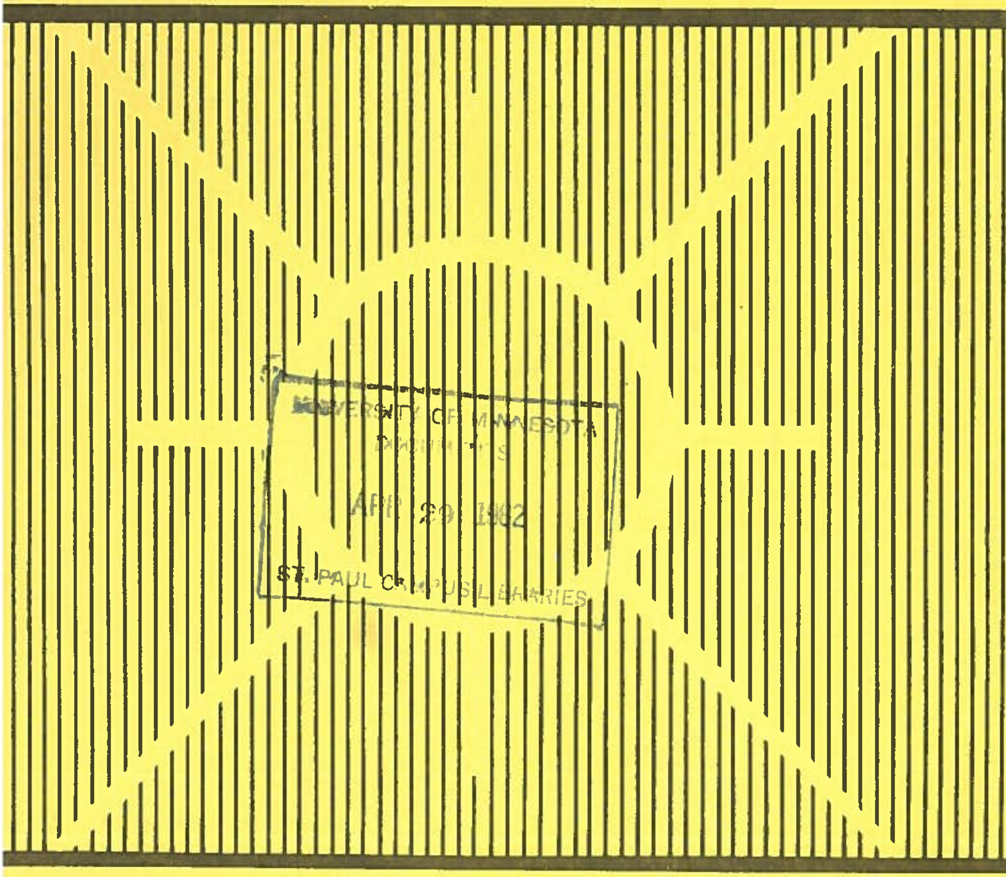
trol of the U.S.
d System

. Project 117
ograph 11

ruary 1982

MARKET STRUCTURE AND TECHNOLOGICAL PERFORMANCE IN THE FOOD MANUFACTURING INDUSTRIES



Agriculture Experiment Stations of Alaska, California, Cornell, Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, New Mexico, North Dakota, Ohio, South Dakota and Wisconsin.

Published by the Research Division, College of Agricultural and Life Sciences, University of Wisconsin-Madison.

CHAPTER 4. STRUCTURE-R & D PERFORMANCE RELATIONSHIPS

This chapter reports the regression results from the firm R & D models estimated separately with the 1950 and 1967 structural data. Although we discussed the substantial body of industrial-organization and econometric theory in this area, the regression models are not completely specified. To achieve this specification, we first examine several measures of firm diversification. While theory establishes a preference ordering on these measures, the question of the preferred measure remains to some extent an empirical one. Second, we estimate a sequence of models based on the results of hypothesis tests. Economic theory is usually unable to specify the functional form of the model. Rather, it posits negative or positive relationships between independent and dependent variables, but not the functional form of the relationship. The determination of the functional forms is also an empirical matter.

To determine the preferred or "best" model for the 1950-1956 period, we begin by estimating models that use separately two dependent variables with each of the four indices of firm diversification. Then, those second-degree terms with t-statistics that are not significant at the 10 percent level are dropped, and the index of diversification that maximizes the R^2 is selected. The resultant "best" model is then re-estimated to test the hypotheses of industrial-organization theory. The same regression strategy is used to determine the "best" models for R & D expenditures, R & D personnel, and R & D patents for the 1967-1974 period.

Since economic theory cannot specify the sign of the market-power variables, two-tailed t-tests are used for CR4, SCR4, RMS, SRMS, AS, and SAS. For firm diversification, (DIVERS), L, LL, the percent nonfood, (NONFO) and the percent foreign (FOREIGN) variables, for which theory hypothesizes the sign of the relationship, one-tailed tests are used.

STRUCTURE-R & D RELATIONSHIPS, 1950-1956

R & D Employment Models

The R & D employment models estimated for this period use the total number of scientists and support personnel that were employed by the firm in its research laboratory in 1950 as the dependent variable. The results of the regression analysis that estimates models with each of the four indices of diversification are presented in Table 4.1. The t-statistics on the diversification variables vary widely. The theoretically preferred variable, the number of 5-digit industries in which the firm has value-of-shipments in excess of $1,000,000 (DIVE1), is clearly the strongest variable, with a t-statistic of 4.52 (equation 1.1). The variables D1, D2, and D3 (equations 1.2, 1.3, and 1.4) are significantly weaker, with t-statistics of 2.38, 1.38 and .98, respectively. In addition, the R^2 in equation 1.1 is greater than those in equations 1.2, 1.3, 1.4. Based on this result, DIVE1 represents firm diversification in our best model of firm research-and-development employment. In equation 1.1 neither the linear (CR4) nor the quadratic (SCR4) variable for four-firm concentration is significant at the 10 percent level. Since the t-statistics are of approximately the same magnitude, both variables are included in the best model. Both linear (RMS) and quadratic (SRMS) relative firm market share are significant at least at the 10 percent level, so neither is deleted. Finally, both firm-asset variables (L and LL) are significant at the 1 percent level and are also included.

Table 4.1. Multiple Regression Models with Firm R & D Employment as the Dependent Variable, 1950-1956

Dependent Variable	Inter-cept	Tech-nology Class Dummy (DUM)	Four-Firm Concen-tration Ratio (CR4)	Squared Four-Firm Concen-tration Ratio (SCR4)	Relative Firm Market Share (RMS)	Squared Relative Firm Market Share (SRMS)	Firm Diversification (DIVE1)	Firm Diversification (D1)	Firm Diversification (D2)	Firm Diversification (D3)	Industry Adver-tising To-Sales (AS)	Squared Industry Adver-tising To-Sales (SAS)	Percent Nonfood (NONFO)	Firm Size (L)	Squared Firm Size (LL)	R^2
1-1 R & D	101.64	-35.86	1.04	-.0064	2.07	-.029	7.00				18.91	-2.90	-.0058	-99.54	14.85	
Employment	(1.48)	(-3.56) **	(.61)	(-.47)	(2.23) *	(-1.94) +	(4.52) **				(1.77) +	(-1.48)	(-1.86) +	(2.96) **	(3.32) **	.75
1-2 R & D	213.19	-42.85	-.27	.0022	2.35	-.038		.99			19.88	-2.32	-.0095	-143.03	22.64	
Employment	(2.96)	(-3.98) **	(-.15)	(.15)	(2.32) *	(-2.31) *		(2.38) *			(1.69) +	(-1.23)	(-2.56) *	(-3.97) **	(4.97) **	.68
1-3 R & D	190.96	-41.26	-.10	.0017	2.66	-.043			.32		22.54	-2.85	-.0064	-140.16	22.48	
Employment	(2.61)	(-3.65) **	(-.053)	(.11)	(2.59) *	(-2.61) *			(1.38) +		(1.87) +	(-1.48)	(-1.85) +	(-3.78) **	(4.81) **	.65
1-4 R & D	173.84	-43.30	-.071	.0016	2.79	-.045				.23	23.00	-2.90	-.0062	-131.85	21.44	
Employment	(2.29)	(-3.88) **	(-.037)	(.100)	(2.64) *	(2.72) **				(.98)	(1.87) +	(-1.47)	(-1.76) +	(-3.58) **	(4.54) **	.64

t-statistics are in parentheses.
Significance levels: ** = 1 percent, * = 5 percent, + = 10 percent.

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

The sample size is 87.

Thus equation 1.1 is the best R & D employment model. Linear relative market share (RMS) is significant at the 5 percent level and SRMS is significant at the 10 percent level, with the polynominal in relative market share attaining a maximum at RMS equal to 36. Both the logarithm of firm assets (L) and the square of the logarithm (LL) are significant at the 1 percent level. This quadratic function in L has a point of inflection—at a firm asset value of $78 million—where the function changes from increasing at an increasing rate to increasing (with firm assets) at a decreasing rate. Finally, the estimated coefficient on diversification (DIVE1) is positive and significant at the 1 percent level; the coefficient on percent nonfood (NONFO), is significantly negative at the 10 percent level, and the linear advertising variable (AS) is significantly positive at the 10 percent level.

Patent Models

Using the number of patents assigned to a firm between 1950 and 1956 as the dependent variable, models are estimated with each of the four diversification indices. As before, these initial regression results (See Table 4.2) are used to select the "best" regression equation.

The diversification index DIVE1 is significant at the 5 percent level (equation 2.1), but the three variables D1, D2, and D3 are not significant at the 10 percent level (equations 2.2, 2.3, and 2.4). The R^2 in equation 2.1 is larger than those in equations 2.2, 2.3, and 2.4. As in the employment model, economic theory and the data are consistent in preferring the variable DIVE1. Although the t-statistic for CR4 in equation 2.1 is not significant, it is larger than the t-statistic for SCR4; the latter variable is therefore deleted. While neither RMS nor SRMS is significant at the 10 percent level, both are included in the best equation because their t-statistics (1.57 vs. -1.56) are of similar magnitude. Both L and LL are significant at the 1 percent level. Finally, while neither AS nor SAS is significant, both variables are included in the best equation.

The resulting best patent model is presented in Table 4.2. The estimated coefficient of four-firm concentration (CR4) is not significant at the 10 percent level. Neither RMS nor SRMS is significant at the 10 percent level. Both L and LL are significant at the 1 percent level. This polynomial in the logarithm of firm assets has an inflection point at $75 million. Diversification, (DIVE1), with an estimated coefficient of 1.71, is significant at the 5 percent level.

Table 4.2. Multiple Regression Models with Firm Patents as the Dependent Variable, 1950-1956

							Firm Diversification									
Dependent Variable	Intercept	Technology Class Dummy (DUM)	Four-Firm Concentration Ratio (CR4)	Squared Four-Firm Concentration Ratio (SCR4)	Relative Firm Market Share (RMS)	Squared Relative Firm Market Share (SRMS)	(DIVE1)	(D1)	(D2)	(D3)	Industry Advertising To-Sales (AS)	Squared Industry Advertising To-Sales (SAS)	Percent Nonfood (NONFO)	Firm Size (L)	Squared Firm Size (LL)	R^2
2-1 Patents	65.41	-10.65	.13	-.000026	.85	-.014	1.71				4.37	-.67	-.0012	(-49.33)	7.49	.48
	(1.71)	(-1.85) *	(.14)	(-.0034)	(-1.57)	(-1.56)	(1.73) *				(.71)	(-.70)	(-.60)	(-2.45) **	(2.72) **	
2-2 Patents	84.03	-12.43	-.20	.0023	.95	-.018		-.0016			5.94	-.89	-.0011	-56.30	9.08	.44
	(2.24)	(-2.15) *	(-.21)	(.30)	(1.75) +	(-1.90) +		(-.0072)			(.94)	(-.88)	(-.52) *	(-2.79) **	(3.44) **	
2-3 Patents	83.98	-11.92	-.14	.0019	.97	-.017			-.044		5.43	-.81	-.0012	-57.42	9.15	.44
	(2.25	(-2.01) *	(-.14)	(.24)	(1.78) +	(-1.91) +			(.36)		(.86)	(-.80)	(-.60)	(-2.83) **	(3.46) **	
2-4 Patents	82.13	-12.28	-.15	.0020	.97	-.018				.0020	5.65	-.84	-.0012	-56.12	9.01	.44
	(2.10)	(-2.11) *	(-.15)	(.25)	(1.75) +	(-1.93) +				(.16)	(.88)	(-.82)	(-.57)	(2.79) **	(3.37) **	
2-5 Patents	64.86	-10.48	.14		.86	-.014	1.71				3.87	-.60		-.48.71	7.34	.48
	(1.91)	(-1.88) *	(.84)		(1.64)	(-1.59)	(1.78) *				(.65)	(-.65)		(-2.51) **	(2.74) **	

t-statistics are in parentheses.
Significance levels: ** = 1 percent, * = 5 percent, + = 10 percent.

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

The sample size is 87.

Summary of Firm R & D Models Estimated with 1950 Structural Data

We tested the hypotheses of industrial-organization theory for a sample of large food-manufacturing firms in the early 1950s. Two dependent variables, the number of patents assigned to the firm over the period 1950-1956 and the number of firm research-and-development employees in 1950, were used in these regressions.

Firm-diversification and the firm-size variables were significant in both the best R & D employment model (equation 1-1) and the best patent model (equation 2.5). The coefficient of firm diversification was positive in both and significant at the 1 percent level in equation 1.1 and at the 5 percent level in equation 2.5. The firm-size variables—the logarithm of assets and the square of the logarithm of assets—were significant at the 1 percent level in both models. The point of inflection in the relationship between firm assets and firm inventive activity occurred at $78 million in the R & D employment model (1.1) and at $75 million in the patent model (2.5). Returns to firm size began to decrease at approximately $80 million in firm assets (1950 dollars). A firm of this size was relatively small for this period. For example, the largest firm in our sample, Swift and Co., had assets of $471 million in 1950. Thus, for the period around 1950, R & D increased at a decreasing rate with firm size beyond a fairly modest firm size.

In the best employment model (1.1), RMS was significant at the 5 percent level and SRMS at the 10 percent level. The quadratic function in relative market share had a maximum at 36 percent. In other words, firms whose sales comprise 36 percent of the sales of the top four firms in an industry, will devote the most inputs to firm research.

The linear advertising-intensity variable had a significant positive coefficient at the 10 percent level in equation 1.1. While SAS is not significant, this quadratic term is only slightly weaker (-1.48 vs. 1.77) than the linear term. The quadratic function in advertising intensity had a maximum at 3.26. While this value was very high, it was not beyond the range of the data. Thus, advertising had a positive effect on firm inventive activity up to fairly high levels, after which it had a negative effect.

Industry advertising not only creates market power by raising barriers to entry, it also complements and substitutes for firm investment in R & D. New product innovations require complementary advertising expenditures to introduce them to the public. In most food industries, many new products that are developed do not depend on new technology for their creation. For example, most new ready-to-eat breakfast-cereal products use advertising and existing technology to create a new, differentiated product. Since the food industries do not, in general, sell technology through their products, unlike the high-technology industries, they do not require advances in technology to create new products. Thus, advertising will not only complement R & D investments, but it will also substitute for them. This suggests a second interpretation of the quadratic advertising relationship. Advertising and R & D are complementary investments in industries with low to moderate levels of advertising intensity; advertising in these industries is used to market new product innovations developed in research laboratories. Industries with high advertising intensities appear to rely more heavily on existing technology and product differentiation strategies to create new products.

Finally, the percent nonfood coefficient was significant at the 10 percent level in equation 1-1 (two-tailed test) and has a negative sign. Economic theory hypothesized a positive sign. The negative sign implies that the technological opportunities in the industries into which the food firms had diversified were lower than the technological opportunities in the food industries.

STRUCTURE-R & D PERFORMANCE RELATIONSHIPS, 1967-1974

Here we report the results from estimating separate regression models for patents, firm research expenditures, and firm research employees, using firm structural data for 1967. Pre-testing bias in the estimation of these models is minimized by relying as heavily as possible on the models previously specified with structural data for 1950. First, based on the significance of the dummy variable for technological opportunity in all of the previously estimated models, the hypothesis that the average level of firm research-and-development activity is unrelated to the industry in which the firm operates is rejected. Despite the fact that the principal products of all the firms in our sample are in SIC 20, these industries can be broken down into higher and lower technological-opportunity classes. Firm diversification in the 1950 data was measured by the four diversification variables DIVE1, D1, D2, and D3. The theoretically preferred variable, DIVE1, was also consistently the empirically preferred variable. For the 1967 structural data, therefore, firm diversification is measured only by the variable DIVE1 (a count of the number of 5-digit products in which the firm had 1967 value-of-shipments greater than $1.25 million). In the models estimated with 1950 structural data both linear and quadratic terms were considered for the firm-size, market-concentration, industry advertising-to-sales, and firm relative market-share variables. For the specification of the models estimated with 1967 structural data, we again estimate models with both linear and quadratic terms for these four variables.

The average values of the structural variables for both 1950 and 1967 are reported in Table 4.3. The mean values of relative market share and four-firm concentration are approximately the same both years. Average firm size is substantially greater in the 1967 sample, increasing from $89 million (1950 dollars) to $236 million (1967 dollars). Values for firm diversification and percent nonfood in 1967 are about twice the 1950 values. Industry advertising-to-sales in the 1967 sample is 36 percent greater than in the 1950 sample.

Table 4.3. Average Values of Structural Variables, 1950 and 1967

	Year	
Variable	1950	1967
CR4	56	54
RMS	20	24
AS	1.98%	2.69%
FIRM ASSETS	$89 million	$236 million
PERCENT NONFOOD	4.3%	9.8%
PERCENT FOREIGN	—	10.0%
DIVERSIFICATION	5 products	10 products

Research-and-Development Employment Models

The models estimated with firm research-and-development employment in 1970 as the dependent variable are equations 4-6 and 4-7 in Table 4.4. In equation 4-6, variables for market concentration, relative market share, the logarithm of firm assets, and industry advertising-to-sales ratio are entered in both linear and quadratic form. Both CR4 and SCR4 are significant at the 5 percent level and are included in the best employment model (equation 4-7). Neither linear nor quadratic relative firm market share is significant at the 10 percent level, thus SRMS, which has the smaller t-statistic, is omitted in equation 4-7. Both firm-size variables, L and LL, are significant at the 1 percent level. The estimated coefficient for firm diversification is positive as hypothesized and is significant at the 5 percent level. Neither the percent nonfood nor the percent foreign variable is significant, so both variables are omitted in equation 4-7. Neither advertising-intensity variable, AS nor SAS, is significant; therefore, SAS, with the smaller t-statistic, is eliminated from the best R & D employment model.

In the best R & D employment model, equation 4.7, the estimated coefficients of CR4 and SCR4 are significant at the 5 percent level; this quadratic function in four-firm concentration attains a maximum at CR4=58. Relative firm market share, with a t-statistic of 1.50, is not significant. The logarithm of firm assets and the square of the logarithm of firm assets are both significant at the 1 percent level. This function in firm size has a point of inflection at $126 million. Firm diversification, with an estimated coefficient of 4.30, is significant at the 1 percent level. Finally, linear industry advertising intensity is not significant.

In summary, the positive influence of market power on firm employment of research-and-development personnel is manifested in the four-firm market-concentration variable but not in the variables measuring relative firm market share or industry advertising intensity. This must be qualified, however, since the function in four-firm concentration has a critical value where it changes from positive to negative. Thus, when CR4 reaches its critical value, further increases in the variable lead to a decline in research-and-development employment. The relationship with firm size also has a critical value where the function has an inflection point. Beyond this point, which is at a modest firm size ($126 million) compared with the largest firm in the sample, firm R & D employment increases at a decreasing rate with firm size. Finally, firm diversification, always one of the strongest variables in the model, exerts a positive effect on R & D employment.

Research-and-Development Expenditures Models

In Table 4.4, the estimated coefficients and t-statistics from the generalized-least-squares estimation of the R & D expenditures model are presented in equations 4.1, 4.2, and 4.3.[1] In equation 4.1, both linear and quadratic four-firm concentration are significant at the 10 percent level. Neither variable for relative firm market share is significant at the 10 percent level; squared relative market share, SRMS, with the smaller t-statistic, is not included in equations 4.2 and 4.3. Firm diversification is not significant at the 10 percent level. The weakness of this variable is largely due to the high correlation between firm diversification and percent nonfood (the simple correlation for the reduced sample is .78). Equation 4.2 includes percent nonfood as an explanatory variable and excludes diversification, and equation 4.3 excludes percent nonfood and includes firm diversification.

Table 4.4. Multiple Regression Equations With Firm R & D Expenditures, Patents, and R & D Employment, 1967-1974.[a]

Dependent Variable	Intercept	Technology Class Dummy (DUM)	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 Monfood (NONFO)	Percent Foreign (FOREIGN)	Industry Advertising-To-Sales Ratio (AS)	Squared Industry Advertising-To-Sales Ratio (SAS)	R^2
4-1 R & D	7.27	1.72	.12	-.0011	.047	-.00031	-6.64	.85	.043	.0013	.031	.42	-.021	.77
Expenditures	(1.62)	(2.47) **	(1.74) +	(1.68) +	(1.07)	(-.42)	(-3.24) **	(3.44) **	(.78)	(1.49) +	(.92)	(1.43)	(-.93)	
4-2 R & D	10.36	1.35	.13	-.0011	.027		-7.97	1.03		.0019		.19		.73
Expenditures	(3.03)	(2.76) **	(2.03) *	(-1.97) +	(2.06) *		(-4.81) **	(5.40) **		(2.65) **		(2.41) *		
4-3 R & D	6.91	1.27	.16	-.0013	.027		-6.72	.87	.10**			-.18		.72
Expenditures	(1.68)	(2.56) **	(2.35) *	(-2.23) *	(1.98) +		(-3.62) **	(3.88) **	(2.25) *			(2.25) *		
4-4 Patents	9.09	39.72	1.70	-.014	.60	-.000043	-.53.96	6.81	1.50	.014	-.28	12.28	-.83	.75
	(.16)	(3.94) **	(1.43)	(-1.37)	(.88)	(-.0038)	(-1.98) *	(2.16) *	(2.18) *	(1.10)	(-.80)	(2.72) **	(-2.31) *	
4-5 Patents	10.39	37.71	1.77	-.015	.55		-53.70	6.71	1.75			11.86	-.82	.74
	(.17)	(3.84) **	(1.51)	(-1.48)	(2.24) *		(-2.01) *	(2.17) *	(2.89) **			(2.69) **	(-2.32) *	
4-6 R & D	149.31	41.01	5.78**	-.051	1.00	.0016	-192.80	25.57	3.98	.014	-.14	12.82	-.75	.74
Employment	(1.13)	(1.77) +	(2.19) *	(-2.18) *	(.68)	(.063)	(-3.14) **	(3.50) **	(2.27) *	(.43)	(-.16)	(1.24)	(-.89)	
4-7 R & D	205.49	25.66	5.93	-.051	.89		-211.57	27.57	4.30			3.96		.73
Employment	(1.81)	(1.61)	(2.33) *	(-2.32) *	(1.50)		(-3.80) **	(4.09) **	(3.05) **			(1.39)		

t-statistics are in parentheses.
Significance levels: ** = 1 percent; * = 5 percent; + = 10 percent.

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

The sample size 51 for models 1-3; 61 for models 4 and 5; and 59 for models 6 and 7.

Both firm-size variables, the logarithm of firm assets (L) and the squared logarithm of firm assets (LL) are significant at the 1 percent level in equation 4.1. The percent foreign variable is not significant and is excluded from equations 4.2 and 4.3. Finally, while neither linear nor quadratic industry advertising intensity is significant, the quadratic term has a substantially smaller t-statistic and is omitted in equations 4.2 and 4.3.

In equation 4.2, CR4 is significant at the 5 percent level and SCR4 at the 10 percent level. This quadratic function in four-firm concentration attains a maximum when CR4 is equal to 59. The linear variable for relative market share, with a coefficient of .027, is significant at the 5 percent level. The quadratic function in the logarithm of firm assets, with both L and LL significant at the 1 percent level, has a point of inflection when firm assets equal $130 million. The percent of the firm's sales that are not food related is significant at the 1 percent level. The coefficient of the linear industry advertising-intensity variable is positive and significant at the 5 percent level.

The final research-and-development expenditures model, equation 4.3, differs from equation 4.2 only in that the diversification variable replaces the percent nonfood variable. Linear four-firm concentration is still significant at the 5 percent level; quadratic four-firm concentration which is significant only at the 10 percent level in equation 4.2, is significant at the 5 percent level in equation 4.3. In this quadratic function, R & D expenditures increase up to CR4=62, and then decline for higher values of market concentration. In equation 4.3, relative firm market share is significant at the 10 percent level, as compared with 5 percent in equation 4.2. The two firm-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 $129 million. The estimated coefficient on firm diversification is positive and significant at the 5 percent level. Finally, as in equation 4.2, industry advertising intensity has a positive effect that is significant at the 5 percent level.

Patent Models

The models estimated with the total number of patents assigned to the firm from 1968 through 1974 are reported as equations 4.4 and 4.5 in Table 4.4. Since patent data are available for all firms in our sample, the regressions are estimated with 61 firms. Equation 4.4 presents the regression results from estimating the patent model with both linear and quadratic terms for CR4, RMS, L, and AS. The linear and quadratic terms for CR4 are not significant at the 10 percent level; however, both are included in the succeeding model because their t-statistics are of similar magnitudes, but of differing signs. The t-statistic on squared relative firm market share is smaller than the t-statistic for RMS, -.0038 versus .88 respectively, so squared relative market share is not included in the best patent model. The linear and quadratic firm-size variables are included because both are significant at the 5 percent level. Neither the percent nonfood nor the percent foreign variable is significant at the 10 percent level; both are deleted in the best model, equation 4.5. Finally, linear AS is significant at the 1 percent level and SAS is significant at the 5 percent level; both variables are included in equation 4.5.

In the best patent model for 1967-1974, equation 4.5, neither linear nor quadratic four-firm concentration is significant at the 10 percent level. Linear relative firm market share, with an estimated coefficient of .55, is significant at the 5 percent level and the quadratic function in 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 least at the 5 percent level; the function in industry advertising intensity attains a maximum when AS equals 7.23 percent.

The regression results in equations 4.4 and 4.5 generally support the hypothesis of economic theory that firm research and market power are positively related (actually, as was discussed earlier, both positive and negative relationships have been hypothesized). While four-firm concentration is not significant, relative firm market share and industry advertising intensity are significant at the 5 percent level or higher. The relationship between patents and AS has a critical value, within the range of the data, where the relationship changes from positive to negative. Firm diversification, which is significant at the 5 percent level in equation 4.4 and the 1 percent level in equation 4.5, has a positive effect on firm patent activity. Finally, firm size has a significant effect on firm patents with a point of inflection in the relationship at $149 million.

Summary of Firm R & D MODELS Estimated with 1967 Structural Data

The best R & D expenditures, patents, and R & D employment models (4.2, 4.5, and 4.7, respectively) for the period around 1970 are strikingly similar: The percent foreign and squared relative firm market share variables are omitted in each of the three models; the percent nonfood variable is deleted from two of the three best models; and the estimated coefficients on the remaining variables have the same sign in each of the best models. Firm diversification has a significant positive linear effect. Four-firm concentration has a significant nonlinear effect, initially positive and then negative, for expected R & D expenditures and R & D employment. The switch from a positive to a negative effect occurs in the best R & D expenditures model (4.2) at CR4=59 and in the best R & D employment model (4.7) at CR4 = 58. Since the maximum value of weighted CR4 in the sample is 89, the maximum in the four-firm concentration relationship is observed within the range of the data. Relative firm market share has a significant positive coefficient in the best R & D expenditures (4.2) and patents (4.5) models. The point of inflection in the size relationship occurs at $126 million in the best employment model (4.7), and at firm size $149 million in the best patent model (4.5). A firm within this size range is approximately 15 percent as large as the largest firm in the sample. Linear advertising intensity has a significant positive effect in the best R & D expenditures model (6.2), and a significant quadratic effect—initially positive and then negative for advertising intensity above 7.23 percent—in the best patent model (4.5).

CONCLUSIONS

The best regression models display remarkably consistent results across two time periods, around 1950 and around 1970, and three indices of research and development activity: total patents assigned to the firm, firm employment of R & D personnel, and firm R & D expenditures. The estimated coefficient of firm diversification is significantly positive in each model in which it appears. The firm size variables are significantly different from zero in every model, and these quadratic functions in the natural logarithm of firms assets have inflection points—where the function changes from increasing at an increasing rate to increasing at a decreasing rate—in the range of $78 million in the earlier period and $126-149 million in the later period. The significance of the estimated relationships between R & D and the market power variables—relative firm market share, four-firm concentration, and industry advertising intensity—are less consistent than are the relationships between R & D and firm size and diversification. However, these results are broadly consistent with the hypothesis that low to moderate levels of market power increase firm R & D, whereas higher levels of market power exert a negative influence on firm R & D.

FOOTNOTES

[1] R & D expenditures data were not available and could not be estimated for 10 firms. For four firms, research-and-development expenditures data are not available for 1972, but are available for at least one year during the period 1971-1976. The expenditures data for these four firms were constructed using the R & D expenditures-to-sales ratio for the year closest fo 1972 for which firm R & D expenditures data are available. The implicit assumption is that firm research intensity is approximately constant over short periods of time for these four firms. While this hypothesis could not be statistically tested due to the lack of sufficient data, inspection of the available data suggests that it is a reasonable assumption. For 17 firms, R & D expenditures data are not available; on the basis of the number of firm patents for 1968-1974 and the number of firm research employees in 1970, it is assumed that these firms had zero research-and-development expenditures. In each of these cases the firms did not report any R & D employees for 1970 and the firm was awarded five or fewer patents for the period 1968-1974. Thus, 51 observations are used to estimate the firm R & D expenditures equation.