem with the profession: " . . . I think one of the problems with a lot of economics is that you have a lot of bright people who have been trained to *publish papers* – not necessarily to figure out which papers are really interesting and what is it worth (sic) to be working on." (p: 186). These concerns were not felt by Griliches only late in life – at the very end (p. 319) of his important 1967 paper on "Production Functions in Manufacturing," rather than exaggerate his current contribution, he warns " . . . , there is a danger that here, as in much of other research, we may be looking for answers where the data are and not where the questions are important." Among those who thought Griliches practiced what he preached was Maddala, who said of Griliches: "Before jumping on any bandwagon, he would ask whether the questions being answered were worth asking." (quoted in Lahiri, 1999).

In the Introduction to *Retrospective* he identifies this point as "the most vital theme" of the book and his career:

> The most vital theme is that one makes progress in economics by focusing on important questions. It is vital to use and develop new tools; this, after all, is how economists learn more. But one should never forget the question. A classic joke about economists tells the story of the economist who lost his car keys somewhere on a dark street. He looks for the keys not where he lost them but under the street lamp, because that is where the light is. I would suggest that the creative economist finds a flashlight, or uses the car's mirror to reflect the light, or if necessary gets down on his hands and knees and grubs in the dark to look for the keys where he thinks they are. (pp. 3–4).

Unlike much of the profession, Griliches valued those who grubbed for the data.[11] He honored Schmookler most by editing a volume to assure that Schmookler's patent data would be widely available. Alan Krueger has claimed that Griliches influenced the profession because "he got his hands dirty with the data." (in Weinstein, 1999). And he urged others to do likewise:

> We ourselves do not put enough emphasis on the value of data and data collection in our training of graduate students and in the reward structure of our profession. It is the preparation skill of the econometric chef that catches the professional eye, not the quality of the raw materials in the meal, or the effort that went into procuring them. (1994, p. 364 in [**RDP**]).

Griliches did his best to rectify the situation in his mentoring of his own graduate students. He was, as Warsh described (1994) him, " . . . the leader of a small but fiercely intellectual and passionately honest tribe of analysts devoted to improving the quality of economic data."[12]

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[11] At the beginning of his survey article on patents, Griliches placed an epigraph that illustrates his wit, and his ambivalence toward problematic data that is relevant to an important question:
"Overheard at a Catskills Resort (one guest to another):
– The food is so terrible here.
– Yes, And the portions are so small."

[12] Whether Warsh is right that the "tribe" is "small" might be doubted after visiting Iain Cockburn's "Tree of Zvi" web site that provides a genealogical tree of Griliches's students and colleagues: http://people.bu.edu/cockburn/tree_of_zvi.html.

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APPENDIX ON CITATION ISSUES

Our source for citations is primarily the "Web of Science" (WoS) database published by the Institute for Scientific Information, incorporating citations in the sciences, social sciences, arts, and humanities. The online WoS was occasionally supplemented with the *Social Science Citation Index* (*SSCI*), which is the book version of the part of the Institute for Scientific Information (ISI) database most relevant to Griliches's work. For the present research, the primary advantage of the Web of Science version of the database is that it has been extended back through 1956 for the social sciences, in contrast to the 1966 starting date for the *SSCI*. Citation counts were available through the year 2001, and approximately the first two-thirds of the year 2002. (We assumed a uniform citation process during the year 2002, and estimated citations for all of 2002 to be 1.5 times the actual citation count through August 2002.)

Based mainly on Griliches's curriculum vitae, as posted on the Harvard University web site, his total number of academic and non-academic publications, (including books, articles, notes, comments, reviews, and government-published congressional testimony) total approximately 221. Table II lists the number of citations for 110 articles and notes of Griliches that had received citations through August 2002. Table III lists citations to all ten of Griliches's monographs.

The book version of the *SSCI* only lists citations under first-authors. The Web of Science (WoS) online version lists a total citation count for each article recognized by ISI. Two significant problems are present in these counts. One is that the WoS misses many articles that are cited, including some important ones. Especially likely to be missed in WoS, are discussant comments, as well as articles that are in edited volumes. Another problem is that for a citation to be counted for an article in WoS, it has to have been entered into the ISI database in a single canonical form decided upon by ISI. If either the citing author, or the ISI data entry person, use a form that deviates even slightly from the canonical form, then the citation will not be counted. This problem sometimes results in a substantial number of citations being missed. Some of the worst discrepancies are when WoS, requires an "s" prefix for page numbers in a supplemental issue of a journal. Since many scholars omit the "s" in their page citations, it is common in such cases for a majority of citations to be missed. For example, Griliches's 1992 "The Search for R&D Spillovers" in the *Scandinavian Journal of Economics* was listed in WoS as having only 16 total citations, as of late-August 2002. By including citations that deviated slightly from the canonical form of the *SSCI* (mainly by lacking the "s" before the page number), we came up with a total of 141.9.

For each article, we did a "Cited Reference Search," using as search terms "Griliches" for the author, and a minimal abbreviation for the journal, along with wildcards for the nonabbreviated parts. (The wildcards are necessary because ISI data-entry persons sometimes have used non-canonical abbreviations for journals – when they do so, the citations are not counted by ISI as part of the count for the article.) We then went through a laborious scan of the citations that resulted, and judged which of them were close enough to canonical form to be counted. This procedure was followed for each co-author of all co-authored publications, in order to obtain final counts.

Rankings based on citations can only be viewed as rough measures of relative importance to the profession for a variety of well-known reasons that do not need to be fully rehearsed here. Since Griliches's older publications have had more years in which to accumulate citations than his more recent writings, citations were counted for a ten year period immediately following the publication date of an article or monograph. This "10 year" citation count was used to rank publications in Tables II and III, although the "total" ranking is also presented.

To estimate predicted citations for articles with less than 10 years citation record, we estimated regressions with linear terms; linear and squared terms; and linear, squared and cubed terms. The functional form with the highest adjusted R-squared was used to estimate predicted citations for future years. This procedure was applied to articles for which there were two or more degrees of freedom in estimating the regression which included the cubed term. As a result, predicted 10 year citations were estimated for the 12 articles published in 1993, 1994 and 1995. No predicted 10 year citations were estimated for the 14 articles published after 1996. These articles are, however, listed at the bottom of Table II, along with the total citations they have received to date.

Although it is well-known that citations are highly correlated with other measures of intellectual distinction and productivity (*e.g.*, Diamond, 1986), it is also well-known that they are not a perfect measure. For example, some studies (*e.g.*, Griliches and Einav, pp. 234–235) divide an article's total citations by the number of co-authors, in order to obtain a better measure of the intellectual contribution of each (based on the crude assumption that each co-author contributes equally to the article). Whether such a weighted count is more appropriate depends partly on the question one is asking, and partly on one's knowledge of the level of Griliches's contribution to co-authored papers. The weighted method may be more appropriate if the question is: which papers respresent Griliches's greatest contributions? Our method may be more appropriate if the question is: what are the most important papers to which Griliches made a significant contribution?

Another potential imperfection in the citation data results from what is sometimes described as citation inflation: that the secular trend has been for the average citations per article to rise. But it is difficult to distinguish whether a general secular increase in citations represents a decline in the average value of a citation, or an increase in the avenge quality of an article. In this paper we concur with Hall *et al.* (2000, p. 36) who suggest that taking out time effects "... would drastically reduce the variance in the data, probably throwing out a good part of the baby with the bathwater."

A final potential imperfection may be worth noting: articles that were reprinted in the 1988 compilation [**TEP**], or in either of the two 1998 compilations [**RDP**] and [**PE**], may be cited in the compilation, rather than in their original form, so counts for reprinted articles may be biased downward, especially for the articles appearing in the earlier 1988 compilation.

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