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Science and Inventions: Any Linkage?

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The "linear" model of science has been in disrepute for many years. This model suggests that each invention can be traced back to its "ancestral origin" in a scientific discovery and that this tracing is simple and direct (i.e., linear). Defenders of public spending on science who attempted to argue that science is the "mother of all inventions" (or even a significant proportion of them) generally could not support their claims (Project Hindsight). Critics had a field day showing that the ancestry of inventions supported the old claim that "necessity is the mother of inventions" more often than the claim that science is the mother of inventions.

The rejection of the linear model has forced defenders of science budgets to appeal to public goods arguments for support for science. This appeal, to the extent that it is successful, has often been congenial to the baser instincts of scientists themselves. This is because it frees them from a sense of responsibility to produce something useful and allows them the luxury of unfettered pursuit of pure knowledge.

Defenders of science who have argued that science can be useful through "downstream training", i.e., where training in a field of science constitutes useful training for inventors (who are downstream in the sociological pecking order and often perceived as failed scientists) have had a better reception. There is broad agreement that most sciences, particularly the general sciences, mathematics, physics, biology, etc., do produce knowledge that can be productive when mastered by non-scientists or more applied scientists.

What is the relevance of this for a developing country seeking to acquire and put in place improved technology? Should developing countries have a

science policy? Will it support their more immediate and direct technology objectives? If so, are there implications for the "mix" of science?

The full rejection of the linear model implies that "science builds on science" and "technology builds on technology." Developing countries, it might be argued, then need science only to support the training of engineers and technologists (who in turn may facilitate copying and imitation of foreign origin inventions). And even this need might be limited because of the option for training in developed countries.

I shall argue in this brief note that there are linkages between science and inventions and that they provide support for a science model that relies on differentation between fields of science. Some fields of science do fit the characterization of the pure science uncontaminated by the requirement that its products (findings) have productive value (presumably they have ornamental value as public goods, much as monuments and art galleries do). But many fields of science accept a responsibility to produce findings, that, in some sense, respond to a "demand" from inventors. These can be described as pre-invention sciences.

Figure 1 depicts this situation in terms of four levels of specialization in the conduct of research. These levels span the biological sciences and biologically related economic activities. Similar categories for mechanical, electrical, and chemical fields could be developed.

The level I general sciences are depicted as furthest upstream and furthest removed from invention (level IV). Level II sciences are described as being pre-invention sciences in a fairly general sense. They have specific orientation to downstream sciences and to some degree to invention fields. Immunology and virology sciences are oriented to some degree to serve downstream medical sciences. Level III sciences, on the other hand, are quite clearly oriented to invention. Many scientists (and technologists) in these

Figure 1: Classes of Science and Invention

I. General Sciences	biology, chemistry, physics, molecular biology, biochemistry, biophysics, microbiology, physiology, anatomy
II. Pre-Invention Science	genetics, pathology, entomology, bio-engineering, limnology, immunology, pharmacology, virology, oceanology, endocrinology, animal pathology, tometrics, economics, nutrition, animal nutrition, food chemistry
III. Applied Invention Sciences	urology, radiology, oncology, veterinary, plant breeding, forestry, surgery, cardiovascular, dietetics sciences, agronomy, fishery
IV. Inventions & Practices	instruments, pharmaceuticals, animals, plants, fertilizers, insecticides, equipment processes, feed additives, herbicides, micro-organisms
V. Commercialization, Extension	medical practice, seeds and chemicals, extension science

medical and agricultural sciences produce inventions and practices as well as science. That is, these units organize research utilizing the framework of science including publishing. They also engage in inventions. Level IV inventions and practices are the activities of many level III researchers and of other yet more applied inventors and technologists in public and private firms. Level IV activities are the commercialization, developmental and extension activities downstream from inventions.

This classification of levels is not particularly meaningful unless bolstered with evidence of vertical linkages between levels. We have two sets of evidence suggesting a reasonable degree of linkage. The first set is for citations between journals and this provides evidence for some vertical integration or linkage between levels I, II and III for agricultural fields of invention. The second is for direct invention science links using citations of science by patents for agricultural, biotechnology and medical fields of invention.

Evidence From the Agricultural Sciences

Researchers who specialize on research problems that are at only one level of science exchange information both horizontally, i.e., within their own field of specialization and with other specialists working on similar problems, and vertically, i.e., with specialists "upstream" and "downstream" from this specialization. Scientific communications systems have been developed primarily to facilitate horizontal exchange in the general or basic sciences. The journal papers, reference citations, specialized language, and elements of style are chiefly designed to allow scientists working on similar problems to disclose findings quickly and accurately to one another. This disclosure process facilitates refereeing of priority claims to new knowledge and the cumulation of verified hypotheses that constitutes scientific knowledge in a field.

The scientific exchange apparatus that originated in level I sciences has been modified and used in Level II pre-technology sciences and even to some extent in level III activities. At all levels, knowledge must be communicated and exchanged to facilitate the knowledge cumulation process. Scientific papers with their specialized language, usually associated with a discipline and with standards set by scientists themselves, have been a useful vehicle for horizontal exchange at all levels.

Scientific papers have also served as a vehicle for vertical knowledge exchange, but some of the features of scientific papers that facilitate horizontal exchange can hinder vertical exchange. Language and style, for example, facilitate horizontal communication. But in different fields and levels of science, they tend to differ significantly. Thus, they can hinder vertical exchange.

Reference citations are a source of evidence about the characteristics of knowledge exchange and the effectiveness of the science system. The Appendix reports a list of journals that have been related to science levels I, II, and III shown in Figure 1. The Science Citation Index and Social Science Citation Index (Institute for Scientific Information or ISI) report inter-journal citations. They report the number of times in a given year that papers from journal A were cited in journal B and vice-versa. Using these data one can then construct measures of horizontal (i.e., within level) and vertical (i.e., between-level) citations, or upstream and downstream citations.

Data for citation patterns for 2 years, 1975 (1978 for journals in ISI, Social Science Citation Index) and 1985, are summarized by field of science in Table 1. The reader can appreciate that the actual classification of journals into different levels of science contains some arbitrariness. Our objective in classifying was to achieve relative homogeneity of research interest among the categories.

Three categories of general science--chemistry/biochemistry, biology/molecular biology, and micro-biology--are shown. (The Appendix reports a list of journals included in each level of science.)

The level II group of journals is important for agriculture. Genetics, entomology, and environmental sciences are fairly distinct fields of science. The crop-related and livestock-related journals in this category were selected in a somewhat more general fashion (e.g., placing genetics in the level II group). Note that I am treating economics as a level II field. The reason is that only a portion of the research in this category is actually conducted by USDA-SAES units.

The level III group is more applied than level II and frequently leads the invention of new technology. Virtually all the articles published in level III applied science journals are the result of research conducted by USDA-SAES units and private firms. The "agricultural sciences" thus encompass most of the level III sciences and the level II sciences.

Citation patterns can be described and summarized in terms of citation indexes. Table 1 reports the following indexes:

1) The proportion of citations-to-literature-published 10 or more years before the citing publication. This is a measure of the degree of stability on "softness" of a field of science and of its growth potential (Price, 1986). Fields of science that cite publications that are 10 years or older at a high rate are undergoing less change and development than fields that primarily cite newer publications.

2) The proportion of self-citations, i.e., to the same journal. This is an index of "inwardness" or intellectual incest of the field. It is affected by the size of the field and the existence of similar journals.

3) The proportion of citations to the same journal- or science-group (e.g., group 1A). This is also a measure of inwardness or horizontality.

Table 1. Total citations, and proportions in each group, 1975 and 1985.

Levels of Science	Total citations	Proportions in Each Category: Older than 10 years	Same journal	Same group	Same level	Upstream Citations: Gen. Sci.	Upstream Citations: Pre-Tech.	Downstream Citations: Pre-Tech.	Downstream Citations: Applied
I. General Sciences	356767[b]	.241	.135	.873	.949	-	-	.046	.004
	(171377)[c]	(.224)	(.199)	(.905)	(.975)	-	-	(.023)	(.001)
Chemistry/Biochemistry (1A)[a]	319285	.240	.141	.944	.966	-	-	.033	.007
	(143264)	(.226)	(.214)	(.973)	(.993)	-	-	(.006)	(.000)
Biology/Molecular Biol. (1B)	36859	.180	.054	.361	.740	-	-	.255	.004
	(10365)	(.208)	(.025)	(.140)	(.583)	-	-	(.391)	(.025)
Micro-Biology (1D)	49575	.290	.130	.671	.937	-	-	.035	.027
	(17708)	(.207)	(.177)	(.570)	(.950	-	-	(.042)	(.007)
II. Pre-Technology Science	190722	.309	.157	.714	.732	.216	-	-	.053
	(77345)	(.273)	(.157)	(.767)	(.790)	(.126)	-	-	(.082)
Genetics (1C)	7623	.361	.130	.712	.786	.098	-	-	.116
	(5479)	(.289)	(.167)	(.691)	(.749)	(.182)	-	-	(.067)
Entomology (1E)	10007	.441	.154	.710	.734	.129	-	-	.136
	(4596)	(.367)	(.199)	(.782)	(.861)	(.107)	-	-	(.032)
Environmental Sciences (1E)	9914	.450	.101	.624	.676	0	-	-	.323
	(3093)	(.418)	(.141)	(.575)	(.703)	(.007)	-	-	(.288)
Crop-Related (II.A.3)	32597	.336	.112	.524	.554	.350	-	-	.095
	(15662)	(.311)	(.127)	(.736)	(.759)	(.033)	-	-	(.208)
Livestock-Related (II.B.3)	139581	.260	.162	.775	.781	.202	-	-	.017
	(48515)	(.241)	(1.62)	(.796)	(.801)	(.157)	-	-	(.041)
IIIa. Applied Crop Sciences	49923	.462	.152	.873	.945	.010	.045	-	-
	(20602)	(.384)	(.237)	(.849)	(.916)	(.007)	(.075)	-	-
Crop Protection (II.A.2)	13509	.447	.175	.854	.958	.019	.023	-	-
	(6169)	(.336)	(.278)	(.937)	(.983)	(.010)	(.007)	-	-
Field Crop Prod. (II.A.11)	22308	.472	.166	.922	.962	.013	.018	-	-
	(11510)	(.373)	(.244)	(.881)	(.926)	(.009)	(.065)	-	-

Table 1. (Continued.)

Levels of Science	Total citations	Proportions in Each Category: Older than 10 years	Same journal	Same group	Same level	Upstream Citations: Gen. Sci.	Upstream Citations: Pre-Tech.	Downstream Citations: Pre-Tech.	Downstream Citations: Applied
Hort. Crop Prod. (II.A.12)	9623	.464	.103	.648	.807	-	.192	-	-
	(1944)	(.348)	(.087)	(.285)	(.604)	-	(.395)	-	-
Forestry Production (II.A.13)	4486	.448	.116	.990	-	-	-	-	-
	(979)	(.882)	(.177)	(.854)	(.925)	-	(.075)	-	-
IIIb. Applied Livestock Science	78431	.358	.137	.743	.816	.019	.165	-	-
	(29512)	(.366)	(.230)	(.798)	(.839)	(.026)	(.128)	-	-
Livestock Protection (II.B.2)	29402	.355	.090	.598	.659	.042	.299	-	-
	(11455)	(.346)	(.170)	(.734)	(.772)	(.044)	(.183)	-	-
Livestock Production (II.B.1)	25327	.282	.271	.884	.903	.007	.090	-	-
	(13202)	(.350)	(.317)	(.844)	(.897)	(.015)	(.088)	-	-
Nat. Res.-Wildlife (II.C)	23702	.443	.052	.614	.896	.005	.098	-	-
	(4855)	(.451)	(.133)	(.769)	(.821)	(.016)	(.162)	-	-
IIIc. Other Fields									
Food Technology (III.A)	22634	.410	.127	.726	.855	.127	.018	-	-
	(10639)	(.319)	(.154)	(.785)	(.952)	(.189)	(.026)	-	-
Human Nutrition (III.B)	13821	.351	.069	.543	.637	.293	.181	-	-
	(5810)	(.360)	(.159)	(.548)	(.666)	(.333)	-	-	-
Home Economics	14364	.376	.121	.993	.997	.002	-	-	-
	(6793)	(.299)	(.110)	(.999)	(.999)	-	-	-	-
Economics	22533	.324	.086	.992	-	-	-	.008	
	(16148)	(.312)	(.104)	(.993)	(.993)	-	-	(.007)	
Agricultural Economics	2838	.355	.139	.637	.648	-	.351	-	-
	(1620)	(.280)	(.154)	(.552)	(.552)	-	(.447)	-	-
Rural Sociology	1069	.354	.47	.999	.999	-	-	-	-
	(804)	(.407)	(.102)	(.999)	(.999)	-	-	-	-

a/ See Table 5.7 for journals listed in each field group. b/ These data are for 1985. c/ These data are for 1975 when journals were covered by the ISI, Science Citation Index, Journal Citation Reports and for 1978 when journals were indexed by the ISI, Social Science Citation Index, Journal Citation Reports.

This is less affected than (2) by the size and complexity of the journals in the field.

4) The proportion of citations to the same science level. This again is a measure of horizontality.

Items 2, 3, and 4 above are indexes of horizontalness or inwardness. Table 1 also reports direct measures of verticalness in the form of upstream and downstream citations. (Note that level I has no upstream citations, and that level III has no downstream citations.)

Certain general consistencies emerge from the cross-journal citation patterns reported in Table 1.

1) Level I fields of science have the lowest level of stability or softness, level II fields are intermediate, and level III fields are most stable, hence softest. Among level II and III sciences, the livestock-related sciences are harder than crop-related sciences.

2) The measures of horizontalness show different patterns according to the indicator. Self-citation, i.e., to the same journal, does not show strong patterns, although it is low as a proportion of total citations for the molecular biology field. Same-group and same-level citations show stronger patterns. Horizontalness is highest for the general sciences, especially chemistry/biochemistry, and lowest for the level II sciences. Most applied sciences also have a high degree of horizontalness. This is to some degree governed by the fact that only the pre-technology sciences have both upstream and downstream citing options.

3) The direct evidence for upstream and downstream citations shows patterns more clearly. Upstream citations show science-linkage and reflect ties into mother sciences. All pre-technology sciences except the environmental sciences have reasonable strong ties to general science. Upstream linkages are strongest for the crop- and livestock-related group.

Among the applied sciences, upstream citation rates are higher to pre-technology sciences than to general science in all fields except food technology and human nutrition. (These two fields are difficult to classify and their pre-technology fields may differ from these identified here.) This indicates that the level II sciences are playing a genuine pre-technology role. Upstream citations in livestock protection are highest to pre-technology sciences. Horticultural sciences also show strong upstream linkages. The forestry field shows weak upstream linkages, while crop protection and crop production show moderate mother-science linkages. In the livestock field, linkages to mother sciences have strengthened over time.

4) In the food technology field, science linkages are strong (and, as Chapter 5 will show, downstream linkages to inventors in this field are also strong). Human nutrition sciences are also strongly linked upstream to general science.

5) The social science parts of home economics (other than human nutrition) are not science-linked. Agricultural economics shows linkage upstream to economics but not to other applied agricultural science fields. Home economics and rural sociology have no linkages upstream or downstream.

6) Downstream linkages from level I are much stronger to pre-technology sciences than to applied sciences. The downstream linkage from biology/ molecular biology to the pre-technology sciences is especially strong.

Table 2 shows these linkages in more detail for specific fields of science for 1985. From this table one can examine how a given field of science, e.g., applied crop protection, environmental sciences, is linked to upstream and downstream science groups. The column for applied crop protection research shows that this field cites field crop production research most heavily. It also cites horticultural crop production sciences. It is a field with strong upstream linkages to the pre-technology sciences (III) and to general sciences

Table 2. Cross-field citation levels 1985, citing-journal field: numbers of citations.

Cited Journal Fields	General Sciences			Pre-Tech Sciences					Applied Crop Tech				Applied Lvstk								
	Chem	Biol	Micro Biol	Genet-ics	Ent	Env-Sc	Crop Sc	Lvstk Sc	Prot	FC	Hort	For	Prot	Prod	Nat Res	Food Tech	Human Nutri	Eco	Agr Eco	Ru Soc	Home Eco
General Sciences																					
IA Chemistry-Biochemistry	X [a]	2184	3635	95	325		698	5844	25	38			222	26	7	687	659				6
IB Biology-Molecular Biology	685	X			15		40	625	8					33	6	9	91				
ID Micro-Biology	1184	126	X	73			252		45	38			39				9				
Pre-Tech Sciences																					
IC Genetics	88	143	318	X	24		161	59	15	94	7		168	45	88	69					
IE Entomology				7	X	14			14												
IE[1] Environment Science						X	112														
IIA.3 Crop Pre-Tech	386		114	8		52	X	153	62	16	527			21	93	90					
IIB.3 Lvstk Pre-Tech	2253	1411	46	117	40	36		X	8				1830	726	71	15	470				
Applied Crop Technology																					
IIA.2 Crop Prot	34		110	28	35		92		X	74	7		35		8	22					
IIA.11 Field Crop Prod			90	30	153	33	588		328	X	433	19		33	376	45					
IIA.12 Hort Crop Prod				14	34		167		91	38	X				7	68					
IIA.13 Forest Prod					54	13	15		15			X			50						
Applied Lvstk Technology																					
II.B2 Lvstk Prot			87	23	55			220					X	134		9					
II.B1 Lvstk Prod			69	103	25	13	14	209		70			289	X	63	372	183				
Other Scien Fields																					
III.C Nat Resources Wildlife		23	18			485		30	8	71			56		X				10		
III.A Food Techno	12														13	X	51				
III.B Human Nutr										23						255	X				
Other																					
I.F Economics												17			8		5	X	295		
II.D Agr.Econ.																	5	52	X		7
II.E Rural Sociol																				X	
II.C Home Econ																					X

[a] An "X" indicates self-citation.

Source: ISI, Science Citation Index, Journal Citation Reports and ISI, Social Science Citation Index, Journal Citation Reports.

(I). Reference to the row for IIA.2 shows that the general and pre-technology sciences have strong downstream linkages to applied crop protection sciences. Reference to the applied livestock protection sciences shows that they are even more integrated with upstream sciences and that the livestock pre-technology sciences have very strong upstream and downstream exchange patterns.

This is in contrast to the environmental pre-technology sciences which have more upstream linkages and strong downstream linkages. The social sciences can be seen to be isolated from the other sciences.

The modern system of scientific specialization and knowledge exchange described in Tables 1 and 2 evolved over a long period of time. It represents the outcome of years of conflict between serving the demanders of level III and IV technology and the development of a supply capability. Economic studies reported in Evenson and Huffman show that the level II pre-technology sciences and their linkages to the level III sciences have been vital to the effectiveness and productivity of agricultural sciences. Most of the level II pre-technology sciences would not have been created had the state experiment stations not either created them or influenced state universities to erect them. The natural tendencies in the sciences favor level I sciences over level II sciences and do not lead to active downstream links. The ultimate viability and effectiveness of level III sciences, however, does depend to a considerable degree on the level II sciences.

Evidence From Patents

Patent examiners examine patents and have a responsibility to establish that novelty and inventive stop requirements have been met. It is the general practice to cite prior patents, industrial literature and scientific literature. (The appendix shows examples of first page references.) One cannot say for certain why each reference was made, but in general the examiner is identifying the "next best" art, i.e., the prior technology to which the

current invention is closest. In many cases this may be construed to be a measure of intellectual "ancestry". In fact the interpretation of intellectual ancestry is probably as valid for patents as for the scientific literature.

Many patents cite scientific publications as "germplasm" in addition to prior pioneering inventions. It does not necessarily follow that a scientific discovery was the "initiating" factor behind the invention. The inventive effort may have been motivated by demand factors. When patent examiners city a science reference they are indicating that a scientific find was a facilitating or germplasmic factor in the invention. While this is not a precise definition of pre-invention science it is a workable definition.

Do patents cite science? Evidence for patents in six production technology fields, biotechnology and post-harvest technologies is summarized in Table 3.

Total citations per patent have increased over time. This is in part due to changes in examiners and application practices. Foreign cites are divided into direct and indirect categories. Direct foreign cites are to foreign patents. Indirect foreign cites are to U.S. patents of foreign origin. The percent of U.S. inventions linked to foreign origin inventions has increased over the two periods. This percent varies considerably by technology field, being especially low in the animal husbandry field. Citations to scientific papers are generally quite low, except in biotechnology, fertilizers, and post-harvest technology. For these fields, a considerable degree of science linkage is apparent. This linkage is also growing over time.

A second sample of U.S. patent were drawn from technology fields that could be classed as molecular biology, botany and genetics, zoology, general agriculture and medicine. The biotechnology field is the new field classification set up by the U.S. patent office in 1985. (Class 435.) All patents obtained for one full year in 1984-5 and in 1984-90 were analyzed.

The three modern high technology fields show high growth in patenting

Table 3. U.S. Patents Granted in Agricultural Technology Fields

Item	Earth-Working Equipment	Planters Diggers	Harvesting Equipment	Threshing Equipment	Animal Husbandry	Fertilizers	Bio-technology	PHT
Patents Granted								
1975-79	554	128	339	83	807	1251	493	2866
1980-84	451	120	418	96	786	1085	527	2340
Ratio, 1980-84/ 1975-79	.82	.94	1.23	1.16	.97	.87	1.06	.82
% U.S. Corporation								
1975-79	.38	.25	.50	.55	.24	.58	.40	.52
1980-84	.36	.33	.48	.35	.24	.52	.42	.49
% U.S.Government								
1975-79	.00	.02	.00	.01	.01	.01	.03	.03
1980-84	.01	.02	.00	.01	.01	.02	.02	.01
% U.S. Individual								
1975-79	.27	.36	.26	.12	.58	.03	.03	.12
1980-84	.30	.28	.24	.18	.51	.02	.04	.13
% Foreign Origin								
1975-79	.35	.35	.24	.32	.17	.38	.54	.32
1980-84	.34	.38	.28	.46	.24	.44	.52	.27
Citations								
Citations/Patents	9.52	17.01	5.71	13.19	15.67	7.53	12.64	7.08
	11.62	20.45	7.46	13.54	10.83	9.43	13.11	9.68
% unknown	.57	.57	.33	.69	.44	.44	.68	.45
i.e. Pre-63 cites	.53	.63	.23	.61	.36	.36	.56	.36
% Citations to 1975-79 U.S. Patents of Foreign Origin 1980-84	.21	.16	.16	.21	.11	.23	.27	.16
	.16	.12	.20	.24	.14	.22	.23	.18
% Citation to Foreign Patents								
1975-79	.25	.32	.06	.11	.08	.09	.06	.08
1980-84	.26	.41	.13	.20	.13	.18	.07	.13
% Total Foreign Citations								
1975-79	.46	.48	.22	.32	.19	.32	.33	.24
1980-84	.42	.53	.33	.44	.27	.40	.30	.31
% Science Citations								
1975-79	.01	.03	.00	.00	.01	.18	.31	.11
1980-84	.04	.02	.02	.01	.03	.15	.37	.13

between 1985 and 1990 (See Table 4.) The more traditional agricultural invention field did not show growth. It is also clear that the three high tech fields are highly science linked while the more traditional agricultural fields of invention are not. In fact, more than 50 percent of the 1990 inventions for the rapidly growing high tech fields have science cites, while only 15 percent of the agricultural inventions have such citations.

Turning to the information on ownership of the inventions, the inventions generated by academic and government organization are more science linked than foreign inventions. Corporate inventions also show high science links. Medical inventions, interestingly show a relatively low level of science linkage, but the field shows strong demand growth.

Further Research

It is now possible to conduct exhaustive analysis of science-linked inventions across all fields. This work requires recording not only the science-cites (as well as other cites) but it also requires recording journal titles. This is because one would like to stratify fields of science in a structured way.

Why is this relevant to developing countries? Most of the poorer developing countries contract for the purchase of technology and ancillary services at level V. Another cluster of countries have sufficient competence to buy and "imitate or adapt" and some competence to copy (perhaps illegally). That is they buy at level IV and invent and modify at level V. Advanced developing countries (the MIC's) usually copy and buy selectively from abroad at level IV but actually have some capacity to invent at level IV and they regularly invent at level V (unless copying at level IV to too easy).

It is easy to see why a capacity in level II and III sciences linked to the production sector of advanced developing countries is relevant. These sciences not only enhance invention locally but they are the right sciences for

downstream training and capacity development.

This argument applies with decreasing power as one works backward from the MIC's. Nonetheless, it appears that a better understanding of the role of science is going to be relevant for most developing countries.

Table 5: Invention Science Linkages

	Number of Patents		Citations Per Patent: US Patents Patents		Citations Per Patent: Foreign Patents		Citations Per Patent: Industry Publication		Citations Per Patent: Science Publication		Percent with Science Citation	
Biotechnology	1985	1990	1985	1990	1985	1990	1985	1990	1985	1990	1985	1990
Individual	1	8	0	6.0	0	.60	0	.75	1	1.87	100	100
Corporations	71	106	5.28	4.34	.83	1.52	1.09	2.26	4.76	4.30	65	71
Academic	18	26	3.55	3.19	.27	.96	.44	.85	5.66	6.73	72	96
Government	1	6	4.0	2.66	3.0	.17	3.0	2.34	2.0	5.33	100	100
Academic plus Government	19	32	3.57	3.09	.42	.81	.58	.97	5.47	6.46	74	97
Foreign	76	92	4.21	5.38	.62	2.0	.99	1.74	1.63	3.92	54	53
All	167	238	4.57	4.63	.68	1.58	.98	1.15	3.39	4.36	61	70
Botany & Genetics												
Individual	11	6	4.91	5.36	.36	1.00	.09	.00	.00	.00	0	0
Corporation	20	66	3.30	2.08	1.35	.95	1.55	.61	4.50	4.09	40	45
Academic	10	5	1.70	1.40	.70	.00	.70	.00	5.30	4.00	50	60
Government	1	6	14.0	3.16	.00	.16	.00	.16	2.00	5.16	100	33
Academic and Government	11	11	2.82	2.27	.64	.09	.64	.09	5.45	4.63	54	45
Foreign	16	30	2.62	5.50	2.00	3.50	1.75	1.00	1.00	2.77	38	70
All	58	113	2.98	2.73	1.21	1.59	1.15	.63	2.86	3.57	34	50

Table 5: Invention Science Linkages

	Number of Patents		Citations Per Patent: US Patents Patents		Foreign Patents		Industry Publication		Science Publication		Percent with Science Citation	
Dentistry	85	90	85	90	85	90	85	90	85	90	85	90
Individual	9	16	5.66	8.12	.78	.06					0	0
Corporations	17	18	9.00	20.8	1.05	1.87		1.0	.82	1.5		
Academic												
Government												
Academic plus Government	0	2	5.0		5.0				6.0			
Foreign	21	25	6.57	9.20	1.28	2.04	.19	.04				
All	47	51	7.27	10.52	1.10	1.35	.11	.21	.32	.49	.043	.078
General Medicine												
Individual	68	127	9.51	9.65	1.0	.94	.15	.38	.75	.40	.22	.08
Corporation	116	188	7.52	10.52	1.17	.98	.38	.37	.47	.29	.12	.12
Academic												
Government												
Academic and Government	7	10	9.14	4.9	.57	.70	.28	—	.57	1.30	.14	.30
Foreign	55	102	8.0	7.35	1.51	1.87	.16	.6	.18	.24	.13	.01
All	246	427	7.55	9.37	1.18	1.18	.26	.30	.49	.33	.15	.11

Table 5: Invention Science Linkages

	Number of Patents		Citations Per Patent: US Patents Patents		Citations Per Patent: Foreign Patents		Citations Per Patent: Industry Publication		Citations Per Patent: Science Publication		Percent with Science Citation	
	85	90	85	90	85	90	85	90	85	90	85	90
Zoology												
Individual	0	11	0	5.73	0	1.36	0	0	0	.1	0	9
Corporations	16	41	2.93	6.56	.31	3.07	.13	.83	3.13	3.29	25	71
Academic												
Government												
Academic plus Government	4	17	3.00	2.17	0	.12	.25	.76	3.50	8.64	100	82
Foreign	5	15	5.40	6.50	2.40	2.53	4.40	.93	5.20	4.86	60	46
All	25	84	3.44	5.05	.68	1.48	1.00	.73	3.60	6.67	44	61
Trad. Agriculture												
Individual	9	5	1.00	3.40	2.33	0	.22	0	0	0	0	0
Corporation	28	25	3.25	4.36	1.71	1.8	.25	1.0	.25	.28	21	16
Academic												
Government												
Academic and Government	1	7	7.00	5.28	7.00	.14	0	1.14	0	2.00	0	25
Foreign	10	22	4.15	3.90	1.90	1.81	1.10	.50	0	.05	0	5
All	58	59	5.68	4.22	3.70	1.45	.51	.74	.12	.37	14	10

Appendix Table 1

The name and date of establishment of learned American journals in sciences related to agriculture and in agricultural sciences.

Year	Journal
I. General Sciences Related to Agriculture	
A. Chemistry, Biochemistry and Biophysics	
1878	Journal of American Chemical Society
1905	Journal of Biological Chemistry
1932	Annual Review of Biochemistry
ab 1941	Biodynamics
1942	Archives of Biochemistry and Biophysics
1954	Methods of Biochemical Analysis
1958	Journal of Chromatography
1958	Talanta
1959	Biotechnology and Bioengineering
1959	Journal of Lipid Research
1960	Analytical Biochemistry
1960	Biophysical Journal
1962	Biochemistry
1963	Biopolymers
1970	Journal of Cellular Biochemistry
1971	Preparative Biochemistry
1972	Critical Reviews in Biochemistry
ab 1973	Journal of Biological Physics
a 1975	Journal of Cyclic Nucleotide & Protein Phosphorylation Research
1976	Applied Biochemistry and Bioengineering
1976	Cell Biophysics
a 1979	Journal of Applied Biochemistry
B. Biology and Molecular Biology	
1926	Quarterly Review of Biology
ab 1939	Symposium of Society of Developmental Biology
ab 1949	Survey of Biological Progress (1962)[c]
ab 1950	Journal of Biology (1966)
B. (Continued)	
1962	Life Sciences
ab 1969	Current Topics in Cellular Regeneration
1972	Adv. in Cyclic Necleotide Research
a 1981	Molecular and Cellular Biology
C. Genetics	
1910	Journal of Heredity
1916	Genetics
ab 1932	Records of the Genetics Society of America (1962)
1951	Advances in Genetics
ab 1960	Studies in Genetics (1972)
ab 1976	Current Advances in Genetics (1980)
a 1979	Developmental Genetics
a 1981	Journal of Molecular and Applied Genetics
D. Bacteriology and Microbiology	
1916	Journal of Bacteriology
1937	Microbiological Review
1947	Annual Review of Microbiology
1950	Advances in Applied Microbiology
1953	Applied and Environmental Microbiology
ab 1974	Mycotoxin
1974	Microbial Ecology
a 1978	Current Microbiology
a 1977	Experimental Mycology
E. Entomology and Environmental Science	
ab 1869	Transaction of the American Entomological Society
ab 1885	Entomological Americana
1908	Journal of Econ. Entomology
1908	Annals of Entomological Soc.
ab 1913	Review of Applied Entomology
1916	Memoirs of American Entomological Society
1920	Ecology (1968)
1933	Pest Control
1947	Coleoptyerists Bulletin
ab 1952	Pesticide Review (1977)
ab 1957	Advances in Pest Control Res.
ab 1967	Pesticide Monitoring J. (1981)
ab 1968	International Pest Control
1971	Insect Biochemistry
a 1975	Ecological Modeling
a 1976	Systematic Entomology
a 1982	Environmental Toxicology and Chemistry
F. Economics (major journals only)	
1886	Quarterly Journal of Economics
1887	American Economic Review
1919	Journal of Political Economy
1933	Rev. of Economics & Statistics
1933	Econometrica
1933	Southern Economic Journal
1933	Rev. of Economic Studies
1934	Journal of Marketing

Appendix Table 1

	Year	Journal	Year	Journal	Year	Journal
I. General Sciences Related to Agriculture						
F. (Continued)						
	1952	Economic Development and Cultural Change				
	1960	International Economic Review				
	1962	Western Journal of Economics (Economic Inquiry)				
	1966	Journal of Human Resources				
	1966	Journal of Finance				
	1968	Journal of Money Credit and Banking				
	1972	Journal of Economics and Business				
	1972	Journal of Econometrics				
	1974	Journal of Mathematical Economics				
a	1975	Journal of Macroeconomics				
a	1977	Journal of Development Economics				
a	1983	Journal of Labor Economics				
a	1985	Journal of Macroeconomics				
ab	1985	Econometric Theory				
II. Agricultural Science						
A. Field Crops, Horticultural Crops, and Forestry						
1. Production			**2. Protection-Maintenance**		**3. Basic**	
ab	1879	Drainage Journal	ab	1885 Journal of Mycology	ab	1897 Plant World
ab	1898	American Farm Equipment		1909 Mycologia		1897 Publication of Botanical Society of America
	1907	Agronomy Journal		1911 Phytopathology		1898 Bryologist
	1913	Journal of Agricultural Research (1949)		1917 Plant Diseases		1914 American Journal of Botany
	1916	Soil Science	ab	1928 Studies in Forest Pathology	ab	1923 Studies from the Plant Physiology Lab.
ab	1924	Wheat Studies (1944)	a	1962 Journal of Research on the Lepidoptera	ab	1926 Plant Research
ab	1926	Fertilizer Review		1969 Journal of Nematology		1926 Plant Physiology
	1936	Soil Science Society of America Journal	ab	1982 Advances in Plant Pathology	ab	1933 Physiologia
	1948	Journal of Range Management	ab	1983 Journal of Environmental Horticulture		1935 Botanical Review
	1949	Advances in Agronomy				
ab	1951	Irrigation Journal				

Appendix Table 1

Year	Journal
1. Production	
1952	Weed Science
1956	J. of Irrig. and Drainage Engineering
ab 1958	Transactions of the Amer. Assoc. of Agricultural Engineers
1961	Crop Science
ab 1963	Agronomist
ab 1970	Weeds Today
ab 1974	Peanut Science
ab 1976	Journal of Seed Technology
ab 1978	Timely Soil Topics
a 1984	Journal of Fertilizer Issues
ab 1985	Fertilizer Technology
1899	Rhodora
1903	Journal of American Society of Horticulture Science
ab 1915	Citrography
1922	American Horticulturalist
ab 1923	Bulletin American Horticulture Society (1926)
ab 1935	Journal of Arbiculture (1974)
ab 1935	Morris Arboritum Bulletin
ab 1946	Fruit Varieties Journal
ab 1951	Garden Journal
ab 1951	Plant Propagator
ab 1966	Hort Science
1979	Horticulture Review
1902	Journal of Forestry (For. Quarterly)
ab 1924	Forest Worker (1933)
ab 1934	Tree-Ring Bulletin
ab 1934	Timber Statistical Review
ab 1947	Harvard Forest Papers (1965)
1951	Forest Products Journal
ab 1951	Journal of Agriculture and Forestry

Year	Journal
2. Protection-Maintenance	

Year	Journal
3. Basic	
1947	Economic Botany
1950	Annual Review of Plant Physiology
ab 1961	Phycology
1965	Journal of Physiology
a 1976	Systematic Botany
a 1977	Experimental Mycology
a 1979	Journal of Plant Nutrition
a 1981	Plant Molecular Biology
ab 1983	Plant Breeding Review
ab 1984	Advances in Plant Nutrition

Appendix Table 1

Year	Journal
	1. (Continued)
1955	Forest Science
ab 1957	Journal of Forest History
ab 1964	International Review of Forestry Research
1968	Wood Science (Wood and Fiber Science)
ab 1977	Southern Journal of Applied Forestry
	B. Livestock and Poultry
	1. Production
1917	Journal of Dairy Science
ab 1920	International Rev. of Poultry Science (1939)
1921	Poultry Science
1942	Journal of Animal Science
ab 1949	Proceedings, American Society of Animal Science
ab 1949	Proceedings, Council on Research of American Meat Institutes
ab 1965	Dairy Field
ab 1983	Animal Technology
ab 1985	Animal Nutrition and Health
	2. Protection-Maintenance
1877	Animal Veterinary (J.Am.Vet.Med. Assoc.)
1911	Cornell Veterinarian
1914	Journal of Parasitology
ab 1931	Veterinary Bulletin
ab 1949	Southeastern Veterinarian
1954	Journal of Protozoology
1957	Avian Diseases
ab 1958	Veterinary Toxicology
1959	Journal of Invertebrate Pathology
1959	Journal Am. Veterinary Radiology, Assoc.
1960	Journal of Small Animal Practice
ab 1962	Veterinary Economics
ab 1963	Veterinarian-International Journal Devoted to Farm Animal Practices
1964	Veterinary Pathology
ab 1965	Bovine Practitioner
1971	Journal of Veterinary Surgery
a 1972	Immunology Investigations
a 1975	Veterinary Parasitology
ab 1976	Livestock and Veterinary Sciences
a 1976	Veterinary Microbiology
ab 1977	Veterinary Clinical Pathology
	3. Basic
1898	American Journal of Physiology
1904	Journal of Experimental Zoology
1916	Journal of Immunology
1917	Endocrinology
1940	American Journal of Veterinary Research
1951	Experimental Parasitology
1961	American Zoologist
1961	Advances in Immunology
ab 1963	New Methods of Nutritional Biochemistry
1967	Methods of Immunology and Immunochemistry
ab 1969	Mammalian Species
1974	Immunogenetics
ab 1977	Advances in Nutrition Research
a 1984	Journal of Leucocyte Biology

Appendix Table 1

	Year	Journal
		2. (Continued)
a	1978	Journal of Veterinary Pharmacology and Therapeutics
a	1979	Veterinary Immunology & Immunopathology
ab	1980	Veterinary Medical Review
	1980	Immunology Today
ab	1985	Parisitology Today
		C. Natural Resources and Wildlife
	1867	American Naturalist
	1909	American Midland Naturalists
	1934	Progressive Fish Culturist
	1935	Soil Conservation (1980)
ab	1935	Living Wilderness
	1937	Journal of Wildlife Management
	1939	Great Basin Naturalist
	1946	Journal of Soil and Water Conservation
ab	1950	Game Research Report
	1956	Southwestern Naturalist
	1958	Water Resource Bulletin
ab	1959	Wildlife Disease
	1961	Natural Resources Journal
ab	1962	Underwater Naturalists
	1963	Wildlife Monograph
ab	1962	Fisheries Industrial Research (1970)
ab	1965	Conservation Research Report
	1965	Journal of Wildlife Diseases
ab	1968	Economics of Clean Water
	1971	International Wildlife
	1972	Conservationist
	1972	Journal of Environmental Quality
	1973	Wildlife Society Bulletin
ab	1974	Western Wildlands
ab	1974	Rangelands
a	1974	Agriculture and Environment (1982)
		D. Agricultural and Resource Economics
	1919	Journal Farm Economics (Am. J. Agr. Econ.)
	1925	Land Economics
b	1928	Studies in Land Economics
b	1938	Agricultural Finance Review
	1949	Agricultural Economics Research
	1956	Agricultural Marketing (1971)
b	1960	Food Research Institute Studies
b	1961	Agricultural Economic Report
b	1966	Land Economics Monographs
	1969	Southern Journal of Agricultural Economics
	1972	Northeastern Journal of Agricultural Economics
	1974	Journal of Environmental Economics and Management
b	1977	Western Journal of Agricultural Economics
b	1979	North Central Journal of Agricultural Economics
b	1979	Agricultural Law Review
b	1983	Journal of Agribusiness
		E. Rural Sociology
	1936	Rural Sociology
ab	1973	Sociology of Rural Life
ab	1980	Rural Development
ab	1981	Rural Sociologist

Appendix Table 1

Year	Journal
C. (Continued)	
a 1976	Journal of Water Resource Planning and Management
ab 1979	Prairie Naturalist
1981	Journal of Freshwater Ecology
ab 1981	North American Journal of Fisheries Management

III. Post-Harvest Sciences

A. Food Chemistry, Science & Tech.		B. Human Nutrition		C. Home Economics (Social Sci. and Textiles)	
ab 1906	American Food Journal (1928)	ab 1886	Dietetic and Hygienic Gazette (1914)	a 1910	Journal of the Textile Institute
1924	Cereal Chemistry	1928	Journal of Nutrition	ab 1912	Journal of Home Economics
a 1937	Journal of Milk and Food Technology (Journal of Food Protection)	1942	Nutrition Reviews	1931	Child Development
1939	Journal of Food Science	ab 1957	Journal of Applied Nutrition	a 1931	Textile Research Journal
1947	Food Technology	ab 1966	Nutrition Today	a 1934	Annals of Child Development
ab 1948	Advances in Food Research	a 1969	Journal of Nutrition Education	1939	Journal of Marriage and the Family
1953	Journal of Agricultural and Food Chemistry	a 1977	International Journal of Obesity	ab 1952	Housing
ab 1958	Agrichemical Age	a 1977	Journal of Food Safety	ab 1957	Family Economics Review
ab 1967	Food Development (1982)	ab 1978	Nutrition Planning	ab 1960	Cornell Hotel and Restaurant Quarterly
ab 1969	Food Industry Studies	ab 1980	Journal of Nutrition of Elderly	ab 1964	Advances in Gerentological Research (1972)
a 1975	Progress in Food and Nutrition Science	a 1981	Nutrition Research	1967	Journal of Consumer Affairs
ab 1976	Advances in Cereal Science and Technology	ab 1982	Nutrition and Behavior	ab 1969	Textile Chemistry and Colorist
a 1977	Journal of Food Biochemistry			ab 1972	Home Economics Research Journal
ab 1977	Journal of Food Distribution Research			ab 1973	Housing and Society
ab 1977	Journal of Food Quality			a 1974	Advances in Consumer Research
a 1977	Journal of Food Processing and Preserving			1974	Journal of Consumer Research
ab 1981	Dairy and Food Sanitation				

[a]The Journal is not indexed in the Journal Citation Reports of the 1975 Science Citation Index or the 1978 Social Science Citation Index.
[b]The Journal is not indexed in the Journal Citation Reports of the 1985 Science Citation Index or the Social Science Citation Index.
[c]Numbers in parentheses are dates when journals went out of existence.