THE INFLUENCE OF MARKET STRUCTURE ON
TECHNOLOGICAL PERFORMANCE IN THE
FOOD MANUFACTURING INDUSTRIES

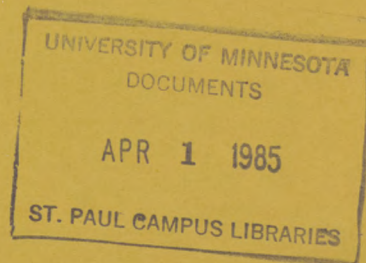by

John D. Culbertson

and

Willard F. Mueller*

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     *John D. Culbertson is an agricultural economist with Economics,
Statistics and Cooperatives Service, U.S. Department of Agriculture.
Willard F. Mueller is Vilas Research Professor of Agricultural Economics,
Professor of Economics, and Professor in the Law School, University of
Wisconsin-Madison. The views expressed here are those of the authors and
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A central thesis of industrial organization is that firm expenditures on invention are partially determined by market structure and firm characteristics. Market power, firm size, and firm diversification all are hypothesized to influence significantly firms' R&D investment decisions. These theories have been tested in a number of firm and industry cross sectional studies [Kamien and Schwartz]. Only one such study has examined the food manufacturing industries [Imel, Behr and Helmberger]. Here we build and expand upon that study using a single equation model for the period around 1970.[1]

Typically, industrial organization studies stop at this point. Here we go beyond the conventional industrial organization R&D performance (IO-R&D) approach by placing the relationship within a broader context that also examines the sources of inventions important to food manufacturers originating outside the food manufacturing industries. The importance of inventions originating outside an industry has been ignored explicitly or implicitly by the numerous cross sectional studies examining market structure-R&D performance.

Below, we first report the results of our test of the market structure-R&D performance model. This is followed by an examination of R&D originating outside food manufacturing, both as measured by patented inventions and by significant innovations.

Hypotheses and Variables

Market Power. Schumpeter envisaged a dynamic process of competition in new products and production techniques that could exist only under the shelter of the restrictive practices that may accompany market power [Schumpeter, pp. 87-92 and 106]. To Schumpeter, the firm's investment in R&D is very risky: R&D effort may be fruitless or the products of successful R&D may be expropriated through imitation by competitors. The output restrictions that accompany market power partially mitigate these uncertainties. Barriers to entry attenuate R&D investment's risk by permitting inventions and innovations to be expropriated only by firms within the industry. Firms invest in R&D if they expect, ex ante, to earn at least a risk-adjusted normal return on investment. Since the return on investment is greater, ceteris paribus, with market power, this condition is more likely to be met in oligopolistic industries. Finally, Schumpeter saw the unusually high returns that reward a relatively few innovations as prizes provided by the capitalist system to stimulate R&D activity.

All economists do not agree with the above assertions. Even Schumpeter equivocated on the issue, recognizing that greater market power does not necessarily stimulate firm investment in R&D [Schumpeter, p. 91]. Managers of firms with market power are free to choose among various goals for the firm, with profits being only one of many. Without the push of competition to force optimal performance, firms have discretion over the size of their R&D outlays. Several empirical studies find that inventive effort does not lend support to classical Schumpeterian hypotheses [Imel, et al. and Scherer, 1965]. Because there exists conflicting hypotheses regarding the functional relationship between market power and R&D performance, we test for nonlinear relationships.

We use three sources of market power: the size distribution of firms as measured by the weighted four-firm concentration ratio; the power of individual firms as measured by weighted relative firm market share[2/] the ratio of the firm's market share to the four-firm concentration ratio; and barriers to entry as measured by the firm's weighted advertising-to-sales ratio.

Firm Size. Firm size is the second variable identified by Schumpeter as playing an important role in determining the rate of firm R&D activity. Schumpeter is usually interpreted as predicting that firm R&D increases at an increasing rate with firm size for three reasons. (1) The variance of the average return on the R&D portfolio declines with the number of R&D projects. Therefore, the risk of the firm's R&D investment decreases as firm size increases. (2) The average cost of R&D may decline with firm size because there are economies of total firm size or because there are economies of scale in R&D laboratories. (3) Process innovations generating given percentage cost savings produce larger total cost savings for larger firms, thus firm demand for process innovations is positively correlated with size [Scherer, 1980, pp. 413-414].

As with market power, economic theory does not unambiguously support the Schumpeterian size hypothesis. The probability that the firm will engage in any R&D investment declines with firm size because the larger firm has more decision-making stages.

We test the hypothesis that R&D initially increases with firm size at an increasing rate and then increases at a decreasing rate by entering both the natural logarithm of firm assets and the squared logarithm of assets as regressors.

Firm Diversification. The diversified firm is hypothesized to have a higher rate of inventive activity because it is better able to use unanticipated inventions and because it has a lower risk R&D portfolio [Nelson]. Unanticipated research outputs are more likely to fall in diversified firms' product lines, making it easier for these firms to identify, evaluate, and market unexpected R&D outputs. Moreover, diversified firms can diversify their R&D projects across product lines to reduce the risk of total R&D outlays. Firm diversification is measured by the number of 5-digit product lines in which the firm had 1967 value of shipments exceeding $1,250,000.[3/]

Technological Opportunity. Interindustry differences in technological opportunities may significantly affect firms' rates of R&D [Scherer, 1965]. To control for these variations in technological opportunities, models with intercept dummy variables to discriminate among eleven food industries were estimated for a 1950 sample of large food firms. Over a wide range of models the intercepts for meat packing, sugar refining, wet corn milling and wheat milling were substantially larger than for the other seven industries.[4/] These results were used to construct the technological opportunity variable for our model. The variable is an intercept dummy with a value of one for firms in the four highest technological opportunity industries and zero for other firms.

Percent Nonfood. Food processing firms are becoming increasingly diversified both within and outside the food industries. Many of the non-food industries into which food firms have diversifed have substantially higher technological opportunities than food. Imel, Behr, and Helmberger used a firm percent nonfood variable to control for the expected increase in firm R&D from diversification into higher opportunity nonfood industries.

Their construction implicitly assumed identical technological opportunities for all nonfood industries. Scherer has found that technological opportunities vary across nonfood industries. We refine the percent nonfood variable of Imel, Behr, and Helmberger by multiplying the percent of the firm's sales outside the food industries by a weighted average of the technological opportunities in the nonfood industries into which the firm has diversified.[5]

Percent Foreign. It has been hypothesized that one factor that explains direct foreign investment by United States firms is firm inventive activity; firms invest in foreign subsidiaries to market new products that were invented and successfully marketed in the United States [Bruber, et al.]. Thus, we hypothesize that as firms' foreign sales rise in relative importance, their R&D expenditures will decline. We measure the extent of the firms' foreign sales by the percentage of total sales that are foreign.

Measures of R&D Performance. Firm R&D studies specify the dependent variable in two ways: total firm R&D and firm R&D intensity, the ratio of total firm R&D to firm size. Studies use R&D intensity for two reasons: to correct for heteroscedasticity and to insure that the regression estimates are not unduly influenced by the observations for large firms [Scherer, 1967, p. 525]. These two reasons are identical since the regression estimator is unduly influenced by large firms only if the variance is not constant. However, the deflation of only the dependent variable is an unconventional technique for eliminating heteroscedasticity and the ordinary least squares estimator of the intensity model is biased for the population parameters in the model of total firm R&D. We control

for heteroscedasticity by estimating the total firm R&D model by generalized least squares.[6/]

We use three measures of R&D performance: the number of patents assigned to the firm, firm employment in R&D laboratories, and firm R&D expenditures. Whereas R&D expenditures and the number of scientific employees measures R&D inputs, the number of patents assigned to the firm measures R&D output. Firm patents is the most readily available measure of firm production of new products and production processes. Although there is considerable variation in the quality and commercial value of individual patents assigned to firms, studies have found that the number of firms' patents serves as a meaningful proxy for the value of R&D output [Comanor and Scherer]. Rather than choosing among these three variables on theoretical grounds, we estimate the model with each separately to determine how market structure affects each. This allows us to test whether alternative measures of R&D inputs and outputs yield different results.

The Data

Firm patent data are from the U.S. Patent Office's Index of Patents, 1968-1974; R&D employment data are from Research Laboratories in the United States, 1970; and R&D expenditures data are from the Securities and Exchange Commission's Form 10-K, 1972. Value-of-shipments at the 5-digit SIC product basis for 33 firms were made available as part of a study prepared for the House Subcommittee on Monopolies and Commercial Law.[7/] Twenty-eight additional firms were added from data made available by Shepherd and from a variety of public sources. These firms covered the full size spectrum (except for very small firms), ranging in asset size from

$20 million to $1,012 million. Industry advertising expenditures at the 5-digit level were available from the work of the late Robert Bailey of the Federal Trade Commission.[8/] The patent model is estimated with the total sample of 61 firms. The R&D employment and R&D expenditures models use 59 and 51 observations, respectively, because data for these dependent variables were available only for these reduced samples.

Empirical Results

The empirical findings from the generalized least squares estimation of the multiple regression models are presented in Table 1. Separate models are presented for the three dependent variables. Equations 1, 3 and 5 are estimated with all three of the market power variables entered in both linear and quadratic form. If the quadratic term of the market power variable is not significant, it is deleted in equations 2, 4 and 6 unless the t-statistics for the linear and quadratic terms are of similar magnitudes and opposite signs; in this case neither the linear nor quadratic term is deleted. The percent nonfood and percent foreign variables are also deleted from equations 2, 4 and 6 if they are not significantly different from zero at the 10 percent level in equations 1, 3 and 5, respectively. Because of the high correlation of firm diversification and percent non-food (the simple correlation for the sample of 51 firms is .78), we have deleted the latter in equation 2. In equation 2, both linear and quadratic four-firm concentration are significant at the 5 percent level. This quadratic function attains a maximum when four-firm concentration equals 60. Relative firm market share is significant at the 10 percent level. Both size variables are significant at the 1 percent level, and the relationship between firm size and firm R&D expenditures has a point of inflection at a firm size of about $130 million. Firm diversification is

TABLE I

MULTIPLE REGRESSION EQUATIONS WITH FIRM R & D EXPENDITURES, PATENTS, AND R & D EMPLOYMENT, 1967[a]

Dependent Variable	Intercept	Technology Class Dummy (DUH)	Four-Firm Concentration Ratio (CR4)	Squared Four-Firm Concentration Ratio (SCR4)	Relative Firm Market Share (RMS)	Squared Relative Firm Market Share (SRMS)	Log of Assets (L)	Squared Log of Assets (LL)	Diversification (DIVE1)	Percent Nonfood (NONFO)	Percent Foreign (FOREIGN)	Industry Advertising to-Sales Ratio (AS)	Squared Industry Advertising-To-Sales Ratio (SAS)	R^2
(1) R & D Expenditures	7.27 (1.62)	1.72 (2.47)**	.12 (1.74)+	-.0011 (-1.68)+	.047 (1.07)	-.00031 (-.42)	-6.64 (-3.24)**	.85 (3.44)**	.043 (.78)	.0013 (1.49)+	.031 (.92)	.42 (1.48)	.021 (-.93)	77
(2) R & D Expenditures	10.36 (3.03)	1.35 (2.76)**	.13 (2.03)*	-.0011 (-1.97)+	.027 (2.06)*		-7.97 (4.81)**	1.03 (5.40)**		.0019 (2.65)**		.19 (2.41)*		73
(3) Patents	9.99 (.16)	39.72 (3.94)**	1.70 (1.43)	-.014 (-1.37)	.60 (.88)	-.000043 (-.0038)	-53.96 (-1.98)*	6.81 (2.16)*	1.50 (2.18)*	.014 (1.10)	-.28 (-.80)	12.28 (2.72)**	-.83 (-2.31)*	75
(4) Patents	10.39 (.17)	37.71 (3.84)**	1.77 (1.51)	-.015 (-1.48)	.55 (2.24)*		-53.70 (-2.01)*	6.71 (2.17)*	1.75 (2.89)**			11.86 (2.69)**	-.82 (-2.32)*	74
(5) R & D Employment	149.81 (1.13)	41.01 (1.77)+	5.78 (2.19)*	-.051 (-2.18)*	1.00 (.68)	.0016 (.063)	-192.80 (-3.14)**	25.57 (3.50)**	3.98 (2.27)*	.014 (.43)	-.14 (-.16)	12.82 (1.24)	-.75 (-.89)	74
(6) R & D Employment	205.49 (1.81)	25.66 (1.61)	5.93 (2.33)*	-.051 (-2.32)*	.89 (1.50)		-211.57 (-3.80)**	27.57 (4.09)**	4.30 (3.05)**			3.96 (1.39)		73

[a]All regressions are corrected for heteroscedasticity. The R^2 is generated by ordinary least squares estimation of the equation.

Significance levels: ** - 1 percent; * - 5 percent; + - 10 percent.

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positive and significant at the 5 percent level. Finally, industry advertising intensity has a positive effect that is significant at the 5 percent level.

In equation 4, neither linear nor quadratic four-firm concentration is significant at the 10 percent level. Linear relative firm market share is significant at the 5 percent level. Both firm size variables are significant at the 5 percent level and the quadratic function of the logarithm of firm assets has an inflection point at $149 million. Firm diversification has a positive effect that is significant at the 1 percent level. Both AS and SAS are significant at the 5 percent level.

The estimated coefficients on CR_4 and SCR_4 are significant at the 5 percent level in equation 6. This quadratic function in four-firm concentration attains a maximum at $CR_4 = 58$. Relative firm market share is not significant. The logarithm of firm assets and the squared logarithm of firm assets are both significant at the 1 percent level. This function in firm size has an inflection point at $126 million. Firm diversification is significant at the 1 percent level. Finally, linear industry advertising intensity is not significant.

Our preferred R&D expenditures, patent and R&D employment models (2, 4 and 6) are quite similar. The percent foreign, percent nonfood, and squared relative market share variables are deleted in each of these three equations. The estimated coefficients on every variable have the same sign in each of the models. The market concentration relationship attains a maximum at CR_4 equal to 58-60 in the three models. The point of inflection in the size relationship occurs at the smallest firm size in the employment model, at a value of $126 million, and the largest firm size in the patent model, at a value of $149 million. The linear

industry advertising intensity variable is significant at the 5 percent level when R&D expenditures is the dependent variable; both AS and SAS are significant at least at the 5 percent level when patents is the dependent variable; and neither AS nor SAS is significant when R&D employment is the depend variable. Firm diversification has a significant positive effect in all three models.

The equations present estimates of the effect of the market structure variables on expected _firm_ R&D. The equations can also be used to calculate the effect of changes in market structure on expected _industry_ R&D. To calculate expected industry R&D, expected firm R&D is summed over all firms in the industry. However, the _ceteris paribus_ assumption, which is widely used in economics so that the theoretical relationships between any two variables can be examined independently of all other variables, is not appropriate when the results of the model are interpreted. Since an increase in market concentration can only occur through the growth of one or more firms and the corresponding decline of others, firm size, market concentration, relative firm market share and the number of firms in an industry are necessarily interrelated. Thus, the _ceteris paribus_ assumption cannot be used in firm studies when interpreting the influence of individual variables on industry R&D. However, when we account for interdependence among structural variables our models predict that reductions in concentration in highly concentrated industries result in at least modest improvements in R&D inputs and outputs [Mueller, Culbertson, and Peckham, pp. 77-86]. But judgments concerning the merits of industry restructuring requires placing in broader perspective the R&D efforts of food manufacturers, a subject to which we now turn.

Inventions Originating Outside Food Manufacturing

Above we examined the impact of industry structure on the extent of R&D activity originating <u>within</u> food manufacturing. Inventions that effect an industry's productivity and product offerings may originate with firms in the industry or with firms, public institutions, or individual inventors located outside the industry. As Rosenberg has observed, "...many of the benefits of increased productivity flowing from an innovation are captured in industries <u>other</u> than the one in which the innovation is made. As a result, a full accounting of the benefits of innovation must include an examination of interindustry relationships" [Rosenberg, p. 41].

In this view, the technological interdependence among industries is a crucial determinant of technological progress. The pact of technical change in the food industries is determined not only by the behavior of firms within the food industries, but also by firms outside it. The food industries receive new technology from other industries that is embodied in purchases by food firms of capital inputs.

Rosenberg argues that historically these interindustry flows of technology have depended on the size of the market for these inputs and the complexity of the inputs. We expect that the food industries purchase a significant proportion of their technology from other industries. The secular expansion of markets for processed foods and the homogeneity among food manufacturers of many of their technical production processes has created a large potential demand for a wide variety of machinery and other inputs. Further, as these production processes have become increasingly sophisticated, the comparative advantage of the machinery, chemicals and electronics industries in performing the R&D that is embodied in these inputs becomes increasingly greater.

In this section, data are marshalled to test the hypothesis that inventions originating outside the food manufacturing industry represent an important, and perhaps the major, source of new technology for food manufacturers. The ideal test of this hypothesis would involve identifying and quantifying the relative importance of all relevant inventions originating both within and outside food manufacturing. Such a test is not within the scope of this study or perhaps any other. We are able, however, to identify the sources of patents relating to technology in several important food manufacturing industries.

Determining the origins of inventions for a certain industry requires identifying the patents relevant to that industry. Such identification is extremely difficult because many inventions are not industry specific. It is possible, however, to identify certain U.S. Patent Office (USPTO) classes that are specific to a certain industry. Our study of the USPTO Manual of Classification identified patent classes covering specialized machinery and other apparatus used in the manufacture of beer, refined sugar, meat and poultry products, dairy products, and starch. The classes selected are particularly narrow in dairy and starch.[9/] Using this procedure, we were able to identify the origins of patents covering various types of apparatus and machinery used in these important food manufacturing industries. Although mechanical inventions were selected because of data availability (comparable data cannot be developed for product patents), it is generally acknowledged that such inventions are the primary source of increased productivity in food manufacturing.

We emphasize that the patents in these particular industry categories cover only part of the total patents relevant to these industries because many patents and the innovations using them have applications for many industries, particularly food manufacturing industries using similar

production techniques. Examples are fork lifts, conveyor systems, wrapping and packaging techniques, canning processes and computerized control systems. Little of such multi-industry technology is included in the patent statistics examined here. <u>We emphasize, therefore, that the following analysis of the origins of inventions applicable to the food industries discussed below almost certainly understate by a substantial margin the relative importance of mechanical inventions originating outside the food manufacturing industries.</u>

Our examination of the origins of patents in six food manufacturing industries proceeds as follows: (1) identify the origin of patents by national origin; (2) examine the origin of patents as among corporations, individuals and government; and (3) compare the market shares of the leading four firms in these industries with the total number of patents originating from all sources.

Origin of Patents: By Nationality of Inventors

During 1963-1977, 73 percent of all patents in the six industries studied originated with corporations, individual inventors and government research laboratories within the U.S. The share originating abroad increased over the period--from 20 percent during 1963-1965 to 37 percent during 1974-1977 [Mueller, Culbertson, and Peckham, p. 93]. The upward trend was most pronounced in poultry processing, where the share of patents originating abroad rose from 2 percent in 1963-1965 to 28 percent in 1974-1977. The share of foreign originating patents also rose for dairy, meat and sugar, while falling in beer.

Four countries accounted for 62 percent of all patents granted foreign nationals. The nations that led in total patents for all six food

industries also were among the leaders in individual products, with Germany the leader in four products. The leaders in various products were: sugar--Germany and France; brewing--Germany, France and Canada; poultry processing--the Netherlands; dairy processing--France, Germany and the Netherlands; meat packing--Germany, France and Canada; and starch-- Germany and the Netherlands.

Origins of Patents: Corporations, Government, Individuals

The most striking feature of the origins of patents examined is that U.S. firms within the six industries studied accounted for a minority share of all patents in their industries (Table 2). Ranging from a low of 5.9 percent for sugar to 28.6 percent for starch, U.S. firms within these industries accounted for only 9.0 percent of the total patents granted in the industries during 1969-1977.

Nearly four times as many patents originated with U.S. firms outside the industries as with firms within them. Starch was the only industry with more patents originating within the industry than from U.S. firms outside the industry.

Only a modest share of total patents originated with U.S. food manu- facturers outside these industries--1.8 percent. Food machinery manufac- turers were the major U.S. corporate source of out-of-industry originating patents. These companies accounted for 18.2 percent of all patents, which was nearly twice as many as the number originating with food manufacturers within these industries. The contribution of food machinery companies varies greatly among industries, being largest in meat, poultry and dairy.

The major U.S. source of patents in these industries were corporations outside the industry involved. These were corporations located in a wide

Table 2: Origin of Patents by Industry, 1969-1977 (Percent)[1]

	Beer	Meat	Poultry	Dairy	Sugar	Starch	Weighted Average[2]
Origins of Patents							
U.S. Firms within the Industry	6.7	10.6	12.6	7.9	5.9	28.6	9.0
U.S. Firms outside the Industry	17.3	42.9	46.4	28.1	20.9	14.3	29.7
a) other food manufacturing	3.8	2.9	.5	1.4	2.6	0	1.8
b) food machinery firms	2.9	18.2	39.9	20.1	3.3	7.1	18.2
c) other firms	10.6	21.8	6.0	6.5	15.0	7.1	9.7
Foreign Corporations	34.6	13.0	11.5	36.7	52.3	21.4	31.3
Individuals	41.3	32.8	27.9	25.9	20.9	32.1	28.8
U.S.	19.2	25.3	22.4	13.7	13.7	3.6	16.7
Foreign	22.1	7.6	5.5	12.2	7.2	28.6	12.1
Government	--	.6	1.6	1.4		3.6	1.0
U.S.	--	.5	1.6	1.4		--	.9
Foreign	--	.1	--	--		--	.1
TOTAL[1]	100%	100%	100%	100%	100%	100%	100%

Source: U.S. Patent Office special tabulation. For list of USPTO classes included see Mueller, Culbertson, and Peckham.

[1] Sum of figures may not equal totals due to rounding.

[2] Weighted by value of industry shipments; 1972 Census of Manufacturing data.

variety of industries. The major source was the chemical industry, where Union Carbide Corporation was the leader, with 37 patents in the meat packing and 1 in poultry processing. Its patents dealt mainly with apparatus for wrapping and packaging.

Individual inventors received very nearly as many patents as U.S. firms outside these industries. Individual inventors were most important in the beer industry, where they received 41.3 percent of all patents; foreign individuals received over one-half of these.

Foreign corporations also were an important source of patents, receiving twice as many as companies within these industries. Such corporations were most important in sugar, where they received nearly nine times as many patents as U.S. corporations within the industry. They were also very important in beer and dairy. Only in poultry and starch did foreign corporations receive fewer patents than U.S. corporations within these industries.

U.S. and foreign governments were a minor source of patents in these industries, although the U.S. government received patents in all industries but beer and starch. The only foreign government receiving patents was the USSR, which received six U.S. patents.

Origins of Inventions: Top Four Companies

In five of the six industries examined, the leading four companies had a smaller share of industry shipments than of patents originating within their industries. This relationship held for the least concentrated industries (poultry, meat, and dairy) as well as two of the most concentrated industries (beer sugar, and starch). However, the top firms accounted for a very small share of all patents in the classes examined--13.3 percent of those originating with all U.S. corporations and 4.9 percent of those originating with all sources.

Table 3:   Top Four Companies Share of Industry Shipments and Their Share of
           Patents Granted in Selected Patent Categories of Six Food
           Manufacturing Industries, 1969-1977.

Industry	Top Four Companies Share of:			
	1972 Industry Shipments[1]	Patents Originating Within the Industry	Patents Originating With U.S. Corporations	Total Patents[2]
	(1)	(2)	(3)	(4)
Beer	54.0%	57.1%	16.0%	3.8%
Meat	28.2	36.9	7.3	3.9
Dairy	30.2	63.6	14.0	5.0
Sugar	60.6	44.4	9.8	2.6
Poultry	24.6	30.4	6.5	3.8
Starch	63.0	87.5	58.3	25.0
Six Industries' Averages[3]	33.5	54.3	13.3	4.9

Source: U.S. Patent Office special tabulation.   For list of USPTO classes included see Mueller,
          Culbertson, and Peckham.

[1] 1972 Census of Manufacturers.   Weighted average of all 5-digit SIC product classes in
each of these industries.

[2] Corporations, individuals, and government, U.S. and foreign.

[3] Weighted by industry shipments.

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The Origins of Significant Innovations

The preceding examination relied on patents to identify the sources of inventions relevant to food manufacturing. Although patents have been found to be good proxies of significant inventive activity, an alternative method of determining the origins of inventions is to identify those recognized as being most significant. This method has been used at both the industry and firm level [Jewkes, et al.; Hamberg; Mueller, 1962].

The first obstacle in applying this research method is the identification on an objective basis of a list of significant discoveries. Fortunately, the Putman Food Award program provides a comprehensive compilation of many of the most significant innovations in food manufacturing.[10/] This awards program was initiated "to recognize advances which have made significant contributions to more efficient and effective operations in the food processing industry" [Food Processing, 1975, p. 23]. The program is conducted by the editors of Food Processing, a leading trade journal in the food processing industries. The competition is open to "food processors and the companies supplying ingredients, processing systems, instrumentation, packaging, production aids and aids to maintaining plant equipment in operable and sanitary conditions."

About 60 awards are given each biennium.[11/] Although awards are not ranked by level of importance, they are divided into categories: "Top Honors" and "Honors," with about 22 percent receiving Top Honors. In addition to identifying the award recipient (or recipients when an award is given to more than a single party), the product receiving the award is described and an explanation given as to why it was selected for an award.

The Putman Awards provide a potentially rich source of information concerning the origins of significant discoveries that improve the efficiency of the food processing system. The awards themselves provide

information concerning innovations believed to be important by industry experts who serve as judges in the awards competition.

Just where do these discoveries originate? What are the characteristics of the recipients, especially their size and the industries from which they originate? To answer these and other (not discussed here) questions, questionnaires were sent to all Putman Food Award recipients in 1971, 1973, 1975 and 1977.[12/] Here we report our findings relating to the industry and size of award recipients.

Table 4 groups the Putman Awards by the primary line of business of the recipient's parent firm. Manufacturers of food and ingredients used in food received only 13 percent of the awards.[13/] Over 60 percent of all awards going to U.S. corporations originated with corporations operating in four industry groups: machinery manufacturing (36 percent); plant maintenance, sanitation and design (12 percent); instrumentation and controls (8 percent) and paper and packaging (6 percent).

Government-sponsored researchers received less than 2 percent of all awards; however, they received top honors for all of their awards, while 25 percent of all awards received top honors. This suggests that government research laboratories (federal and university) were less inclined than those in corporations to submit for competition innovations of lesser importance. The small number of government recipients also likely reflects that such researchers devote proportionately more of their time to fundamental research than do researchers in private corporations, so that the fruits of government research are more likely to fall in the pre-innovation stage.

The most striking feature of the size distribution of Putman Award recipients is that awards were received by corporations covering a broad

Table 4. Distribution of Putman Awards by Recipient Parent's Size and Primary Line of Business, 1971-1977

Recipient's Primary Line of Business	Size Unknown	Under $1	$1-10	$11-100	$101-500	Over $500	Total U.S. Firms	Gov't.	Total Foreign Firms	Total
(Sale in millions of dollars in year award received)										
Food Processor and Ingredient Manufacturers	2(0)[a]	1(0)	2(0)	7(5)	11(3)	9(3)	32(11) 13%[b](19%)[c]	--	2(1)	34(12) 13%[d](18%)[e]
Machinery Manufacturers	5(1)	14(5)	42(19)	15(5)	4(1)	9(2)	89(23) 36%(40%)	--	4(1)	93(24) 35%(36%)
Plant Maintenance, Sanitation & Design	3(0)	7(1)	11(1)	2(0)	6(0)	1(0)	30(2) 12%(4%)	--	0(0)	30(2) 11%(3%)
Instrument & Controls Manufacturer	0(0)	3(1)	7(1)	1(0)	5(1)	4(1)	20(4) 8%(7%)	--	3(1)	23(5) 9%(7%)
Packaging & Paper	1(0)	0(0)	2(0)	2(1)	6(1)	5(0)	16(2) 6%(4%)	--	0(0)	16(2) 6%(8%)
Chemicals & Paint	1(0)	1(0)	2(1)	1(0)	1(0)	8(2)	14(3) 6%(5%)	--	0(0)	14(3) 5%(4%)
Other[f]	10(2)	7(2)	3(1)	2(0)	3(1)	22(6)	47(12) 19%(21%)		4(3)	51(15) 19%(22%)
TOTAL	22(3) 9%[b](5%)[c]	33(9) 13%(16%)	69(13) 28%(23%)	30(11) 12%(19%)	36(7) 15%(12%)	58(14) 23%(25%)	248(57) 100%(100%)	4(4)	13(6)	265(67) 100%(100%)

[a] Number of top honors awards in parentheses.

[b] Percentage of total U.S. awards.

[c] Percentage of total U.S. top honors awards.

[d] Percentage of total awards.

[e] Percentage of total top honors awards.

[f] The other category includes 14 awards to firms whose primary line was unknown, 12 to large predominately manufacturing conglomerates, 7 to firms in basic industries such as steel, oil and aluminum, 4 to equipment importers and/or distributors, 2 to independent research firms, and 12 to firms in diverse other fields.

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spectrum of sizes, with the majority received by very small firms. Fully 40 percent of all awards to U.S. corporations went to firms with sales below $10 million and another 9 percent to firms whose size we could not determine. Since the great majority of the latter firms were also small businesses, about one-half of all domestic, nongovernment Putman Awards recipients were very small business units. These firms also received a large share (44 percent) of all awards designated as "top honors."

A significant share (12 percent of the total awards and 19 percent of "top honors") of the remainder of the awards granted U.S. corporations went to modest-sized firms, those with sales of $11 million to $100 million.

At the other extreme, corporations with sales in the $101-$500 million sales range received 15 percent of total awards to U.S. corporations and 12 percent of those receiving "top honors." Corporations in the over $500 million sales class received 22 percent of all domestic awards to corporations and 25 percent of the "top honors" awards.

In addition to the 248 awards granted U.S. business firms of all sizes, four were granted to government researchers and thirteen to foreign corporations. As noted above, Putman Awards very likely understate the contribution of government research. The contribution of foreign companies also is understated because these companies are less likely to participate in the Putman Award competition than are U.S. companies. Nonetheless, foreign corporations did make an important contribution to significant food innovations: 5 percent of all awards and 9 percent of the awards receiving top honors.

Conclusion

This study made two principle findings: R&D activity of food processing firms is partly determined by market structure and R&D effort of food companies represents but a small subset of the total R&D effort that ultimately result in inventions and innovations important to food manufacturing. The latter finding explains the paradox that whereas the R&D intensity of food manufacturers is relatively low, they experience quite rapid increases in productivity. Indeed, some food industries (e.g., beer) that have spent trifling amounts on R&D have experienced much more rapid increases in productivity than have most R&D-intensive industries.[14/]

The econometric analysis of firm R&D does not support the Schumpeterian and Galbraithian hypotheses that great market power and very large firm size best promote R&D effort. Rather, in food manufacturing industries decreasing returns to firm scale and market power occur beyond medium-firm size and below high levels of concentration. Insofar as the estimated models can be used for making decisions regarding public policy, it appears that antitrust and other policies that promote competition or place restraints on the growth of large firms are not likely to affect adversely R&D inputs and outputs in food manufacturing.

Based on an analysis of six food industries, it appears that the greater part of inventive activity inducing greater efficiency in food manufacturing originates outside these industries. This finding has important implications for public policy aimed at the competitive structure of industry. The potential benefits (or costs) of industry restructuring pale considerably when they are placed in perspective by comparing them with total R&D outputs as measured by patents, i.e., patents originating outside as well as within

an industry. For example, even if the patent output of beer companies were doubled, it would still be less than 15 percent of the total patents in USPTO categories closely identified with the beer industry.

Examination of the sources of innovations identified as making significant contributions to the efficiency of food manufacturing yielded the same general results as the study of patent recipients. Only a small share of the significant innovations were made by food processors. Over half were made by firms that made food machinery, provided plant maintenance, sanitation and designs, and developed instrumentation and control systems. Smaller firms made a large share of the innovations, with about 40 percent going to companies with sales below $10 million.

In sum, the evidence assembled here indicates that most inventions and innovations affecting efficiency originate outside the food manufacturing industries. Another finding is the great diversity of the sources of total inventive and innovative activity. Firms of all sizes within and outside the food manufacturing industries, individual inventors, independent research laboratories and government-sponsored research laboratories have all made meritorious inventions and innovations.

These findings support the view that invention and innovation are best promoted by multiple sources of research effort, a conclusion consistent with the findings of Jewkes, Sawyers and Silverman's study (p. 288) of important inventions in all fields. They concluded:

> It cannot be disputed that inventions and discoveries
> have had, and continue to have, many sources. It may
> be tempting to argue that one or other of these sources
> is more fruitful than others and should be stimulated
> even at the expense of the rest. Our impressions are
> that, given the present state of knowledge, it is safer
> to strive to keep all the sources open since competition
> strengthens the total flow of new ideas.

The finding that most new production technology originates outside food manufacturing is not an indictment of these industries; rather it supports Rosenberg's theory of interindustry technological interdependence. This theory posits that the beneficiaries of increased productivity flowing from many innovations are located outside the industry originating the innovation. Although this theory has relevance for all industries, it is particularly important in food manufacturing industries because of their large size and the common production processes shared by many food manufacturing industries.

Food machinery companies illustrate these points. Not only does the size of many individual food manufacturing industries create a large market for food machinery, but this market is further enlarged because of many food manufacturing industries employ common technical processes. This enables machinery makers to develop technology common to several industries. As a result the technical know-how of food machinery companies may be used to develop equipment for several food industries. The result is that food machinery companies have a larger potential market than do the individual food manufacturers whose primary concern is with their own industry. This difference in the size of markets for firms within and outside an industry encourages specialization in food machinery manufacturing.

This was not always so. In earlier years, food manufacturers often built much of their own equipment, not by choice but of necessity. During the infancy of the prepared baby food industry, for example, firms were forced to design and build much of their own equipment. But as the industry grew, its demand for machinery grew sufficiently to give machinery manufacturers an incentive to supply the necessary equipment. Today prepared baby food makers can purchase practically all their machinery and equipment.

The lessening demand for mechanical inventions by baby food manufacturers is illustrated by the declining importance of mechanical inventions of Gerber Foods, the industry leader. Whereas during the 1950s, 71 percent of Gerber's patents covered mechanical inventions, this percentage fell to 35 percent during the 1960s and 14 percent during the 1970s.[15/] Although we have not examined the historical trends in the patent mix of food manufacturers, we believe that the baby food industry typifies what has occurred in many other food industries.

We reemphasize a caveat made earlier about the nature of this study and the interpretation of its findings. The great majority of inventions and innovations examined relate to matters that are primarily important to the productive efficiency of food manufacturers. Where patents dealt with new products we were unable to determine their economic or social value. We did not address this question because it was beyond the scope of the data analyzed, not because we believe the question is unimportant.

Our findings are relevant to the interpretation of observed relationships between the competitive organization of industries and their technological performance. They suggest that when there exist significant relationships between industrial structure and technological performance, as have been found here and in most other cross sectional studies, these findings must be placed in a broader context that includes the sources of all inventions and innovations affecting an industry. In many food processing industries, alternative industrial structures would have an insignificant impact on total inventive effort influencing technical efficiency.

This is not to denigrate cross sectional studies or the public policy questions that they seek to answer, particularly those relating to competition policy. But our findings suggest that considerable caution must be used in

interpreting the public policy significance of studies focusing solely on how an industry's competitive structure influences its technological performance. More or less competition may be a good thing in food manufacturing but public policy decisions as to this question must be based on other than technological considerations, e.g., the impact of market power on income distribution or allocative efficiency. Subsequent research may prove that this is also true in many other industries.

FOOTNOTES

[1] The study, which covers the period around 1970, replicates a similar study by the authors for the period around 1950, as reported by W.F. Mueller, J.D. Culbertson and B. Peckham.

[2] For discussion of the rationale for using firm relative market share see Marion, et al.

[3] This theory predicts that the R&D investment's risk declines with the number of products, so our diversification measure enumerates firms' products that contribute significantly to sales. Five-digit product classes best discriminate among dissimilar production techniques. We assume that product production and marketing expertise require value of shipments of $1.25 million (1967 dollars). The author's 1950 study employed a $1 million cut-off and this value was increased by 25 percent to control for inflation [Mueller, Culbertson and Peckham].

[4] By using opportunity classes identified in a study for an earlier period (1950), we avoid pretest bias that might have resulted had these been identified with the circa 1970 data set.

[5] The index of technological opportunities is the intercept terms from Scherer's (1965) regression analysis on two-digit industries.

[6] The heteroscedastic patterns is estimated from the ordinary least squares residuals by regressing these residuals on the product of a constant term and firm assets to the "a" power. The estimated "a" values, which are point estimates of the heteroscedastic pattern, are .42 with patents, .36 with R&D employment, and .50 with R&D expenditures.

[7] See Culbertson in Mueller (1979, pp. 189-92).

[8] See Mueller and Rogers, for a more complete description of these data.

9/ For a list of the USPTO classes included see, Mueller, Culbertson, and Peckham, pp. 90-91.

10/ Studies of technology often differentiate between invention and innovation, though drawing sharp dividing lines between them in particular cases may be difficult or even impossible. However, here we shall characterize the products receiving Putman Awards as innovations rather than inventions, though they often involve elements of each: inventions insofar as they are new products or processes, and innovations because they have been carried to, and often over, the threshold of commercial usage. Indeed, to qualify for consideration for a Putman Award a product must "have made significant contributions to more efficient and effect operations in the food processing industry." They thus have, to some degree at least, been subjected to the test of the market place, the ultimate arbiter of technological success or failure.

11/ The editors of Food Processing, 1975, p. 23, described the judging process as follows: "The entries were organized into categories and judged by panels of experts in the different categories. The judges represent all segments of the food industry and are well qualified to appraise the different developments as to their value to food processors. Three separate, independent judging periods occurred over a three-month period. Entries were rated on three factors: the novelty or innovation factor; breadth of application in the food industry; and significance to the food industry."

12/ Completed questionnaires were received from 214 (81 percent) of the award recipients. Information on firm and industry characteristics were obtained from secondary sources for another 31 (12 percent) of the recipients.

13/ Of the 32 awards going to food processors and the ingredient manufacturers, 20 were for new ingredients, 4 were for packaging, 3 were for processing equipment and 5 were for miscellaneous purposes.

14/ For 71 manufacturing industries for which data are available between 1972-1977, 18 food industries' average annual labor productivity rose 2.5 percent, which was identical to the average of the 53 nonfood industries. The beer industry ranked sixth among all 71 industries, increasing at an annual rate of 5.8 percent [Bureau of Labor Statistics 1978, p. 5]; in contrast, R&D expenditures of brewers were among the lowest of all food processors.

15/ The absolute number of mechanical patents also declined. This pattern is all the more remarkable because Gerber was a much smaller firm and factor in the industry in 1950 than in the 1970s. In 1950 it had assets of $26 million and a market share of about 40 percent; in 1972 it had assets of $154 million and a market share of nearly 70 percent.

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