R&D Activity and Acquisitions in High Technology Industries: Evidence from the U.S. Electronic and Electrical Equipment Industries

Bruce A. Blonigen
Department of Economics
1285 University of Oregon
Eugene, OR 97403-1285
bruceb@oregon.uoregon.edu
(541) 346-4680

Christopher T. Taylor
Antitrust Division, Bureau of Economics
Federal Trade Commission
Washington, DC 20580
ctaylor@ftc.gov
(202) 326-2997

Abstract: Theory argues that R&D intensity and acquisition activity may be either directly or inversely related. However, empirically we know relatively little about which firms are responsible for acquisition activity in high-technology industries. Using a panel of 217 U.S. electronic and electrical equipment firms from 1985-93 and limited dependent variable estimation techniques, we find relatively low R&D-intensity firms are more likely to acquire. This result is true both when looking at between and within estimators, indicating that acquisitions may be used as a short term or long term strategy. These results are robust to a number of sensitivity test.

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I. Introduction

R&D activity and innovation have taken center stage in economic analysis of high-technology industries. A number of papers including Dasgupta and Stiglitz (1981), Reinganum (1985) and Jovanovic and MacDonald (1994a; 1994b) model and simulate industry evolution through patterns of innovation and imitation by firms.[1] Firm survival in these models depends on their ability to innovate or imitate new products. This line of research suggest that firms must generate marketable products on their own or exit.

However, this ignores the fact that firms may obtain technology (or other assets) through acquisitions or licensing. In other words, acquisition or licensing activity may be important in determining firm survival and growth as R&D. Papers such as Salant (1984), Gallini and Winter (1985), Katz and Shapiro (1986), and Gans and Stern (1997) show that licensing or acquisitions can alter firms incentives to innovate. By allowing innovations to be obtained by the firm with the highest-valued use, the acquisition market plays an important role in these high-technology sectors.

Empirically, licensing and acquisition activities are important for high-technology industries.[2] The first two columns of table 1 show annual average acquisitions and average annual share of all manufacturing acquisitions for some select high technology sectors in the United States from 1989-94.[3] For comparison columns 3 and 4 show each sector's share of total manufacturing firms and total manufacturing shipments, respectively. Table 1 demonstrates that acquisition activity in these high technology sectors is much larger than their share of total manufacturing firms or shipments. For

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[1] In addition to the papers mentioned above, chapter 10 of Tirole (1988) has a thorough overview of this literature.

[2] We look at acquisition activity here because that is the focus of this paper. Licensing arrangements seem to most important for the pharmaceutical industry.

[3] Our choice and definition of high technology sectors was limited by the categories reported by *Mergers and Acquisitions*.

example, computer and office equipment firms represent 0.6 percent of all manufacturing firms and account for 2.2 percent of all manufacturing shipments, but represents almost 5 percent of manufacturing acquisition activity. All four high technology sectors in table 1 display this same pattern.

This paper examines the empirical evidence on the relationship between R&D and acquisition activity in industrial sectors where innovations and technology are important. The question is which firms are acquiring assets in these industries – in particular, is it firms that are investing in R&D or not. Theoretically, the relationship between R&D and acquisitions is an open question. The traditional acquisition literature can support the view that either relatively high R&D or low R&D firms will acquire more. There could be synergy gains by acquiring like assets, R&D, or complementary assets, such as sales or distribution.

In this paper we empirically examine the relationship between R&D intensity and acquisition activity in over 200 firms in the U.S. electronic and electrical equipment industry from 1985 to 1993. Controlling for traditional merger motives, we test whether high R&D intensity firms are more or less likely to make acquisitions. Estimation is complicated by 1) availability of only discrete counts of acquisitions, our dependent variable, 2) issues of simultaneity, and 3) dynamic considerations of the relationship between R&D intensity and acquisition activity over time. Using a recent GMM estimator for count/panel data sets suggested by Wooldridge (1997), we overcome these difficulties.

Our results show a strong negative correlation between R&D intensity and acquisition activity; in other words, relatively low R&D firms in these industries are more likely to participate in the acquisition market. These results are robust to a wide variety of specifications and sensitivity tests. This includes allowing for unobserved firm-specific effects and controlling for simultaneity in our nonlinear panel data set.

The rest of the paper is organized as follows. The next section discusses in greater detail the potential for competing hypotheses on the relationship between R&D intensity and acquisition activity. The following section presents the econometric models used to test our hypotheses and other merger motives in high-technology electronics. We then present our empirical results and a final section concludes.

II. R&D and Acquisition Activity in High Technology Industries

A traditional motive for acquisition activity is the potential for synergy gains. As formulated in Hall (1987), the acquisition market is a matching process. In this matching process a firm calculates the potential synergy gains and costs from an acquisition with all the possible target firms. A firm with more assets will have a greater potential for synergy with another firm's assets, ceteris paribus, and thus, more likely to acquire. If firms with higher R&D intensity are generating more technological and innovative assets, one would expect R&D intensity to be positively correlated with acquisition activity. This assumes there is a strong correlation between R&D intensity and valuable innovations, which may not be true (Trajtenberg (1990)). However, Geroski et al. (1993) find that the process of innovation may be just as important to firm profitability as the product of innovation; thus, the assets connected with the R&D process may be as important for synergy motives as the innovations they may generate. Thus, there is a credible case for a positive correlation between R&D intensity and acquisition activity.

Hall (1987) specifically explores the role of R&D activity in creating synergy gains that lead to acquisitions. She estimates a matching model of the acquisition decision by a firm. Conditional that a firm is in the acquisition market, the firm considers all other firms as potential targets and acquisitions occur when assets of the acquiring and target create synergy gains to yield a large enough return. The paper uses a large cross-industry sample constructed from all firms in the Compustat data files and focuses on synergy gains with respect to R&D assets and activity. The main finding with this matching model is that firms of like sizes and R&D intensity are more likely to merge. In addition, Hall (1987) finds that the shadow price of R&D intensity of the target firm increases in the acquiring firm's R&D

intensity. These results suggest that R&D intensity may create important synergies that make a firm's valuation of a potential target greater. However, it should be noted that this result does not necessarily mean that R&D intensity is positively correlated with acquisition activity since it is conditional on the firm already having decided to acquire. In fact, when Hall (1987) explores determinants of the probability that a firm engage in acquisitions, R&D intensity is not a significant explanatory variable across the study's sample of years, 1976-86. However, for a subsample, 1982-86, R&D intensity is *negatively* related to the probability of acquisition.

A negative correlation between R&D intensity and acquisition activity may occur because firms are choosing between an internal growth strategy with relatively high R&D intensity versus an external growth strategy with acquisitions. This is what is traditionally known as "make or buy" strategy. Anecdotal evidence of managers using acquisitions for growth are common in high-technology industries. For example, a 1991 *Electronic Business* (January 7, 1991, pp. 28-32) article reports that the CEO of Seagate Technology, a manufacturer of disk drives, blamed financial losses in early fiscal 1989 for a slow down in R&D which then made Seagate tardy in bringing new innovations to the marketplace. As a result, Seagate acquired Imprimus Technology Inc., formerly a disk drive subsidiary of Control Data Corporation which claimed the fastest disk drive in the world at that time, in October of 1989. In another example, Vishay Intertechnology, a manufacturer and distributor of electronic resistors, apparently decided on external over internal acquisition of technology in the late 1980s as well. Again, an *Electronic Business* article reports that the CEO of Vishay, Felix Zandman, felt that "Vishay could have grown either by developing new products or by acquiring companies in a related business. 'We decided to acquire,' he says" (*Electronic Business*, Jan. 7, 1991, p. 39). From November 1987 to October 1988, Vishay bought three resistor companies. A final example comes from the software industry. Mark Bailey, Vice President at Symantec Corporation, writes in an article for the March/April, 1995 issue of *Mergers & Acquisitions*,

> “de novo innovations are becoming riskier, more expensive, and more time consuming in markets where survival depends on speed. Hence, high tech firms, as exemplified by software developer Symantec Corp., are going outside to get companies with talented people and proven products that can meet market demands and generate technological throw-offs for the future.” (p. 31)

The article notes that Symantec Corporation acquired 18 firms in its 12-year history.

Interestingly, these examples point out that acquisitions may be either a long-run strategy for growth or, in the case of Seagate, potentially a response to difficulties generating innovations and growing internally. If the latter case is the norm, it is not clear that there would be negative relationship between R&D intensity and acquisition activity in general, as would be true with the former case. As Trajtenberg (1990) points out, while there is a strong relationship between R&D and patents, the relationship between R&D and valuable innovations is much weaker. Perhaps firms do not vary their R&D efforts, but use acquisitions in those periods when they have a below average realization of valuable innovations. In this case, one would expect to find a correlation between R&D intensity and acquisition activity using a within estimator.

A recent paper by Gans and Stern (1997) in the patent race and innovation literature suggests the relationship between R&D intensity and licensing/acquisition activity may be theoretically ambiguous. They begin with the standard model in this literature where an incumbent firm and entrant firm compete in a patent race. However, if the entrant wins the race, they do not assume the entrant will start production. Instead, the entrant may license the new technology to the incumbent (or equivalently the incumbent may acquire the potential entrant). They find that licensing/acquisition, rather than product market competition, is a unique equilibrium in their model when the entrant innovates before the incumbent. Intuitively, they obtain their results because the firms can do better by sharing monopoly profits which are greater than the sum of the duopoly profits. Importantly, this environment can have quite different impacts on the incumbent firm’s research activity. Even if the entrant wins, the incumbent’s research activity is important for bargaining over the rents from the new innovation. The threat of matching the entrant's innovation with its own can increase the rents accruing to the incumbent. Gans and Stern find that when the expected licensing fee (or acquisition cost) is small, the incumbent considers the entrant's research as an imperfect substitute for its own research; i.e. the incumbent's and entrant's research activities are strategic substitutes. In contrast, when the expected licensing fee is large, they are strategic complements, which is consistent with the traditional literature on patent races.

Besides the papers mentioned above, a few other notable papers have empirically examined acquisition activity in high technology industries and its relationship to the R&D process. Granstrand and Sjölander (1990) suggest acquisitions in high-technology industries are large firms acquiring the technology generated by small firms. They also present preliminary empirical evidence this occurs with Swedish firms. Hall (1990) is the most comprehensive study to explore the general relationship between R&D intensity in an industry (as proxied by R&D expenditures as a percent of sales) and acquisition activity, however the study mainly focuses on the *ex post* intensity of R&D activity after a merger or acquisition takes place, rather than its potential role as a factor in acquisition decisions by firms. An empirical trend found by Hall suggests a possible *ex ante* relationship between R&D and acquisition activity -- Hall's analysis of over a thousand manufacturing firms from 1977-1987 shows acquiring firms tend to have lower R&D expenditures relative to the rest of their industry. One explanation is some firms have chosen an external method of acquiring innovation or technology. Finally, Friedman et al. (1979) examine the relationship between R&D and joint venture activity (as opposed to acquisition activity) at the firm level across a cross-section of industries. They find the greater the involvement of firms in joint venture activity, the lower the R&D expenditures, suggesting joint venture activity may be an external substitute for internal R&D activity. They also compare the degree of substitutability between R&D and joint ventures across industries and find higher degrees of substitution in industries with higher average R&D levels (i.e., in high-technology industries).

In summary, theory argues that the relationship between R&D intensity and acquisition activity may be either one of substitutes or complements. The sparse empirical work on this issue finds mixed results. Previous empirical work has typically examined firms across a wide cross-section of industries, yet the R&D process and technological innovation is much more important in certain sectors of the economy. The hypotheses discussed above may be almost solely applicable to high technology industries, so that estimates from a sample of firms across a wide variety of industries may obscure a strong interaction between R&D intensity and acquisition activity in these particular sectors. In response, this study narrows the focus to an industry with a preponderance of firms with relatively high R&D intensity: the electronics and electrical equipment industry.[4]

III. Methodology and Data

A. Methodology

To test the relationship between R&D intensity and acquisition activity, we estimate the determinants of acquisition activity by a firm, which include its R&D intensity. Measuring a firm's acquisition activity level in dollars is impossible since the terms of acquisition deals are often kept private. Therefore, we measure acquisition activity by observing the annual discrete counts of acquisitions by a firm (ACQ_{it}) reported in the publication, *Mergers & Acquisitions*, and use this as our dependent variable. Acquisitions were defined broadly to include not only acquisitions of whole firms but also partial acquisitions and equity increases of more than $1 million dollars in another firm.[5] These

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[4] We note that there is a decently wide variance in R&D intensity across sectors in these industries as well. However, as we note below, our results are robust to eliminating observations of very low R&D or very high R&D intensity, or controlling for industry effects.

[5] About one-third of our acquisition observations were partial acquisitions and most of the complete acquisitions were of quite small firms. For those acquisitions where a price was reported, approximately 40 percent, the average price was slightly less than 150 million. When less than half a doxen transactions over a billion are removed the average transaction drops to less than 75 million, The descriptions of the acquisitions in *Mergers and Acquisitions* for our sample firms' acquisitions often listed "technological" assets as a motivation for the acquisition. Over sixty percent of the transactions listed items like engineering services, computer programing sercies, radio frequency ID cards, or tantalum capacitors.

modes of acquisitions often involve transfer of technological assets just like complete acquisitions. Previous studies have often specified a probit analysis to model such a dependent variable. However, a probit model may suffer from specification bias, since it treats a firm with one acquisition in a period as observationally equivalent to a firm that has two or more acquisitions during the period. There are a fair number of multiple acquisition observations, so we initially model our dependent variable as following a negative binomial specification which specifically handles the integer property of the dependent variable directly and includes “0" observations as natural outcomes.[6] In particular, we specify our dependent variable (ACQ_{it}) as following a Poisson process which has a Poisson parameter, λ_{it}. Then we make the common assumption that this Poisson parameter is a function of regressors, X_{it} . We choose the particular relationship, $\ln \lambda_{it} = \exp(\beta' X_{it}) + \varepsilon$, where $\exp(\varepsilon)$ has a gamma distribution with mean one and variance α, and β is a vector of parameters to be estimated. This leads to the following negative binomial specification which we use for our initial analysis:

$$\mathrm{Prob}[ACQ = ACQ_{it}] = \frac{\Gamma(\theta + ACQ_{it})}{\Gamma(\theta)\,\Gamma(ACQ_{it} + 1)}\, u_{it}^{\theta}(1 - u_{it})^{ACQ_{it}} \qquad \textbf{(1)}$$

where $u_{it} = \theta / (\theta + \lambda_{it})$ and $\theta = 1/\alpha$.

Our choice of regressors incorporates our R&D-related hypotheses concerning the relationship between R&D intensity and acquisition activity, while controlling for other firm-level variables that may

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Another 6 percent of the transaction involved software companies. The remaining less than thirty percent were in services, like financing or customer service or in low technology equipment and parts, such as fuses or wholesale electrical parts. Our method has both advantages and disadvantages from Hall’s (1987) study. Unlike that study we do not have target firm characteristics and are not testing a “matching” model. However, our definition of acquisitions is not limited to only firms for which we can obtain financial data, as with Hall’s study. If we followed Hall’s study, we would have ended up with only a handful of acquisition observations versus the 531 acquisitions we record for this sample.

[6] We note that our results are qualitatively identical for a probit specification where the dependent variable is defined as whether there any acquisitions in a period or not.

affect a firm's acquisition activity. We measure R&D intensity ($RDPER_{it}$) as the ratio of the firm's R&D expenditures to total assets.[7] Of course, previous empirical studies of M/A motives have tested for a wide variety of other determinants of acquisition activity.[8] Some of the more common variables used include the size of the firm, indebtedness, and profitability.[9] The majority of studies in the merger and acquisitions literature (including Hall (1987), and Tremblay and Tremblay (1988)) control for the size of the firm, invariably finding a significant positive correlation between size and the probability of acquiring. We use the firm's total assets ($ASSETS_{it}$) to proxy for size. To take into account capital constraints, we include a firm's debt position (ratio of total debt to total assets - DAT_{it}) , expecting a negative correlation between debt position and acquisition activity. Jensen (1988) suggests that better performing firms will acquire and Tremblay and Tremblay (1988) find that "more successful" firms in the beer industry (defined as output share of market previous two years) are more likely to acquire. Constructing a variable as in Tremblay and Tremblay (1988) is problematic for our sample, since they do not produce for similar output markets. However, profitability of a firm is likely an important signal that a firm is well managed and performing well. Therefore, we include a measure of the firm's income (after expenses, before extraordinary items, and before provisions for common and preferred stock) divided by sales ($RETSALE_{it}$) and expect a positive correlation. Finally, in a related vein, we include a measurement of a firm's cash flow (CFL_{it}) given Jensen's (1988) free cash flow hypothesis that suggests

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[7] We follow Hall (1987) in defining R&D intensity this way and in using an assets measure as a proxy for the firm's size. As we note in the text below, our results are essentially identical if we use a firm's sales in the construction of these variables, rather than total assets.

[8] Comprehensive surveys of the merger motives literature include Hughes et al. (1980), Jensen and Ruback (1983) and Scherer and Ross (1990).

[9] Schwartz (1982), and Harris et al. (1982) are examples of studies that have used random samples of Fortune 500 companies to test M/A motives. Tremblay and Tremblay (1988) and Hannan and Rhoades (1987) focus on individual industries. A large number of determinants have been examined across these studies. We use a fairly parsimonious specification, but note that our results of interest, the correlation between R&D intensity and acquisition activity, is quite robust to alternative regressor sets.

that better performing firms will also have higher cash flow and be more likely to acquire. We use a cash flow measurement reported by Compustat which is defined as a firm's income (after expenses, before extraordinary items, and before provisions for common and preferred stock) plus depreciation and amortization.

The above empirical model assumes that the regressors, including $RDPER_{it}$, are exogenous. This is highly unlikely. These endogeneity issues are not unique to our R&D intensity variable, but potentially affect all the financial variables we include in our regressor set. However, endogeneity is difficult to control for in the limited dependent variable models we employ. Previous studies that have encountered similar endogeneity considerations have often ignored the issue or have created predetermined regressors by lagging them one period to avoid potential simultaneity. Both of these approaches have obvious drawbacks. After the preliminary results below we address this issue, by first reporting results when the regressors are lagged, and then using a relatively new GMM estimator suggested by Wooldridge (1997) which allows us to exploit the panel nature of the data to control for endogeneity. Estimates from both the lagged-regressors and GMM specification suggest that the simultaneity bias works toward understatement of our coefficients in the preliminary results.

B. Data

Our sample is a panel of data on electronic and electrical equipment firms, covering the period from 1985 to 1993. All firms listed in the Compustat database with primary Standard Industrial Classification (SIC) of 36 and 357 were sampled. However, any firm without complete coverage of all the independent variables for the regressions are eliminated.[10] This leaves 217 firms in our sample.

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[10] A balanced panel is necessary for some of the statistical specifications we use below. In addition, we eliminated firms (less than five) that were completely acquired during this period and thus, no longer reported financial characteristics and firms reporting negative total assets.

These financial data correspond to a firm's fiscal year, which is not necessarily the calendar year.[11] Because *Mergers and Acquisitions*, our source for the acquisition data, reports on a quarterly basis, we were able to match acquisitions closely to the period corresponding to the firm's fiscal year. Table 2 reports all variables used in the empirical analysis along with the sources, mean, standard deviation, the minimum value, the mode and the maximum value. The average yearly number of acquisitions by firms in our sample is considerably less than one, with zero acquisitions for well over half our observations and a maximum number of fourteen. Table 2 also shows that R&D intensity is quite high across these firms and time periods, averaging 9.7 percent of total assets. One concern is that there are a number of observations with very high R&D intensity. Below we examine sensitivity of our results to these potential outliers in the R&D intensity dimension, as well as across other regressors we use, since there is substantial variability in these control regressors too. However, as we discuss below, our results are not driven by outliers in these variables.

Table 3 shows descriptive statistics stratified over time for the main variables in this analysis. The total number of acquisitions in the data set fluctuates between 40 and 80 over the ten years. The average number of acquisitions by a firm ranges from between 0.184 and 0.369. However, the percentage of firms making at least one acquisition ranges between 13.8 and 19.2 percent. The difference between the two indicates a decent amount of multiple acquisitions by firms in a year. Average R&D intensity is increasing over the length of the data set. These "yearly" observations should be treated with some caution, however. Since firms' fiscal years vary, these yearly observations only cover roughly the same time period.

As a first look at the relationship between R&D intensity and acquisition activity across our sample, table 4 matches observations in different R&D intensity ranges and the associated average

[11] It is possible to construct (and Compustat reports) data for firms by calendar year, however, these are based on appropriately combining unaudited quarterly reports. We felt the audited fiscal year reports would reduce measurement error.

annual acquisition rate. It also lists relatively large representative firms in each R&D intensity range. A fairly substantial negative relationship between R&D intensity and average annual acquisitions emerges, ranging from 0.39 acquisitions for very low-R&D observations (less than 5% of assets) to 0.02 acquisitions for very high-R&D observations (greater than 20% of assets). Even eliminating the extremes of the R&D intensity range, average annual acquisitions are almost two times higher for firms with R&D intensity between 5% and 10% of assets and firms with R&D intensity between 15% and 20% of assets. Of course, this does not control for other factors that may be correlated with R&D intensity and determine acquisition activity. Thus, we turn next to a more formal empirical analysis.

IV. Results

The first column of table 5 shows the results of a negative binomial maximum likelihood estimation on the full data set. A log-likelihood ratio test rejects the hypothesis that the coefficients are jointly zero for the specification. RDPER shows a negative sign and is statistically significant at standard significance levels. The negative correlation provides evidence that firms' R&D intensity and acquisition activity are substitutes, suggesting that there is specialization in R&D and product market activities across firms. The marginal effect of R&D intensity on a firm's acquisition activity is quite substantial. At the sample mean, our estimates suggest a firm with a 5 percentage point higher R&D intensity ratio (e.g., from 7 percent of assets to 12 percent of assets) has an approximately 28 percent lower yearly acquisition rate.

As expected, ASSETS is strongly significant with expected positive sign. Other explanatory variables have expected sign as well, with point estimates for RETSALE and CFL statistically significant. A variety of other specifications were estimated as sensitivity checks, including estimation of OLS, probit, and Poisson models, as well as a variety of alternative explanatory variable matrices.[12] While the point estimates on some of the explanatory variables are sensitive to choice of specification, the coefficient on RDPER is quite insensitive to these alternative specifications, both in terms of sign and magnitude. In addition, using a firm's sales as a proxy for size rather than total assets and/or defining RDPER as the ratio of R&D expenditures to sales yields qualitatively identical results. Further sensitivity checks, particularly with respect to potential outliers and choice of sample, are reported and discussed below.

One concern with our estimates is that we are not controlling for time effects. As table 3 shows, there is some variability in total acquisitions occurring across our sample of firms. Controlling for these effects is complicated by the fact that our sample firms vary in the time period covered by their fiscal years and hence in the period covered by their annual observation in our data, as discussed above. In order to judge if the time series nature of our data is a concern, we tried a number sensitivity tests. First, we added year dummies as explanatory variables and found these to be jointly insignificant.[13] This approach suffers from the problem of varying fiscal years across firms. To address this, we next constructed a variable of total U.S. domestic acquisition activity (excluding the electronic and electrical equipment industries to avoid endogeneity) that more closely corresponded to each firm's fiscal year.[14]

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[12] Alternative regressors included other measures of firm profitability, such as return-on-equity and return-on-investment measures. These generally yielded similar, but noisier, estimates relative to RETSALE, We also tried alternative measures for a firm's liquidity to test the free cash flow effect on the probability of acquisition, including a firm's current ratio and quick ratio. These generally yielded noisy point estimates and quantitatively similar coefficients on other regressors, including RDPER. We also estimated various functional forms of the dependent variables which similar effects.

[13] We also ran each year of our panel as a separate cross section. While the estimates were less precise, each cross section estimated a negative correlation between R&D intensity and acquisition activity, with four of the nine RDPER coefficients estimated as statistically significant at standard confidence levels. Marginal effects of R&D intensity were generally quite similar as well to that estimated over the entire sample, especially in the years in which RDPER was estimated with precision.

[14] This variable was constructed from *Mergers and Acquisitions* as well, which lists acquisitions by quarters. Thus, for example, if a firm's fiscal year end is March 31, this variable is U.S. domestic

Including this variable does not significantly alter any of our coefficient signs and was typically insignificant in most specifications we tried.

Another substantial concern with our estimates is simultaneity bias, not only with the RDPER, but all right-hand side regressors. If an acquisition or merger is large enough relative to the firm's initial size, it is likely that it will substantially alter the firm's financial variables. With respect to R&D intensity, Hall's (1990) analysis suggests endogeneity bias works toward finding a negative coefficient on RDPER in our estimates, since her time series analysis shows that firm's typically reduce R&D intensity after an acquisition or merger. On the other hand, there may be reasons to expect the bias to work the other way. For example, a third factor, capital constraints, may be positively correlated with both acquisitions and R&D intensity. Himmelberg and Petersen (1994) find evidence that capital market imperfections may substantially affect R&D activity because it means the firms must rely on internal financing. These same considerations may similarly affect acquisition activity and lead to both activities moving together depending on the firm's finances and biasing RDPER toward a positive coefficient. In the end, these considerations are substantial and could lead to an estimate on RDPER that has substantial bias in either direction.

Other papers in this literature (e.g., Hall (1987)) often address endogeneity concerns by lagging the regressors so they are predetermined. In like manner, we next report the results from a negative binomial model where all right-hand side regressors are lagged one period in column 2 of table 5. Interestingly, this specification yields results that are qualitatively similar to a specification with contemporaneous regressors. The point estimate on RDPER declines modestly, but the difference is not statistically significant. The coefficient on ASSETS falls by about a third, while the coefficients on RETSALE and CFL increase.

However, it is clear that lagging regressors is not an ideal method of addressing endogeneity

acquisitions for quarters 2, 3, and 4 of the previous year and quarter 1 of the current year.

concerns. First, the lagged regressor specification with annual data means that the firm makes current acquisition decisions based on last year's R&D intensity, debt, profitability, etc., which may be a difficult assumption to defend. In addition, as Wooldridge (1997) points out, lagging regressors in a panel data set does not control for all sources of endogeneity if current values of the dependent variable affect future values of the regressors. In our case, this means that our estimates may be inconsistent if current acquisition activity affects future R&D intensity, profitability and other financial characteristics we include as controls.

Until recently it was difficult, if not impossible, to address these issues in the nonlinear count/panel data framework we employ in this paper. However, Wooldridge (1997) develops a generalized method of moments (GMM) estimation approach that corrects for these endogeneity concerns in a panel and count data model. Wooldridge's paper suggests a forward-difference transformation that leads to appropriate orthogonal moment conditions when simultaneity or feedback over time from the dependent variable are possible in a multiplicative panel data set. Following Wooldridge, define a transformation function

$$r_{it}(\beta) = ACQ_{it} - ACQ_{i,t+1}[\mu_{it}(\beta)/\mu_{i,t+1}(\beta)], \quad t = 1,\ldots,T-1, \tag{2}$$

where T is the number of periods in our panel and β is the vector of coefficients. We define $\mu_{it}(\beta) = \exp(x_{it}\beta)$, where x_{it} is the matrix of regressors, which is the common functional form used to represent the mean in a count data model, such as Poisson or negative binomial. Given an appropriate instrument matrix, w_{it}, Wooldridge shows that

$$E[w_{it}' r_{it}(\beta)] = 0, \quad t = 1,\ldots,T-1. \tag{3}$$

The orthogonality conditions represented in (3) allow us to obtain consistent GMM estimates. We use contemporaneous and one-period lagged values of regressors for instruments, as well as an additional variable and its one-period lag: patents per level of sales.[15] The latter is used as an additional instrument for our variable of interest, R&D intensity. Previous studies have demonstrated a strong correlation between R&D expenditures and patents (e.g., Trajtenberg [1990]), but it is unlikely that acquisition activity affects current-period patents, since patents are generated through an often lengthy R&D process. An appendix provides more details of the GMM estimation procedure we use. To our knowledge, Montalvo (1997) is the only other application of this estimation approach to date.

Besides addressing endogeneity concerns, the GMM estimation procedure also controls for fixed effects across the panel. The results to this point examine pooled data across all firms in our sample. While we find a number of firm-level variables with substantial explanatory power, there may be sources of unobserved heterogeneity in firms' acquisition patterns. Unobserved firm-specific effects may be likely in our sample for a number of reasons. Some managers may simply have a predilection for acquiring other firms. Roll (1986) suggests that hubris on the part of managers of bidding firms may mean that some firms pay more than is warranted for a target firm.[16] However, if this is true then a potential implication is these managers are also acquiring more often than they should based on observables. Finally, by accounting for firm-specific effects we are assure that more broadly classified fixed effects, such as industry-specific effects, are not driving the inverse relationship between R&D intensity and acquisition activity.[17]

The third column of coefficients in Table 5 give results from our GMM estimation. We use a

[15] With the forward difference transformation used for this estimator, this means that contemporaneous regressors are predetermined and thus appropriate as instruments. Firm-level patent data were retrieved from the U.S. Patent and Trademark Office CD-ROM, CASSIS (Classification and Search Support Information System).

[16] In a related vein, Morck et al. (1990) find that personal managerial objectives can often explain acquisitions that perform badly in increasing shareholders' profits.

[17] Including 4-digit industry effects in the negative binomial specification, both with and without lagged regressors, yields very similar results to the GMM estimates that control for fixed-effects below.

fixed effects Poisson model (as suggested by Wooldridge (1997)) as our starting values for the coefficients. The GMM over identification statistic ($P^2(99) = 103.9$ with p-value 0.35) fails to reject the null hypothesis, which suggests that our instruments are appropriately orthogonal to $\mu_{it}(\$)$. Controlling for endogeneity and fixed effects significantly increases the size of the coefficient on RDPER. Most of this difference is due to controlling for fixed effects, as the fixed-effect Poisson starting value for RDPER in the GMM estimation (before controlling for endogeneity) is 9.333. Thus, the endogeneity bias works toward reducing the coefficient some, which is consistent with the difference between the negative binomial and lagged regressor negative binomial specification (in columns 1 and 2 of table 5). The other control variables have identical signs to the negative binomial specification with the exception of CFL, though RETSALE is statistically insignificant while DAT is now significant with the GMM specification.

Since R&D intensity and acquisition activity are substitutes using a fixed-effects estimator, this relationship occurs over time within individual firms' operations as well. In other words, with firm fixed effects, the substitute relationship between R&D intensity and acquisition activity is being estimated solely from within-firm variation. This suggests that firms' strategies concerning external versus internal growth are not necessarily predetermined, but evolve and change over time.

A. Further Sensitivity Checks

Although we have discussed numerous sensitivity analyses as we presented results above, in this section we examine sensitivity to potential outliers and issues surrounding the sample of firms in our data. Examining the descriptive statistics in table 2, there is a high degree of variance among most of the variables. In our data, one firm is an order of magnitude larger than virtually all the firms in our sample and responsible for a proportionally large percent of each year's acquisitions, General Electric. Additionally, there are a three firms, Computer Automation, Power Designs and Dian Controls, that have annual observations where R&D intensity is 100 percent of total assets or larger. These firms are quite small and have only one acquisition between them in our data. Whether these "outliers" are driving the negative correlation between R&D intensity and acquisition activity is an important question.

Table 6 displays the descriptive statistics when these four firms are eliminated from the sample. Elimination of these firms has a significant impact on the descriptive statistics for a number of the variables. Means are affected to some degree in all cases. In addition, standard deviations and maximum values are reduced in all variables, except for CFL. This is particularly true with the dependent variable, ACQ, and explanatory variables, RDPER and TA, which see their maximum values and standard deviations decrease substantially from their former value.

We next reestimate our empirical model with this reduced sample. Columns 4 and 5 of table 5 report results from a negative binomial with lagged regressors and the GMM specification on the new data sample. Interestingly, most of the estimated coefficients and their associated marginal effects at the means are quite similar, suggesting that the outlying firms were not driving the estimated relationships. This is particularly true of the relationship between R&D intensity and acquisition activity. The only exception to this is ASSETS for which the coefficient increases by an order of magnitude.

Other sensitivity tests included eliminating firms with no acquisition activity in the data set. One might be concerned these firms' acquisition decisions follow a completely specification than firms that do acquire. However, there was virtually no impact on our estimated coefficients. Another concern may be that the SIC listed by Compustat may be misleading and we are including firms that may be distribution firms rather than high-technology electronics manufacturers.[18] Distribution firms would have negligible R&D expenditures and our results on R&D intensity may just be suggesting that distribution firms acquire more than manufacturing firms. We ran a sample of firms where RDPER

[18] Firms often have interests in a number of industries and must choose one "primary" SIC to report. Thus, for example, a firm could have 33 percent of its operations in wholesale distribution, 33 percent in retail, and 34 percent in electronics manufacturing and would report the manufacturing as its primary SIC.

averages over 2.5 percent. This led to qualitatively identical results and the coefficient of interest (RDPER) is insignificantly affected.

V. Conclusion

This paper has provided evidence for a significant relationship between R&D activity and patterns of acquisitions in a high technology industry. Robust to a variety of alternative specifications and sensitivity tests, we find R&D intensity and acquisition activity substitute for each other across a panel of electronics firms. This supports the notion that firms in high-technology industries may have different strategies by at least partially specializing in one of these two modes, internal R&D or acquisitions, for survival and growth. Our results are potentially relevant for the Gans and Stern (1997) paper as well. The inverse relationship is consistent with a market where expected acquisition costs for incumbents are low enough that acquiring incumbent firms R&D activity may be a strategic substitutes for R&D. In fact, the internal/external growth story and the results of Gans and Stern complement each other to the extent that a substitute relationship between R&D and acquisition activity is possible only if there is an efficient acquisition market. In that sense, our paper suggests that a well-functioning acquisition market plays an important role in determining the structure of an industry.

We foresee future work in this area along a number of lines. First, while our results show that firms may take substantially different paths toward growth and survival, our results do not address whether firms pursuing one strategy or the other tend to be more successful. Second, we have controlled for firm-specific effects, but these firm-specific effects may not be constant if there is turnover in management. In other words, we controlled for corporate hubris, not necessarily manager hubris. Examining whether new management affects the firm’s acquisition propensity is an interesting avenue to pursue.

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APPENDIX
GMM Estimation Procedure

This appendix follows Wooldridge (1997) and gives further details of the GMM procedure used for estimation. The GMM estimator is obtained by solving

$$\min_{\beta} \left[\sum_{i=1}^{N} \hat{W}_i' r_i(\beta)\right]' \hat{\Omega}^{-1} \left[\sum_{i=1}^{N} \hat{W}_i' r_i(\beta)\right],$$

where β is a vector of parameters, $r_i(\beta)$ is a (T-1)x1 vector, $(r_{i1}(\beta), \ldots, r_{i,T-1}(\beta))'$, and $\hat{W}_i$ is a matrix of instruments defined as

$$\begin{bmatrix} \hat{w}_{i1} & 0 & 0 & . & . & . & 0 & 0 \\ 0 & \hat{w}_{i2} & 0 & . & . & . & 0 & 0 \\ & & & & . & & & \\ & & & & . & & & \\ 0 & 0 & 0 & & & & 0 & \hat{w}_{i,T-1} \end{bmatrix}$$

where $\hat{w}_{it}$ is a 1xL vector of instruments for each t=1, . . . T-1. In addition, given an $\sqrt{N}$ - consistent estimator, $\hat{\beta}$, one can obtain

$$\hat{\Omega} \equiv N^{-1} \sum_{i=1}^{N} W_i(\hat{\beta})' r_i(\hat{\beta}) r_i(\hat{\beta})' W_i(\hat{\beta})$$

From this set up a one-step estimator, which is first-order equivalent to the GMM estimator, takes the form

$$\beta_{GMM} = \hat{\beta} + (\hat{R}' \hat{\Omega}^{-1} \hat{R})^{-1} N^{-1} \sum_{i=1}^{N} \hat{s}_i$$

where $\hat{R} \equiv N^{-1} \sum_{i=1}^{N} w_i(\hat{\beta})' \nabla_{\beta} r_i(\hat{\beta})$, $\nabla_{\beta} r_i(\hat{\beta})$ is a matrix of derivatives of $r_i(\beta)$ with respect to β, and $\hat{s}_i = \hat{R}' \hat{\Omega}^{-1} \hat{w}_i' \hat{r}_i$. The asymptotic covariance matrix of β_{GMM} is estimated by $N^{-1}(\tilde{R}' \tilde{\Omega}^{-1} \tilde{R})^{-1}$, where $\tilde{R}$ and $\tilde{\Omega}$ are defined as above, except with parameter vector β_{GMM} in place of $\hat{\beta}$.

TABLE 1: Acquisition activity in selected high technology U.S. manufacturing sectors.

Sector	Sector's average annual domestic acquisitions, 1989-94	Sector's average share of domestic manufacturing acquisitions, 1989-94	Sector's share of total U.S. firms in manufacturing (1992)	Sector's share of total U.S. manufacturing shipments (1992)
Chemicals and Drugs	73.7	7.8%	4.6%	5.7%
Computer and Office Equipment	46.2	4.9%	0.6%	2.2%
Electronic and Electrical Equipment	84.3	8.9%	3.1%	4.5%
Measuring, Medical and Photographic Equipment	96.0	10.2%	2.2%	6.6%

Sources: Acquisition data for columns 1 and 2 come from the publication *Mergers and Acquisitions,* various issues. Data for columns 3 and 4 are from the U.S. 1992 *Census of Manufactures*.

Notes: Chemicals and Drugs includes SIC 281, 283, 286, 287, and 289, Computer and Office Equipment is SIC 357, Electronic and Electrical Equipment is SIC 36, and Measuring Medical and Photographic Equipment is SIC 38. Acquisition classifications were by target firm and only those transactions of $1 million or greater are recorded by *Mergers and Acquisitions*.

TABLE 2: Descriptive statistics of variables.

Variable	Description	Mean	Standard Deviation	Min	Median	Max
ACQ_{it}	Number of acquisitions by firm I in year t.	0.272	0.862	0	0	14
$RDPER_{it}$	R&D expenditures divided by total assets.	0.097	0.165	0	0.073	3.755
TA_{it}	Total assets in billions.	1.398	11.033	0	0.051	251.51
$RETSALE_{it}$	Income before extraordinary items divided by sales.	- 0.018	0.219	- 3.321	0.028	1.036
DAT_{it}	Debt to total assets ratio.	0.024	0.043	0	0.017	1.020
CFL_{it}	Cash flow in billions.	0.109	0.681	-2.209	0.003	10.237

Notes: Data on acquisitions come from the publication *Mergers and Acquisitions*, various issues. All other data are from the Compustat database.

TABLE 3: Time series descriptive statistics for sample firms.

Year	Total Acquisitions	Average Acquisitions	Firms Acquiring (%)	Average RDPER (%)
1985	40	0.184	14.8	8.6
1986	66	0.304	19.3	8.8
1987	60	0.277	19.3	8.4
1988	55	0.254	18.4	9.1
1989	60	0.277	19.4	10.5
1990	62	0.286	15.7	9.1
1991	46	0.212	13.8	9.5
1992	62	0.286	18.9	11.5
1993	80	0.369	19.8	12.0

Notes: All data pertain to the 217 electronic and electrical equipment firms sampled from the Compustat database. Total acquisitions are across all sample firms for the year. Average acquisitions is total acquisitions divided by number of firms (217), whereas firms acquiring gives the percentage of firms that made at least one acquisition during the year. The difference in these measures is due to the multiple acquisitions by firms in a year. Average RDPER are yearly cross-section averages for the variable as defined in table 2.

TABLE 4: Acquisition activity by R&D intensity ranges across the sample.

R&D intensity range	Average annual acquisitions	Number of sample observations in R&D intensity range	Large representative firms in R&D intensity range
0.0 - 5.0%	0.39	653	Cobra Electronics Corp. Kuhlman Corp. Sheldahl Inc. Ametek Inc. Bell & Howell Co. International Rectifier Corp.
5.0 - 10.0%	0.25	639	Andrew Corp. General Instrument Corp. IBM Corp. ADC Telecommunications Inc. Storage Technology Corp. Texas Instruments Inc.
10.0 - 15.0%	0.24	369	General Datacomm Industries Hewlett-Packard Co. National Semiconductor Corp. Intel Corp. Tektronix Inc. Siliconix Inc.
15.0 - 20.0%	0.13	166	Advanced Micro Devices Inc. Analog Devices Inc. Cray Research Inc.
More than 20%	0.02	126	Evans & Sutherland Computer Corp. Xicor Inc.
Entire sample	0.27	1953	

TABLE 5: Determinants of firm-level acquisition activity in U.S. electronic and electrical equipment manufacturers, 1985-93.

	Full sample			Sample without outliers	
Regressor	Negative Binomial	Neg. Bin./ Lagged Regressors	GMM Estimation	Neg. Bin./ Lagged Regressors	GMM Estimation
Constant	-1.027***	- 1.091***		-1.170***	
	(0.176)	(0.166)		(0.167)	
RDPER	- 5.675***	- 5.208***	- 9.266***	- 4.825***	- 8.520**
	(1.338)	(1.281)	(1.670)	(1.304)	(3.538)
ASSETS	0.024***	0.016*	0.006***	0.080***	0.069***
	(0.005)	(0.010)	(0.001)	(0.021)	(0.004)
RETSALE	2.110***	2.872***	1.055	3.274***	1.157
	(0.768)	(0.669)	(1.787)	(0.675)	(0.906)
DAT	- 3.870	- 4.929	- 6.603***	- 3.416	- 8.665
	(4.452)	(4.504)	(0.682)	(4.582)	(12.341)
CFL	0.146*	0.321***	- 0.077***	- 0.238	- 0.041***
	(0.085)	(0.124)	(0.014)	(0.190)	(0.013)
Alpha	2.193***	2.179***		2.238***	
	(0.329)	(0.322)		(0.346)	
Log-Likelihood	- 1135.66	- 1131.75		-1090.87	
Likelihood-ratio Test (p-value)	175.51 (0.000)	181.79 (0.000)		143.52 (0.000)	
Sample Size	1953	1953	1953	1917	1917

NOTES: The dependent variable is the number of acquisitions for a firm during a fiscal year (ACQ_{it}). Likelihood-ratio test is of the null hypothesis that slopes (excluding constant) are jointly zero and is distributed $?^2(5)$. Standard errors are in parentheses, except for the likelihood-ratio test which reports p-value of test in parentheses.

TABLE 6: Descriptive statistics of variables for sample without outlier observations.

Variable	Description	Mean	Standard Deviation	Min	Median	Max
ACQ_{it}	Number of acquisitions by firm I in year t.	0.241	0.654	0	0	7
$RDPER_{it}$	R&D expenditures divided by total assets.	0.088	0.072	0	0.073	0.856
TA_{it}	Total assets in billions.	0.848	5.379	0	0.053	92.473
$RETSALE_{it}$	Income before extraordinary items divided by sales.	- 0.011	0.190	- 3.321	0.029	0.355
DAT_{it}	Debt to total assets ratio.	0.022	0.032	0	0.017	0.629
CFL_{it}	Cash flow in billions.	0.084	0.557	-2.209	0.003	10.237

Notes: Data on acquisitions come from the publication *Mergers and Acquisitions*, various issues. All other data are from the Compustat database.