ORGANIZED RESEARCH, BASIC INFORMATION AND THE PRODUCTIVITIES OF INVENTORS

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It is often argued that basic research is underproduced, and that firms engaging in R & D concentrate mostly on development research.[1] Many major breakthroughs in private industries allegedly emerge to a disproportionate degree from sources outside the industries or from independent inventors.[2] This paper applies transaction cost economics to analyze how research activities are organized. Contrary to the conventional belief, it can be shown that in the absence of government regulation, private companies can arrange to capture the return to basic ideas, and that more useful ideas should, on the average, emerge from large organizations than from small independent concerns.

I. Definitions and Preliminary Discussions

(a) Basic Research: Inventive activities are commonly classified into three types: (1) basic research, defined by some as research to gain knowledge for its own sake; (2) applied research, directed toward obtaining knowledge with practical implications; and, (3) development research, aimed at the translation of knowledge into concrete new products and processes.[3] The distinctions are quite vague, and not necessarily useful. A simplified approach here is to view the value of each idea as consisting of two components: the improvement aspect, defined as the expected value derived from using the idea in the production of goods and services (usually estimated by the area beneath the demand curves and the marginal costs of production); and the basic aspect, defined as the expected reduction in the cost of inventing future ideas. The ratio of these two value components determines whether the research is "basic," "applied," or "developmental" in nature. For expositional simplicity this paper treats ideas as either purely basic or improvement. For example, a chemical formula which by itself is useless can be modified and applied in medicine, paint, and other chemical products. We will treat the formula as a basic idea and its numerous applications as improvement ideas.

(b) Organized Research: In the common view, organized research consists of a team of cooperating inventors in a research laboratory with elaborate equipment, while an independent inventor is usually pictured as someone working casually in his own garage. Implicitly, this view distinguishes organized from independent research solely on the basis of methods of research, i.e. technical complementarity of research (team production vs. working alone) and capital intensity (research equipment vs. garage facilities). However, neither of these factors is truly responsible for the organization of research activities. As pointed out by Coase in 1937, and more recently by Alchian and Demsetz (1972) both team cooperation and capital equipment can be arranged by explicit market transaction. Specifically, in a world of zero transaction cost, one can think of inventors independently renting research facilities (e.g. buying computer time) from the owners of this equipment. And in situations where cooperation among different types of inventors is needed, market transactions can be arranged in a fashion similar to a homeowner's arranging the cooperation of an electrician and a plumber in fixing his house. The questions of technical complementarities and capital intensities are really about how to invent rather than how inventive activities are organized. Our main interest is in this latter question, which must be answered by including transaction costs.

Organized research must be identified on the basis of contractual forms rather than technical means of invention. In this paper, we define organized research as a set of contracts having both of the following characteristics: (a) the contracts require the assignment of patent rights with methods of compensation prespecified before the act of inventing, and (b) the contracts involve more than one inventor working on related areas.[4] Inventors' employment contracts in the real world do correspond quite well to these two definitional characteristics. In a descriptive study of inventors' employment contracts, the following observation was reported.

> (Employment contracts) typically include three major provisions: (1) an obligation by the employee to assign inventions he makes; (2) a duty to cooperate in disclosing inventive activities, and in providing necessary data, affidavits and testimony for purposes of patenting; and (3) an obligation to retain in confidence trade secrets and other confidential information.[5]

Two intuitive explanations for why inventors would choose an employment contract rather than independent work are: (a) risk aversion and (b) team production of inventors. The first is Frank Knight's; the second is that of Alchian and Demsetz. The risk argument is most plausible, but it does not really explain the assignment of patents because an inventor could grant nonexclusive licenses to multiple firms, each with payment prespecified, and the innovation risks would be shifted just as in an employment contract. Apparently, risk alone cannot explain the observed contracts.[6] Furthermore, very risky situations would probably require the sharing of royalties between the owner of the "firm" and the inventor,[7] but several case studies have reported this as quite infrequent.[8]

The team production argument also has some limitations in the case of innovation. Alchian and Demsetz characterized a firm as having a "centralized contractual agent in a team production process." The reason is that team production (defined as a production function of having positive cross partials) makes it difficult to detect the shirking of an individual worker on the basis of final output; if the metering of input is relatively less costly, a contractual agent will be employed to monitor the shirking of input. This presumption about transaction cost may not apply in the case of producing ideas. If one considers ideas as the output and the process of thinking as the input, it seems more costly to meter input than output. Even though half-baked, ideas usually can be evaluated with some degree of accuracy by successful patents, written publications, interim reports, or debates, etc. By contrast, the shirking of mind is impossible to detect. Thus, the centralized agent's role of monitoring input seems ineffective, and there is no point in having this middleman to facilitate the production of ideas.

Consider the daily activities of an employed inventor in a typical research organization: he researchers a little in the library or in the laboratory, he discusses a little with his colleagues, and he thinks independently the rest of his time. This set of activities does not seem to be seriously disturbed if the inventor rents the research facilities and keeps the output (patent) himself. Interaction with colleagues can then come about not by centralized agent employment, but by the clustering of independent, non-cooperative inventors having similar interests, in the same manner that complementary business interests have a tendency to cluster around business districts without explicit cooperation. These possibilities should generate curiosity as to why assignment of patents are observed to be so predominant. In the following section, we will provide a reason for organized research which requires assignments of patents but which does not necessarily involve team cooperation or inventors' risk aversion.

II. The Hypothesis

The central hypothesis of this paper is that competition among inventors of improvement ideas (as defined) will result in rent dissipation of basic ideas (as defined). The pooling of patentable improvement ideas, in the form of organized research (as defined), will minimize the dissipation of nonpatentable basic ideas. We begin by examining three alternative property structures governing the dependence of improvement ideas on basic ideas. Then, by including the effects of competition into the model, we show why prior contracts in the form of patent assignment or exclusive territories would result when nonpatentable basic ideas are incorporated in patentable improvement ideas. Furthermore, based on a very simple model, we can easily show that the superior inventors would have the strongest incentives to organize this type of contract. Thus, important ideas should, on the average, emerge from organized research rather than from "independent" efforts.

It is clear that there are at least three ways to delineate the rights between a basic and an improvement idea. First, a patent system could award a basic idea not just its share of the innovation, but the whole innovation.[9] Second, the patent system could reward a basic idea with nothing and give the right of the whole innovation to the improvement idea.[10] Third, the patent system could delineate each idea its share of the innovation. Specifically, the patent system can grant property rights to both ideas, i.e. a person utilizing an improvement idea will be considered as infringing upon the basic idea without a contract from the latter but the owner of the basic idea cannot freely utilize the improvement idea either.[11]

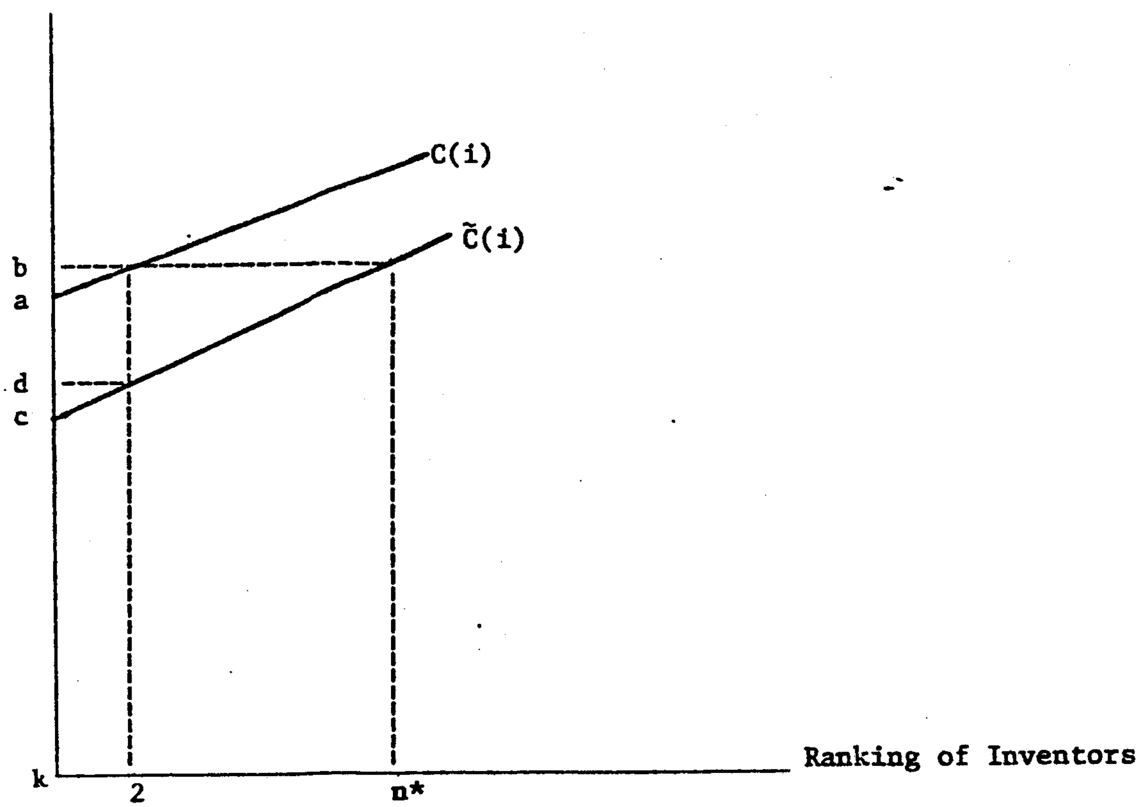
Superficially, the first system "over-rewards" and the second system "under-rewards" a basic idea; only the third system seems to facilitate contracting between basic and improvement inventors. However, in a world of zero transaction cost, and over-or-under reward problems can be resolved by having the "under-rewarded" inventor contracting with the "over-rewarded" inventor before the former has committed resources in inventing. Thus, a change in property rights will alter only the timing of the contract, with no effects on resource allocation if contracting cost is zero.[12]

Extreme forms of property right delineation, by itself, cannot explain why patent rights are assigned, even though they are consistent with the real world observation that employment contracts are before the act of inventing. To further explain the assignments of patents in employment contracts, we include also the effects of competition by improvement inventors into the picture.

Assume a group of improvement inventors, each having his own field of specialty, but each being a potential inventor in the others' specialties. Consider a particular specialty and rank the cost of inventing among these inventors in this specialty by a function $C(i)$, where i serves as an index for an inventor (see Figure 1). The superiority of an inventor is defined in terms of his cost of inventing, and his rank will be denoted by i. The slope of $C(i)$, C', is the cost differential between the ith and the $i + 1$th inventor.[13]

The equilibrium return to the innovation in this specialty depends on how inventors within that specialty compete. In general, they can rush to innovate, they can offer more useful innovations, or they can simply cut royalty rates before innovation.[14] For expositional simplicity, I assume here that potential competition among this group of inventors is viable. Thus, at

Figure 1



equilibrium we expect the superior inventor to win the race to invent, but his return is constrained by the cost of the next best inventor.[15] In terms of Figure 1, this amount can be represented by bk. Since ak represents the cost of the superior inventor, the differential rent of the innovation is ba.

A basic idea now reduces the cost of inventing this innovation to $\tilde{C}(i)$. If all inventors are equally efficient in utilizing the information, it will be a parallel shift as drawn. If a superior inventor is more (less) efficient in utilizing the basic information than the less superior ones, the slope of $\tilde{C}(i)$ will be steeper (flatter). As the way the curves are drawn, the vertical difference between the two curves (ac) measures the value of the basic idea.

If property rights to the basic information are fully enforced, its value (ac) is easily capturable through licensing of patents or trade secrets in the market. But if the basic idea is not protected by property rights whereas its improvements <u>are</u>, altering the timing of the contract as explained in the previous paragraphs would not resolve the capturability problem: The superior inventor in this situation has no assurance that the basic inventor would not disclose the information to his competitor; and if the basic inventor does, the superior inventor will suffer a loss in value of some information which he has paid for, but the lack of property right on the basic information would not permit him to request compensation. The dilemma is compounded by the fact that it is efficient to let his competitors to know the basic information because they may be superior inventors in other specialties. Thus, disclosing the basic information to everyone maximizes its value, but doing so without some restraint on competing inventors implies its return is noncollectable. In terms of Figure 1, competition among improvement inventors after public disclosure of basic information would lower the return to the improvement idea to dk. The rent to the superior inventor is dc, which must be the same as ba, the differential rent before information is disclosed. Thus, no inventor would contract with the basic inventor unless some contractual arrangements are first worked out among competing inventors.

The contractual remedy to the dissipation problem above requires restraining competition among the improvement inventors in some dimensions. The assignment of patents covering the improvement ideas will serve this purpose. By yielding the patent rights to a central agency, each inventor cannot grant license independently to compete with other inventors. The superior inventor can then charge a higher royalty to cover his expense for the basic information.[16]

The number of inventors necessary to form such a coalition depends on the value of the basic information and the ability variance of the improvement inventors. To capture the basic information value of ac in Figure 1, the coalition must have at least n^* inventors, as labeled on the x-axis of the diagram. The inventors would have incentive to contract more than n^*. However, if there is competition in establishing coalitions, the maximum number cannot exceed n^*, since without the basic information, the buyers of the improvement idea only have to pay a royalty of bk. Competition of potential coalitions in obtaining prior contracts from these buyers would thus put an upper limit on the size of the coalition.

Several implications immediately follow:

(a) In industries where organized research is formed to capture basic information, the superior inventor (one who has the lowest cost of inventing but not necessarily the one having the basic information) will always be in the coalition. This implication is obvious from the formulation of the problem.

(b) The higher the value of basic information, the larger is the size of the coalition. A high basic value is equivalent to a larger discrepancy between $C(i)$ and $\tilde{C}(i)$ curves. Holding the slope of the curves constant, a larger n^* is required.

(c) The lower the ability variance of improvement inventors, or the cost differentials of improvement inventors, the larger is the size of the coalition. A lower cost differential is equivalent to a flatter slope of the cost curves. Holding the value of basic information constant, a larger n^* is required.

(d) If the ability to invent improvement ideas is positively correlated with the ability to utilize basic information, the size of the coalition should be smaller than the case where the abilities are negatively correlated. Positive (negative) correlation is equivalent to a steeper (flatter) $\tilde{C}(i)$ curve, and n^* should be smaller when $\tilde{C}(i)$ is steeper.

Similarly, if the abilities of inventing basic and improvement ideas are positively correlated, i.e., a basic inventor is also superior in improving his own idea, the size of the coalition should be smaller than the case where the abilities are negatively correlated, i.e., the basic inventor is not very good at improving his own idea.

It is important to emphasize that our "organized research" does not necessarily require the basic inventor to be part of the coalition. Recruiting these inventors may reduce communication cost, but it is not the essence of organized research. Organized research here is viewed as a system among improvement inventors by which payment to the basic inventor can be assured. In fact, there might not even be a contract between the basic and the improvement inventors. The basic inventor could speculatively purchase the stocks of the improvement inventors prior to the disclosure of his basic information (Hirhsleifer, 1971). However, the point is that he would not have done so unless he noticed that the competing improvement inventors have been organized, because in the absence of such arrangement, the stock value would not have risen even if his basic information was proven useful.

III. Empirical Results

Data limitation has been a major handicap in the testing of our hypothesis. Basic research statistics are available only in annual aggregate form, and the very nature of the activity makes any small sample classification dubious. Ability variance of inventors can be potentially estimated by income variance, but the latter is not in any public record, and private research organizations are often reluctant to disclose such information.[17] The only data information that is available and that has been studied quite intensively in the past concerns the importance of innovations. This will be the subject matter in this section.

As described in the introduction, most past studies have demonstrated evidence contradictory to our implication that relatively more superior innovations should, on the average, originate in organized research. However, these studies do contain some interpretation errors and we will discuss them before we present our evidence.

In all studies, some "expert opinions" are first used to preselect a set of "important innovations." The proportion of this set originating from research organization is then compared with that originating from independent inventors or firms outside the industries. Observing a large proportion of outside innovation has formed the core of their arguments.

Their testing procedures can be formalized as follows. Suppose there are two groups of inventors, the superior and the inferior; each has a frequency distribution on the values of their innovation, $f_s(v)$ and $f_i(v)$. By definition, $E_s(v) > E_i(v)$. The "expert opinion" is equivalent to someone selecting a sample of innovation based on some implicit critical value of the innovation, $\bar{v}$. The probability of an inventor inventing something major is represented by the area of the frequency distribution to the right of $\bar{v}$. The probability of each of the two types of inventors can be represented by P_s and P_I respectively in Figure 2. Without any assumptions about the variances of the two distributions, it is possible that $P_s < P_I$ even though $E_I(v) < E_s(v)$.

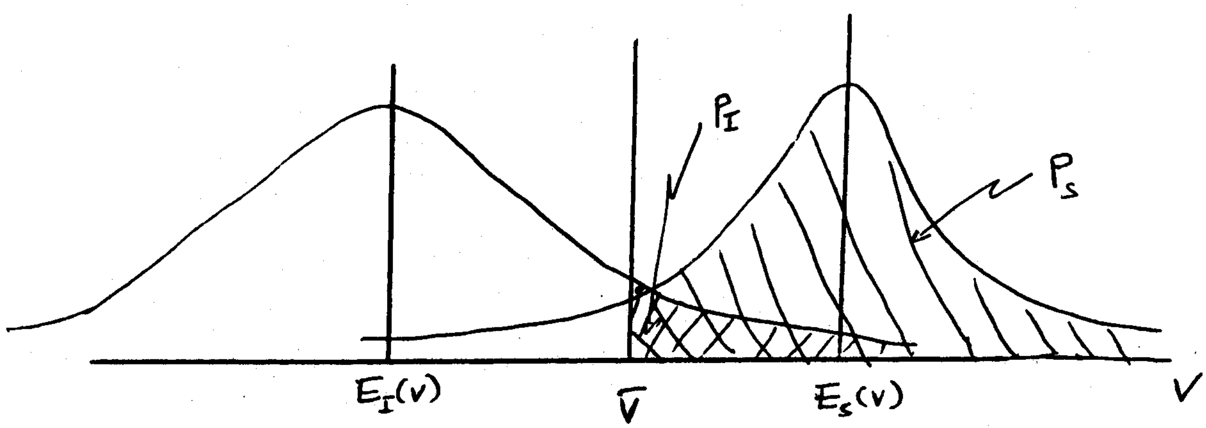
Even if one assumes identical variances, the observed proportion of major innovation from the inferior inventors may still be higer if there are relatively numerous inferior inventors. More specifically, suppose there are m inferior inventors and n superior inventors and suppose the former group is independent while the latter is organized. The expected observed proportion of major innovation originating from organized research is

$$\frac{nP_s}{mP_I + nP_s} = \frac{P_s}{\frac{m}{n} P_I + P_s}$$

Even if $P_s > P_I$, this observed proportion can be close to zero for a high proportion of inferior inventors, i.e. high $\frac{m}{n}$. In other words, a small proportion of "major" innovations originating from organized research may still be consistent with the hypothesis that relatively superior inventors tend to organize their research.[18]

To re-evaluate organized and independent research, consider a different testing procedure: instead of comparing inventions, let us try comparing inventors. More specifically, we can randomly sample m independent inventors and n employed inventors in a given industry, construct some

Figure 2



average productivity measures on the lifetime performance of these inventors, and see how such measures vary among the two groups. This testing procedure is free from the interpretation error mentioned above because m and n will only affect the variances, but not the means of the estimates. Furthermore, the law of large numbers would imply that summary statistics based on lifetime performance is more reliable than statistics recorded at a particular point in time.[19] We utilize two data sets in this paper. The first is based on a 1938 study of Petroleum cracking patents by David McKnight, Jr., who spent five years compiling a catalogue of all patents relevant to the field of petroleum cracking between 1861 and 1938.[20] McKnight examined a total of 2,886 patents covering the works of 1,003 inventors. For each patent, his catalogue gives the patent number, the name of the inventor, the application date, the date of issue, a general description of the patent, and most important to our study, the assignment records of the patents and the names of the assignees (if any). This last information is what we will use to distinguish independent from organized research.[21]

A testing procedure similar to past studies will count the proportion of assigned patents (2,300) to total patents (2,886) in this sample, which is 0.80. Aside from the interpretation error mentioned above, this number is also misleading in that many of the patents were assigned to one-man corporations or firms unrelated to the oil industry. Counting only the patents in large firms in the oil industry, the number shrinks to 0.57.[22] The numbers also vary from year to year if the data is broken down annually.[23]

Our testing procedure first reconstructs the life histories of the 1,003 inventors from McKnight's catalogue. Summary statistics regarding an inventor's career life, his total patents, his assigned patents, the length of time he remains with an organization, the size of that organization, the number of jobs he has in his career, his extent of specialization, and the extent of his joint inventive works with others, etc. can then be estimated. (See Table I for a complete list of the constructed variables and their definitions.) An inventor could have none of his patents assigned to anyone. In that case, he is clearly an independent inventor and will be classified as such. If he assigned part or all of his patents to one or more organizations, we identify the organization that has the largest proportion of his patents as his primary employer. If he has most of his patents unassigned, he is identified as an independent inventor. An example of this identification procedure and its limitations will be described in the Appendix.

We compare the distributions of independent inventors with the inventors that have a primary employer in Table II. Column One lists the set of variables we are comparing. Column Two gives the means, the variances, and the number of observations on those variables for the independent inventors. Column Three gives the same for the assigned inventors. Column Four reports the t-statistics on the differences of the means by assuming equal or unequal variances.

One interesting feature of Table II is that assigned inventors seem by some measures to be more productive than independent inventors. Both total patents and patents per year of the assigned inventors are higher than that of the independent inventors (Rows 1 and 3). The discrepancies are even larger for assigned patents and assigned patents per year (Rows 4 and 6). Furthermore, when both the assigned inventors and the independent inventors have found their respective specialties (i.e. comparing the patents assigned to a primary employer to the patents an independent inventor keeps himself, and comparinmg the patents per year when an assigned inventor is with a

Table I: List of Constructed Variables

ALFE	Years between the dates of first assigned patent and last assigned patent. Enter as a missing variable if there are no assigned patents.
APA	The number of assigned patents. Enters as a missing variable if there are no assigned patents.
ASPC	Percentage of assigned patents, APA/TPA. Equals zero if there are no assigned patents.
DEL^1	The difference in productivities (patent/year) when the inventor is associated with his primary organization and when he is not. Enters as a missing variable if TLFE = OLFE. The formula is XOLFE - ((TPA-OPT)/(TLFE-OLFE)).
DEL^2	The difference in productivities (patent/year) when the inventor assigns his patents and when he does not. Enters as a missing variable if TLFE = ALFE or APA = 0. The formula is XALFE - ((TPA-APA)/(TLFE-ALFE)).
DISV	Years between the dates of first patent in the inventor's career and the first patent assigned to his primary organization.
DM	Proxy for team cooperation, 0 if the inventor has no joint patents and 1 if the inventor has one or more joint patents.
HYPR	(HYPY-TLFE)/TLFE.
HYPY	Sum of active lives. Active life of an organization is defined as years between the first and last patents in that organization the inventors assigns patents to. All independent or unassigned patents are counted as one organization or job.
IDISV	Years between dates of first patent in the inventor's career and first assigned patent.
JBS	The number of different organizations the inventor assigned patents to. Unassigned patents are counted as one organization.
OLFE	Years between the dates of first and last patent belonging to the inventor's primary organization.
OPT	Number of patents belonging to the inventor's primary organization.
ORG	Number of inventors employed by the inventor's primary organization. If an inventor worked for more than one company, his primary organization was assigned on the basis of most patents to that company. In the case of a tie, the inventor's latest job was chosen. Independent inventors have ORG equal zero.

Table 1 (Continued)

SPL	For independents, SPL equals the number of unassigned patents divided by years between the first and last unassigned patents, for assigned inventors, SPL equals XALFE.
TLFE	Years between the first and last patent in an inventor's career life.
TPA	Total number of patents in career life.
XALFE	Number of assigned patents divided by years between the first and last assigned patents, APA/ALFE. Enters as a missing variable if there are no assigned patents.
XOLFE	Number of patents belonging to inventor's primary organization divided by years associated with that organization, OPT/OLFE.
XSPEC	Number of patents belonging to inventor's primary organization divided by the total number of the inventor's patents, OPT/TPA.
XTLFE	Number of total patents in the inventor's career divided by length of his career, TPA/TLFE.
YSPEC	Number of years associated with the inventor's primary organization divided by the length of his career, OLFE/TLFE.

Table II: Summary Statistics of Independent and Assigned Inventors

(All Observations Included)

Variable	Independent μ	Independent σ^2	Independent n	Assigned μ	Assigned σ^2	Assigned n	t_{eq}	t_{uneq}
TPA	1.954	1.961	281	3.978	9.468	722	-3.55	-5.45
XTLFE	.999	.455	281	1.144	.812	722	-2.83	-3.57
TLFE	3.067	4.675	281	3.398	4.26	722	-1.07	-1.03
APA	1.667	1.451	33	3.807	9.343	722	-1.31	-4.98
ALFE	3.152	5.44	33	2.954	3.55	722	.303	.206
XALFE	.906	.328	33	1.177	.855	722	-1.81	-4.13
OPT	1.754	1.512	281	3.61	9.12	722	-3.38	-5.27
OLFE	2.484	3.572	281	2.616	3.045	722	-.588	-.548
XOLFE	1.0218	.428	281	1.221	1.218	722	-2.69	-3.85
SPL	1.022	.428	281	1.177	.855	722	-2.900	-3.798
JBS	1.142	.448	281	1.230	.544	722	-2.397	-2.61
DM	.324	.469	281	.508	.500	722	-5.34	-5.49
HYPR	-.022	.162	281	-.009	.223	722	-.873	-.999
XSPEC	.955	.1311	281	.933	.157	722	+2.25	+2.08
ASPC	.044	.131	281	.965	.113	722	-110.68	-103.86
DISV	.409	2.399	281	.584	2.273	722	-1.08	-1.05
IDISV	3.212	5.195	33	.4017	1.970	722	7.16	3.098
DEL^1	.4976	.5379	25	.9002	2.974	104	-.672	-.129
DEL^2	.095	1.121	30	.869	1.41	57	-2.60	-2.79

primary employer to the patents per year when an independent inventor is by himself), we see that the assigned inventors are more superior (Rows 7 and 9). Similarly, the assigned patents per yer of the assigned inventors are higher than the unassigned patents per year of the independent inventors (Row 10).

One might speculate that the observed difference in patent statistics reflects only the difference in propensity to patent between the two groups of inventors. The casual impression is that organized research is often assisted by able and experienced patent attorneys whereas independents are not. We have no information in our data set to support or refute this opinion. However, on both theoretical and empirical grounds, we do not consider this opinion as obvious. On theoretical ground, it is not clear that the best patent attorney necessarily make more money by working for a firm; it is also not clear that the best attorney always wants to maximize the number of patents per idea. Such issues depend largely on the prevalent forms of contracts between patent attorneys and their clients, which have not been investigated thoroughly in the literature yet. From the inventors point of view, it also does not necessarily follow that an organized inventor would have a higher propensity to patent than an independent. In fact, one could argue that independents should have a greater incentive to patent their innovations than employed inventors because the evaluation and the diffusion of ideas in the former case have to rely totally on market mechanism, whereas such activities in the latter case can occur without explicit market transaction. It goes without saying that market transactions require stronger property right protections than nonmarket transactions. Finally, there exist some empirical studies suggesting that the largest firms in the U.S. usually barely held their own in the receipt of invention patents despite their disproportionate share of both government and private R & D spending.[24]

Table II can also be modified by first deleting inventors with only one patent, and secondly by recounting the number of joint patents. The first modification is motivated by the intuitive speculation that the uncertainty and spontaneity of innovation may not allow an inventor to make rational choices between assigned and unassigned strategies ex-ante. To the extent that such possibilities in fact happen, they should be most frequent among inventors who have a single patent in their life histories. Thus, it may be useful to recalculate Table II by deleting single-patent inventors from the sample. Table III reports the findings. There appear no conflicting results from Table II.

The second modification is motivated by the existence of some joint patents in our sample. The identification procedure in Table II double-counts joint patents. To the extent that joint works are more frequent among assigned than independent inventors, the counting procedure would be biased in favor of our results.[25] This problem can be partially corrected for in subsequent regression analysis by inserting a joint work proxy, DM, as an explanatory variable (see p. 28). But for the purpose of making group comparisons, we might want to recount the patent statistics by allocating only part of a joint patent to an inventor. Table IV reports the results. The group difference is smaller but still significant in almost all cases.

Other information we can get from the comparisons in Table II and III regard the risk hypothesis of organized research. The IDISV variable in Table II (Row 17) tells us that independent inventors were employed much later in their career lives than the assigned inventors. In other words, independent inventors, if eventually employed, are independent first and then employed rather than the other way around. This evidence is inconsistent with

Table III: Summary Statistics of Independent and Assigned Inventors

(With TPA = 1 Deleted)

Variable	Independent μ	Independent σ^2	Independent n	Assigned μ	Assigned σ^2	Assigned n	t_{eq}	t_{uneq}
TPA	3.53	2.50	106	7.44	13.11	334	-3.05	-5.16
XTLFE	.996	.742	106	1.31	1.17	334	-2.60	-3.26
TLFE	6.48	6.28	106	6.18	4.98	334	.503	.447
APA	1.67	1.45	33	7.07	13.01	334	-2.38	-7.15
ALFE	3.15	5.45	33	5.22	4.21	334	-2.62	-2.12
XALFE	.906	.328	33	1.38	1.23	334	-2.22	-5.39
OPT	3.00	1.89	106	6.63	12.77	334	-2.92	-5.03
OLFE	4.934	4.93	106	4.49	3.67	334	.983	.847
XOLFE	1.05	.698	106	1.478	1.76	334	-2.41	-3.59
SPL	1.06	.698	106	1.381	1.27	334	-2.59	-3.40
JBS	1.38	.668	106	1.50	.713	334	-1.53	-1.58
DM	.283	.453	106	.599	.491	334	-5.88	-6.13
HYPR	-.06	.261	106	-.02	.327	334	-1.099	-1.234
XSPEC	.881	.192	106	.856	.204	334	1.129	1.66
ASPC	.117	.193	106	.924	.157	334	-43.58	-39.27
DISV	1.08	3.82	106	1.25	3.21	334	-.444	-.406
IDISV	3.21	5.19	33	.856	2.82	334	4.159	2.57

Table IV: Summary Statistics of Independent and Assigned Inventors

(With Joint Patent Classified as ½ Patent)

Variable	Independent μ	Independent σ	Independent n	Assigned μ	Assigned σ	Assigned n	t_{eq}	t_{uneq}
JPT	.456	.836	281	1.37	4.304	722	-3.53	-5.45
	.6415	1.197	106	2.46	6.123	335	-3.03	-5.13
XJPT	.292	.446	281	.407	.450	722	-3.65	-3.63
	.208	.379	106	.384	.391	335	-4.07	-4.14
OJPT	.431	.790	281	1.27	4.14	722	-3.37	-5.20
	.575	1.121	106	2.242	5.918	335	-2.88	-4.88
ATPA	1.726	1.94	281	3.30	7.94	722	-3.28	-4.95
	3.208	2.518	106	6.197	10.97	335	-2.78	-4.618
AAPA	1.530	1.468	33	3.145	7.801	722	-1.187	-4.174
	1.53	1.468	33	5.867	10.836	335	-2.29	-6.726
AXTLFE	.844	.460	281	.913	.7034	722	-1.504	-1.798
	.871	.686	106	1.058	.9786	335	-1.83	-2.194
AXALFE	.836	.367	33	.942	.7573	722	-.8088	-1.537
	.836	.367	33	1.122	1.052	335	-1.55	-3.33
AXOLFE	.865	.444	281	.9795	1.043	722	-1.78	-2.439
	.924	.653	106	1.204	1.478	335	-1.88	-2.715

JPT = total number of joint patents
XJPT = number of joint unassigned patents
OJPT = number of joint organized patents
ATPA = adjusted total patents = TPA - JPT/2
AAPA = adjusted assigned patents = APA - (JPT-XJPT)/2
AXTLFE = adjusted patents/year
AXALFE = adjusted assigned patents/assigned years
AXOLFE = adjusted organized patents/organized years

For each variable, the top row includes all observations, the bottom row deletes inventors with single patent. Some variables in Table III are not listed either because recounting would not change the estimates (e.g. years) or because it is not directly related to productivity measures (e.g. specialization proxies).

the common notion that inventors' employment contracts are used to diversify risk. The uncertainties conerning the productivity of the inventor ought to be less when he ages; and thus, the incentive to diversify risk should be lower at the latter part of his career. Also, some argue that a superior inventor would like to monopoly price his service when his ability is better known; which should occur at the latter part of his career also. The evidence in Row 17 seems inconsistent with both of these notions.

The joint work proxy, DM (Row 12 in Tables II and III) can be used as an indicator of team production activities. The higher frequency of joint works among assigned inventors suggests some influences of Alchian and Demsetz' theory of firm. This is further supported by counting joint total patents (JPT) and joint organized patents (OJPT) in Table IV. However, the XJPT variable in Table IV reveals that the assigned inventors also have more joint works on their unassigned patents than the unassigned works of the independent inventors. This suggests that the extent of joint work may be a function of the abilities of an inventor rather than a function of the organization form as identified by assignment record.

The life-history statistics of inventors can also be used to study the information cost of ex-ante contracting in innovation. It takes time for both the inventor and his employers to discover his comparative advantage. It is, therefore, interesting to compare the time it takes an average inventor to become associated with the entity which owns most of his patents. The DISV variable in Row 16 of Table II suggests that it takes roughly the same time for the assigned and the independent inventors to sort out their comparative advantages. More detailed investigation of this issue, however, would require information on inventors' specific socio-economic variables as well as a theoretical integration with analyses in the search literature.

Finally, the life-history statistics of inventors can be used to study the issue of specialization in innovation. Here, we get a mixed picture from Tables II and III. Assigned inventors have more jobs (JBS in Row 11) than the independent inventors. But it is not clear whether this means that assigned inventors are less specialized, or tht the assigned inventors have large absolute advantages. Also, specialization can be measured in otherways such as XSPEC, ASPC, DEL^1 and DEL^2. These options open up a set of complicated issues that cannot be resolved until more theoretical works have been formulated. We report our findings here in hope of providing useful clues to future research.

Our second data set uses the patent statistics in the glass container industry, which around 1932 had about 90 manufacturers and research organizations.[26] The names and number of assigned inventors in these organizations in 1932 can be found in the Index of Patents published by the U.S. Patent Office. Based on this list of inventors, we construct the life histories by tracing their assignment records backward and forward in time starting at 1932. We stop tracing if the inventor has five years without any patents.[27] The data set so constructed has 112 inventors employed in 25 glass firms. By construction, there are no indepndent inventors in this set.

Based on past studies (Bishop, 1950; Brown, 1966; Beck, 1976) and the Court Transcript of U.S. vs. Hartford-Empire Co., 323 U.S. 386 (1965), we segregate the 25 firms into "small" and "large" groups. The large group consists of four firms that entered into cross-licensing arrangements with each other -- Owens Illinois Bottle Co., Hartford-Empire, Hazel-Atlas, and Ball Brothers.[28] They were also the chief defendants in the Antitrust case mentioned above. The rest of the firms were classified as "small" firms.

Table V: Summary Statistics of Inventors Working for Small and Large Firms in the Glass Container Industry

Variable	Small μ	Small σ^2	Small n	Large μ	Large σ^2	Large n	t_{eq}	t_{uneq}
TPA	9.87	12.55	45	19.82	30.41	66	-2.08	-2.38
TLFE	9.38	8.78	45	10.80	8.62	66	-.849	-.846
XTLFE	1.07	.587	45	1.63	1.45	66	-2.45	-2.81
APA	8.49	10.70	45	19.00	29.79	66	-2.27	-2.63
ALFE	8.40	7.94	45	10.41	8.21	66	-1.28	-1.29
XALFE	1.07	.597	45	1.61	1.42	66	-2.39	-2.73
OPT	6.89	7.16	45	18.02	29.07	66	-2.51	-2.98
OLFE	6.87	5.74	45	9.52	7.28	66	-2.05	-2.14
XOLFE	1.07	.618	45	1.63	1.42	66	-2.49	-2.84
SPL	- NOT AVAILABLE FOR THIS SAMPLE -							
JBS	1.91	1.26	45	1.76	1.20	66	.648	.642
DM	- NOT AVAILABLE FOR THIS SAMPLE -							
HYPR	.059	1.96	45	.057	.220	66	.061	.062
XSPEC	.831	.207	45	.919	.113	66	-2.90	-2.61
ASPC	.924	.156	45	.963	.073	66	-1.79	-1.58
DISV	1.38	3.04	45	.439	1.30	66	2.22	1.95
IDISV	.556	1.87	45	.152	.707	66	1.60	1.39
DEL_1	-.067	.866	19	.340	1.140	20	-1.25	-1.26
DEL_2	-.001	.933	8	.026	.827	10	-.064	-.063

The summary statistics of the same list of variables in Table II were calculated in Table V.

Group comparisons of certain productivity measures as well as the timing of first assignment (the test for the risk hypothesis) are similar in Table V, and in Table II. As in the oil industry, the bigger firms in the glass container industry also have more able inventors according to some measures, and the small companies inventors also tend to assign their patents late rather than early. The later comparison, however, suffers from a low t value in Table V.[29]

The general pattern behind group comparisons can be further tested by regression techniques. In formulating this problem, the first question confronting us is: what is the meaning of productivity? Inventor A may be better than inventor B according to some measures but A may be worse than B according to others. A competitive market presumably will give an overall evaluation of an inventor's package of productivity characteristics and will reward the inventor accordingly. In fact, one can postulate an "innovation production function" in the form of $P(x_1, x_2, \ldots)$ where x_i are various measures of productivities. Setting the reward of inventor (both pecuniary and nonpecuniary) to equal this function, one can estimate the relative market values of each productivity characteristic. To the extent that coefficients of the productivity measures have the expected signs, the proposition in this paper can be tested by simply comparing the pecuniary and nonpecuniary rewards of inventors in large research organizations with those that are small or independent.

Our data sets do not have income information and the above test is unfeasible; still, we can test our hypothesis "ordinally." Assume the aggregate productivity measure is a function of the total career life

(TLFE) and the average patent per year (XTLFE). The isoquants of this function are shown in Figure 3; their shapes vary depending on the relative importance of longevity (TLFE) and intensity (XTLFE), the inventing techniques specific to an industry, the emergence of unexpected information, and various exogenous factors. The higher-level curves in Figure 3 represent more able inventors because, ceteris paribus, an increase in either TLFE and XTLFE has higher value (no matter how small).

How an inventor chooses his position on the "innovation production function" probably depends on his wage rate, his education, and a whole string of socio-economic variables. These are not observable in our data set, and we will not attempt to model this aspect of the problem. Instead, we treat the data points of the inventors in our sample as mapping out the industry's "innovation production function," and test whether inventors on the higher level curves are employed by bigger firms. Table VI reported the finding in the oil industry. In all seven regressions, the signs of the productivity variables TLFE and XTLFE are positive and highly significant. When a time variable BYPT is inserted to adjust for shifts in the innovation production function over time, the significances of TLFE and XTLFE become even higher. The positive and significant coefficient of BYPT is also consistent with the notion that organized research has become more frequent over time. The coefficient of a specialization measure, ASPC, is positive and significant. This suggests that holding productivities constant, inventors who have a larger proportion of their patents assigned tend to be employed by bigger firms.

The team work proxy, DM, is also included in some regressions in Table VI to evaluate the alternative hypothesis about team production. If organized research arises from team work, the correlation between DM and ORG should

Figure 3

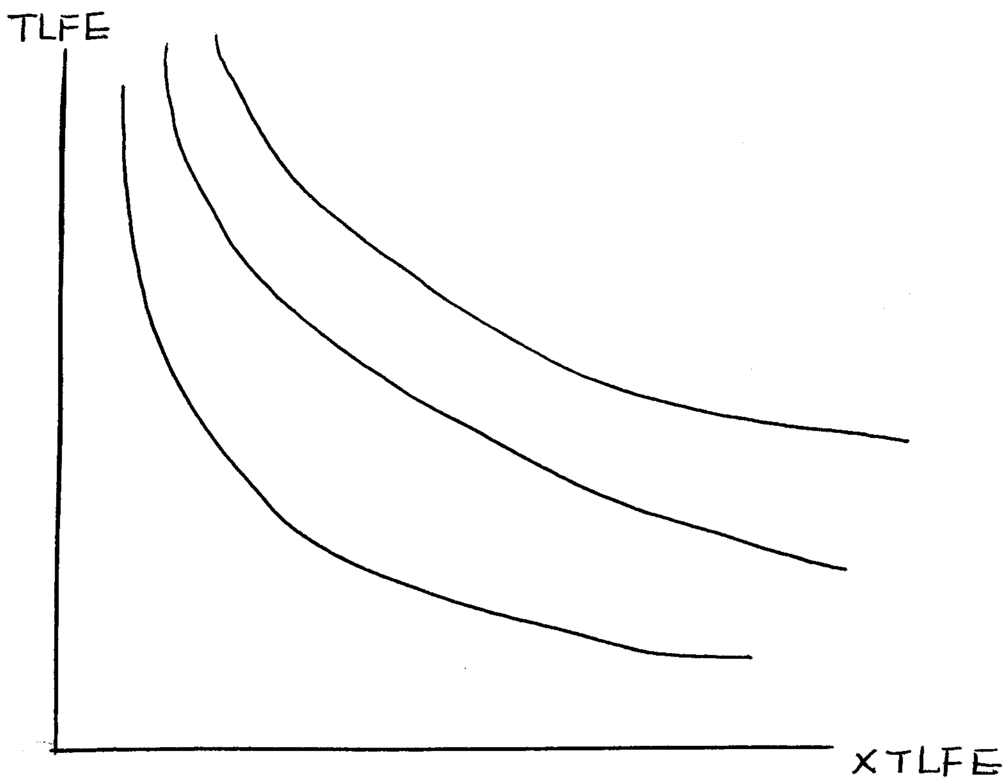


Table VI: The Organization of Inventors

The Dependent Variable in Each Regression is ORG
The Numbers in the Parentheses are t-values

	TLFE	XTLFE	BYPT	ASPC	DM	R^2
1.	.446 (2.95)	6.16 (6.84)				.050
2.	.897 (5.92)	5.73 (6.64)	.661 (9.75)			.1327
3.	.414 (3.06)	4.93 (6.05)		21.33 (15.43)		.233
4.	.657 (4.63)	4.86 (6.04)	.3495 (5.17)	18.57 (12.67)		.253
5.	.427 (2.84)	5.88 (6.51)			3.77 (2.85)	.058
6.	.876 (5.77)	5.59 (6.45)	.645 (9.41)		1.91 (1.49)	.1345
7.	.656 (4.61)	4.85 (6.01)	.349 (5.14)	18.55 (12.56)	.678 (.07)	.253

be positive. Although this effect is detected from regression 5, it becomes insignificant when the time and specialization measure are also included (Regressions 6 & 7).

It is also interesting to examine whether superior inventors also tend to cooperate more: I.e., we want to know if inventors on the higher levels of the innovation production function have more joint works. Table VII reported the findings in the oil industry by using DM as the dependent variable. In general, both the coefficients of TLFE and XTLFE are positive, although their significances are lower than those on Table VI; and in regressions 1, 3 and 5 the coefficients of TLFE were insignificant. ORG continues to have an effect on DM (regressions 5 & 8), but when adjusted for other things, the significance level again goes down.

The general picture that emerges from Table VI and VII seems to be the following: superior inventors as measured by longevity and intensity as defined tend to work in larger research organizations and they tend to cooperate more often.[30] The hypothesis in this paper, as well as the team production theory, can both be the reasons behind organized research in some general sense (regression 5 in Table VI and VII). However, when the test conditions are more refined, the hypothesis in this paper seems to explain organized research better.[31]

Conclusions

The role of corporate research in technological progress cannot be satisfactorily analyzed without first understanding the nature of corporate research. Often, corporate research is loosely defined as organizations associated with elaborate research equipment, or the management of team cooperative research. The validity of such opinions has seldom been

Table VII: The Team Co-operation of Inventors

The Dependent Variable in Each Regression is DM
The Number in the Parentheses are t-values

	TLFE	XTLFE	BYPT	ASPC	ORG	R^2
1.	.00499 (1.35)	.0747 (3.49)				.0133
2.	.0106 (2.84)	.0693 (3.27)	.0082 (4.91)			.0365
3.	.0047 (1.33)	.0635 (2.99)		.1937 (5.37)		.0410
4.	.0086 (2.32)	.0623 (2.95)	.0057 (3.20)	.1489 (3.87)		.0507
5.	.0040 (1.13)	.0616 (2.82)			.0021 (2.85)	.0212
6.	.0095 (2.52)	.0627 (2.89)	.0074 (4.25)		.0012 (1.49)	.0386
7.	.0086 (2.28)	.0621 (2.88)	.0057 (3.14)	.1479 (3.56)	5.416×10^{-5} (.07)	.0507
8.					.0026 (3.51)	.0127

Acknowledgement

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questioned empirically and theoretically in the literature. In fact, many economic propositions, such as one conerning the distribution of major innovations, have been formulated on the assumption that these are stylized facts too frivolous to be questioned.

For at least two reasons these issues are worth some investigation. First, the intuitive opinions are statements concerning the <u>method</u> of research which should not be expected to differ between corporate and independent inventors if all inventors have the same information set. Any observed difference in research methods between corporate and independent inventors, therefore, reflects only a difference of opinions about which economists have very little to say. Second, the stylized facts concerning corporate research have never been statistically documented. Casual empiricism suggests many exceptions; for example, newspaper and magazines often report instances where independent inventors were successful in vastly improving gasoline mileage. These inventors do not appear to be handicapped by the lack of research equipment -- an assumption implicit in the view that corporate research has more facilities. Also, the management strategy observed in corporate research may be very different from those observed in managing production. In fact, there are managers who believe the best way to manage inventors is to leave them alone -- a strategy that would be inconsistent with team production as the explanation of organized research. Thus, on both logical and casual empirical grounds, team production or research equipments should not be taken for granted as identical to organized research.

This paper suggests an approach to identify and to analyze issues of organized research from a contractual viewpoint. Each inventor is assumed to confront the choice of preassigning his invention results to someone else or selling his realized research results ex-post. We identify an inventor as corporate (independent) inventor if most of his lifetime patents belong to he former (latter) category. A study on organized research therefore becomes a study on the economic incentives behind these two forms of contracts. In pursuit of this line of inquiry, we single out a specific type of transaction cost -- the cost of selling basic information — as most crucial. We argued that the centralization of ownerships of patentable information in the form of employment contracts is a mechanism for the capturing of the value of nonpatentable information. The hypothesis yields the implication that superior inventors have the strongest incentive to organize research. Empirical results in the oil and glass container industries supported this implication.

Our hypothesis should not be treated as mutually exclusive to other hypotheses. Strictly speaking, any explanations of organized research (and for that matter, of the firm) can be phrased in terms of transaction costs of various types. The explanation of the need for advance technological research equipments can be viewed in terms of the high cost of renting capital equipment. The explanation of team production is really a statement about the cost of enforcing inputs relative to that of the output. The explanation of risk hinges on the high cost of adopting alternative risk diversification devices. Even the recent explanation of quasi-rent (Klein et al. 1978) is really an abbreviation for the multiplicity of the high cost of enforcing multiple charcteristics contracts and the high cost of finding substitutes. These are logical possibilities that may have different degrees of influence in different industries. For this reason, we do not think our findings in the oil and glass container industries are conclusive. In fact, given the industry-specific nature of our study, our empirical section may be best interpreted as suggesting a method of inquiry — one that can be repeated when new data are accumulated.

While the relative significiance of alternative hypotheses must await future evaluation, one conclusion that emerges from our industry study is the following: many stylized facts concerning organized research simply do not exist in the oil and the glass container industries. Inventors do not tend to withhold their patent rights even after they have been proven successful -- evidence doubting the risk explanation of organized research; also, inventors in organized research do not have more joint works than the independents -- evidence doubting the team-work explanation of organized research. These findings further suggest the need for more detailed investigations of organized research.

Appendix: The Construction of Lifetime Summary Statistics

Consider the lifetime Record of C. J. Pratt

Year	Patent No.	Assignment Record
1929	1,741,535	Universal Oil Prod. Co.
1930	1,752,264	Unassigned
1931	1,810,574	Automotive Distillate Corp.
	1,827,107	Universal Oil Prod. Co.
	1,827,908	Universal Oil Prod. Co.
1932	-	-
1933	-	-
1934	1,946,947	Universal Oil Prod. Co.

Using the definitions on Table II, the followimg numerical values were assigned to describe C. J. Pratt: ALFE = 6, APA = 5, ASPC = .833, DEL1 undefined, DEL2 undefined, DISV = 0, DM = 0, HYPR = .333, HYPY = 8, INDISV = 0, JBS = 3, OLFE = 6, OPT = 4, ORG = 70 (see footnote 21), SPL = .833, TLFE = 6, TPA = 6, XALFE = .833, XOLFE = .667, XSPEC = .667, XTLFE = 1.0, YSPEC = 1.0.

Do the numerical values above in fact measure what we want? We believe for the purpose of comparing the two groups of inventors, the answer is yes, but with qualifications. The following sets of problems are particularly troublesome:

(a) The assignment record may not actually represent an employment contract because some patents invented without employment contracts might be sold to a corporation before they are issued. Although we have no way of measuring the frequency of these cases, the problem should not be particularly severe in situations where assignments to a particular firm occurred repeatedly over time (e.g. Universal Oil Product Co.), because repeated sales are likely to be replaced by some long-term contractual relationship. It would seem that the longer the assignment records, the more likely an employment contract. (We note also that in the McKnight's data set, 97.4% of inventors have two or less jobs in their career.) For firms that have a single assignment record (e.g. Automotive Distillate Corp.), we are less certain about the severity of the problem. At present, we are relying on the judgment of Schmookler (1966, pp. 25-26), and we treat assignment records and employment contracts as identical.

For a different reason, this assumption is not as severe as it might first appear. The firms having infrequent assignment records are not likely to be classified as the primary organization anyway. The assumption may indeed bias the measure of the number of jobs, but should not affect the productivity measures for the inventor's primary activity too severely. Also, there are situations where employed inventors managed to keep some patents for their own. Thus, we have no a priori reason to believe the estimates of "independent" and "assigned" inventors will be biased systematically, and comparison between the two groups may still be accurate.

(b) The relationship between patents and research effort is stochastic. Even though an inventor may be fully employed during a certain period of time, his patent record may show only partial or no evidence. On the other hand, the lack of patent record may truly mean that the inventor has reallocated his effort from research to other jobs. For example, C. J. Pratt has no patents in 1932 and 1933. Our current identification procedure would classify these years as employment years if another assignment record shows up at the future date. Thus, in the case of Pratt, we assume that he was employed by Universal Oil Product Co. roughly betweenn 1929 and 1934. This may be quite different from his actual employment years. But for the purpose of making group comparisons, the divergence may not matter too much. Also, these possibilities arise mostly in situations where the lag is less than five years. (See footnote 27 in the text.)

Another related problem is the following: suppose inventor A has two patents ten years apart, and inventor B has two patents in consecutive years. If we measure the ability of the inventors solely in terms of the length of employment, it may be highly misleading, because both have the same number of total patents even though one is employed nine years longer than the other. Thus, some other productivity measures have to be used jointly with the length of employment in order to get a more accurate picture. Consider the measure of patents per year: A will have a lower number (1/5) than B (1). Thus, this second measure in a sense can adjust for the deficiency of the first measure. In fact, this is the idea behind the innovation production function in the text (p. 27).

(c) Partly because of the stochastic element, and partly because an inventor can work part time or overtime, an inventor might have more than one job at a particular point in time. For example, Pratt has two jobs in 1931.

Our current identification procedure assumes he works double time in 1931. This would overestimate the patent-per-year measure of the primary activity and underestimate that of his secondary activities. However, it will not affect the group comparison on the primary activities (i.e. OPT, OLFE, and XOLFE).

The extent of double-counting of time will be reflected in HYPR, which measures the percentage deviation of what we call the hypothetical life from the actual career life. If double-counting is high relative to "unemployed" periods, HYPR would be positive. Observed negative values of this variable in Table III suggest that double-counting may not be too frequent in the petroleum industry sample.

(d) The heterogeneity of patents: almost by definition, patents cannot be homogeneous. This is a problem inherited in all quantitative works on innovation. On this difficult issue, we take the position of the pioneer work of Schmookler: heterogenous patent statistics are surprisingly "well behaved." Recent contributions by Pakes and Griliches, Hausman, Brown and Griliches, and Scherer further increase our confidence in this position.

Footnotes

[1]This is certainly the most dominant view in the 1960s and the 1970s. For example, see R. R. Nelson, "The Simple Economics of Basic Scientific Research — A Theoretical Analysis," Journal of Pol. Econ., Vol. 67, June 1959; D. Hamberg, "Invention in the Industrial Research Laboratory," Journal of Pol. Econ. (April 1963). Most recent publications on the subject, however, have taken a more skeptical attitude on this issue. See Richard R. Nelson, "The Role of Knowledge in R & D Efficiency," The Quarterly Journal of Economics, August 1982, Vol. XCVII, No. 3, p. 453.

[2]Evidence supporting these views seem overwhelming; see W. M. Grosvenor (1929), Schmookler (1957), W. F. Mueller (1962), M. J. Peck (1962), J. L. Enos (1962), D. Hamberg (1963), Mansfield (1968), Jewkes, Sawers and Stillerman (1969), Freeman (1974), and Brock (1975). Grosvenor in "The Seeds of Progress," Chemical Markets, reported that 17% of 72 major inventions made during 1889-1929 originated from corporate laboratories. W. F. Mueller found 28% of 18 new products in DuPont originated in the research in DuPont lab. D. Hamberg found 26% of 27 major inventions made during 1946-55 originated from large industrial labs. Brock found 28% of 21 major computer innovations originated in IBM. The only studies that provided slightly mixed evidence were Mansfield's and Freeman's.

[3]Definitions according to the National Science Foundation.

[4]An arrangement having both of these characteristics is analogous to one where a development company in the housing market prearranged for various inputs and sells the final output to the homeowners. The significance of these two conditions can be seen by contrasting them with situations where one or both conditions are absent: If both are absent, inventors would market

their finished products (patented inventions) independently (even though they might be working with the same capital equipment under the same roof). Holding companies may develop in this situation to select and package the finished products of various inventors; but because the contracts were made after the invention, such arrangements will not be called an organized research both according to the definition in (a) and according to the common intuitive meaning of the term. Similarly, if inventors contract among themselves on existing patents (i.e. [a] is absent), this will not correspond to organized research because the transaction is equivalent to a market exchange on outputs, and the notion of a firm does not exist. Finally, there are situations where patent licenses involve the granting of future patents. See Yu (1981). The transfer of future patents, though satisfying (a), is not the result of the conjoint action of related inventors (i.e. the absence of (b)), and thus no organized research is implied.

[5]Fredrik Neumeyer, with legal analysis by John C. Stedman, The Employed Inventor in the United States: R & D Policies, Law and Practice, Ch. 2 (1971).

[6]Some refuting evidence can also be presented in Section 3 of this paper.

[7]We are implicitly assuming the sharing of royalties is a risk-diversifying device. The alternative is to view it as an incentive device.

[8]Based on a sample of 269 firms, Masanori Hashimoto found that only 10% have some form of royalty-sharing arrangement: see his "Rewards to Employed Inventors," mimeo, University of Washington; see also Neumeyer, op. cit., Ch. 3.

[9]This is similar to the idea of the "prospect" function of patents as noted by Kitch (1978). More realistically, many practices in court can be interpreted as having the effect of awarding a basic idea the "whole" of

innovation, for example, the court may very broadly interprets the claims in a dominant patent, or the court may stringently apply the nonobviousness requirement for patentability. See Kitch (1967). Some have called this the case of "blocking patents."

[10]Examples of this are the nonpatentability of abstract basic ideas, or the stringent enforcement of the utility requirement for patentability.

[11]The classic case was the improvement of triode over diode in the radio industry. See Alf K. Berle and L. Sprague de Camp, Inventions, Patents, and Their Management, pp. 68-71. See also Yu (1981), p. 229-230.

[12]In the real world, the nature and magnitude of transaction cost differ depending on whether contracts are made before or after the innovation. Contracting before the innovation involves searching for potential contracting partners and enforcing the delivery of innovation of some anticipated value. Contracting after the innovation involves bilateral monopoly bargaining. Thus, even if rights to each idea are fully enforced, there may still be prior contracts in some situations as methods to resolve post-innovation bilateral hold-up. However, the important thing we wish to emphasize is that whatever the frequency of prior contracts is in this situation, it will be even higher if the property right regime is changed to either one of the extremes where rights are wholly assigned to one inventor.

[13]The formulation here is nonstochastic. For stochastic problems, one can assume the cost differential as a function of the variance of inventors' ability distribution.

[14]See "Two Models about Competition in Innovation," UCLA Working Paper.

[15]Cheung (1976) proposed this point. Its implication and its viability were examined in Yu (1981).

[16] To see the importance of nonpatentable basic information in our argument, consider contracts under alternative property right systems. If the rights are wholly assigned to the basic inventor, improvement inventors would be employed by the basic inventor, but their employment contracts would not specify the assignment of patent rights because there are simply no patents to be assigned if the improvement ideas are not protected. If property rights are awarded to both basic and improvement ideas, the improvement inventor would require a license from the basic inventor but not vice versa. Furthermore, even though such licenses may delineate exclusive territories among the improvement inventors, each improvement inventor can contract independently with the basic inventor without explicit cooperation. An example of this can be found in an old contract between Ball Brothers (a glass manufacturer) and Hartford-Empire (a research organization). Hartford-Empire owned some basic patents covering the general principle of a glass feeding technique. The technique required precise timing in the coordination of a set of shears and a plunger. The timing factor varied depending on the size, shape and quality of the glass bottles. Ball Brothers was famous for producing fruit jars, which are heavier, bulkier, and sturdier than ordinary beverage bottles. The manufacturing of fruit jars thus required some specific modifications of the basic feeding principle. Perhaps this explains why an exclusive license was granted by Hartford-Empire to Ball Brothers in the field of fruit jars. For more detailed information about the case, see U.S. v. Hartford-Empire Co., 323 U.S. 386 (1945).

[17] See Hashimoto, op. cit.

[18] Recent studies slightly modified the method by comparing the percentage of major innovations with the percentages of output, employment or, capacity among the big and small firms. (Mansfield, 1968, p. 91, Freeman, 1971.)

However, this will not eliminate the interpretation error explained in the text. The percentage of various output proxies obviously depends on the size distribution of firms. Given n large firms and m small firms, the employment percentage of the large firms is $\frac{nx}{my}$, where x and y are the average sizes of the firms in the two categories. Depending on the difference in x and y, the employment percentage can be anything.

[19]Ideally, we are interested in comparing outputs per attempt. The testing procedure in this paper defines an inventor as an attempt. An alternative way will be to define one dollar worth of R & D expenditure as an attempt. Both methods have some drawbacks and a discussion of their relative merits will go beyond the scope of this paper. Furthermore, our data set does not have R & D figures, and we will not pursue the alternative here. Mansfield (1968) did, however, use a small sample in experimenting with this alternative. He showed that large firms have lower productivities.

[20]McKnight claimed that the purpose of the study was to "familiarize himself with the practical art of cracking petroleum oils." He concluded that there are ten principles which he can learn from the patent disclosures, p. 121. McKnight considered himself as very objective because he was "neither a lawyer nor a person directly connected with the oil industry" (Forward). However, his objectivity could very well be considered by people in the art as naivete. For this reason, we are not overconcerned about his general conclusion concerning the overcrowding of cracking patents.

[21]It is possible that some employment contracts do not require the assignment of patents. It is also possible that some independent inventors choose to sell their patents to a corporation before the patents are issued. These problems have been discussed in Jacob Schmookler's Invention and Economic Growth (Cambridge: Harvard University Press, 1966). He did not

think the problems are severe, pp. 25-26. We examined the robustness of this identification method in a paper with Bruce H. Kobayashi, "Indexing Individual Inventors: The "Sources of Invention" Revisited."

[22]The large firms were selected based on the size of the research staff and its dominance in the art as described in Enos' Petroleum Progress and Profits (M.I.T. Press: Cambridge, Mass., 1962). They are Gasoline Products Co. (25), Houdry Process Corporation (12), I. C. Farbenindustria Aktiengesellschaft (26), Shell Development Co. (13), Sinclair Refining Co. (Maine Corp.) (26), Standard Oil Co. of California (10), Standard I. G. Co. (Delaware) (22), Standard Oil Co. of Indiana (43), Standard Oil Development Co., also known as Standard Oil of New Jersey (31), The Texas Co. (52), Universal Oil Products Co. (70). The numbers in the parentheses are the estimated numbers of inventors in the corporations.

[23]It ranged from a low of 0 in 1911 to a high of 0.757 in 1935.

[24]See Scherer, p. 418; Jacob Schmookler, "Inventors Past and Present," Review of Economics and Statistics, Volume 39 (August 1957).

[25]I thank Kenneth Sokoloff for raising the issue.

[26]The names of these organizations are listed in Temporary National Economic Committee Hearing, pt. 2, pp. 806-809.

[27]We estimated that the probability of prematurely cutting the career life of an inventor is less than 5%. This number was estimated by first plotting a frequency distribution of the length of lags between two patents (not counting zero lags). An exponential probability function is used to fit the observed distribution. The lowest chi square fit gives us a parameter value of .635. The critical level which has 5% remaining on one tail is 4.7.

[28]Owens and Hartford-Empire cross licensed in 1923 and the license was extended in 1933. Hartford-Empire and Hazel-Atlas cross licensed in 1932.

Hartford-Empire granted exclusive territory in the field of fruit jars to Ball Brothers in 1932, and in return, they acquired the first right to Ball Brothers existng and future patents on feeding devices.

[29]Other than the productivity measures, comparisons on variables such as JBS, XSPEC, ASPC, DISV between the two industries reveal great inconsistency.

[30]A stepwise procedure has also been performed on both the ORG and DM regressions to see how sensitive the reported coefficients reacted to other variables. The coefficient on XTLFE remains positive and significant for all the regressions; the coefficient on TLFE becomes insignificant and even negative (but insignificant) in some regressions.

[31]We have also tried the same sets of regressions in Table VI and VII by counting a joint patent as half a patent. There was no significant difference in results on the regressions explaining ORG. But on the regressions explaining team cooperation (estimated by percentage of joint patents), the coefficients on longevity and intensity changed from positive to negative, and the correlations between ORG and the proxy for team cooperation became inconclusive. The results reaffirm our conclusion that at least for the oil industry, it is the high ability of the inventors (rather than joint works arising from able inventors) that leads to organized research.

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