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Determinants of the Acquisition of Smaller Firms by Larger Incumbents in High-Tech Industries: Are they related to Innovation and Technology Sourcing?

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Determinants of the Acquisition of Smaller Firms by Larger Incumbents in High-Tech Industries: Are they related to Innovation and Technology Sourcing?

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Abstract

Innovation activities in high tech industries provide considerable challenges for technology and innovation management. In particular, firms frequently face significant technological challenges since these industries has a long history of radical innovations which are taking place through distinct industry cycles of higher and lower demand. The paper investigates these issues for three high-tech industries, namely semiconductor manufacturing, biotechnology and electronic design automation which is a specific sub-segment of the semiconductor industry. It analyses the association of firm characteristics with different aspects of acquisition behaviour. Particular focus is put on innovation-related firm characteristics. The paper finds that the determinants for acquisitions are mostly related to firm size, financial conditions and geographical origin of the firm. Only for biotechnology, a substitutive relationship is identified between acquisitions and own research activities.

Keywords: acquisition, innovation, semiconductor, design, automation, biotechnology

JEL classification: L10, L86, M20

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1. Introduction

Innovation activities in high-tech industries such as semiconductors, biotechnology (biotech) or electronic design automation (EDA) are diverse and driven by a variety of determinants. In particular, firms frequently face make-or-buy decisions, especially as concerns radical innovation. This, together with the cumulative and rapid nature of innovation makes innovation management a very challenging task in such industries.

For example in the semiconductor industry, levels of research and development (R&D) input are strongly affected by the highly cyclical nature of the industry, whose most severe downturn was in 2000 to 2001. R&D expenditure has significantly dropped in this period and has not recovered so far. In parallel to this, semiconductor firms' propensity to patent has considerably increased in US in 1980s, especially after formation of a centralized appellate court in 1982 as a means to strengthening patent rights (Hall and Ziedonis, 2001). In parallel, there is also evidence of considerable innovation-related acquisition activity in the industry (Bloningen and Taylor, 2000; Sanchanta, 2007)

As another example, the EDA industry is a particular sub-segment of the semiconductor industry and focuses on chip design. EDA has a simple market structure as concerns the supply side with three large firms and a number of small firms being active in the industry, which are frequently acquired by larger firms in the industry. The industry covers a number of complex processes from chip design through to testing. Increasingly, the products of the electronic design automation industry also get integrated into manufacturing processes in order to enable direct feedback from the production to the design stage in turn making innovation processes even more challenging.

Finally, looking at the third sector, also biotech can be characterised by strengthening patent rights (especially in the US) and rapid technological change for cumulative technologies. Again, acquisitions are a frequent phenomenon in this industry as are intensive collaboration and cooperation activities (Jack, 2007; Hofmann, 2007; Jack, 2006; Rothaermel and Deeds, 2004; Pangarkar, 2003).

The purpose of this paper is against this backdrop to analyse the determinants for acquisitions in terms of value, frequency and technological relevance of the acquisitions.

2. Theoretical foundations and literature review

It seems that classical themes of technology and innovation management such as the concepts of architectural and competence-destroying innovation and the distinction between radical and incremental innovation have particular relevance in the high-tech industries. These concern for example whether small start-ups are largely responsible for incremental innovation or whether radical innovation requires large-scale industry cooperation as has been set up in the past in semiconductor manufacturing. The paper discusses these aspects in some detail from a theoretical perspective and draws in doing so mainly on new institutional economics and transaction cost economics. This line of thinking is also relevant for the EDA and biotech industries. For example, Sangiovanni-Vincentelli (2003) argues that for the former partnering, intensive research collaboration and innovation networks may be needed to bring about radical innovation there and Pangarkar and Klein (2001) and Zhang et al. (2007) point to the relevance of cooperation in the biotech industry. In addition to this, another stream of scholarly work of relevance here is the economic theory of acquisitions and the numerous empirical studies related to it, for example in terms of make or buy decisions regarding technology sourcing (e.g. Rüdiger, 1998). Two aspects are noteworthy in this respect:

(i) Innovation cooperation in its various forms (see e.g. Tidd et al., 2005) can foster radical innovation. This seems to be particularly true for innovation networks (Gulati, 1998; DeBresson and Amesse, 1991), which have been shown to successfully yield innovation on a number of occasions, and in the semiconductor industry in particular in terms of Sematech (Flamm, 2003; Spencer, 2003).

(ii) The acquisition of innovative start-up firms can equally foster radical innovation in a situation where large firms are lacking relevant competencies to carry out the innovation. Yet, this approach may be limited in that small firms are sometimes not capable to carry out specific radical innovations themselves, e.g. due to the limitations of newness and smallness they often face. In this case again, innovation cooperation may be necessary. Innovation networks as a specific form of innovation cooperation are therefore discussed in more detail in the following section before looking at economic arguments for acquiring innovation.

Research on innovation networks (e.g. Teichert, 1994; Tidd et al., 2005) has shown that innovation networks are often considered when innovation is so radical that no subgroup of firms can achieve it, but only a network. It may be in this case that a number of (larger or smaller) firms on the same level of the value chain cooperate closely (examples for such cooperation are Sematech in the USA or the cooperation of small textile firms in Italy's industrial districts).

Three main theoretical perspectives on innovation networks can be identified. These are:

1) network theory based on e.g. the idea of weak versus strong ties and the notion that especially innovation networks integrate partners that represent loose ties, thereby increasing the search capability of the corporation, whereas other (e.g. bilateral) innovation cooperation such as joint ventures are more focused on strong ties (Granovetter, 1985; Gulati, 1998).

2) a perspective on innovation networks from the perspective of strategic management drawing on the well developed resource- and market-based views (Stuart, 2000; Sampson, 2005)

3) a transaction cost-based approach rooted in new institutional economics and focussing on cost-benefit considerations.

From a network perspective, innovation cooperation can be horizontal or vertical. Whilst Gemünden et al. (1996) and Kirchmann (1994) focus on vertical relationships along the supply chain and horizontal ones outside the competitive space, Hamel et al. (1989) propose that horizontal cooperation with direct competitors in the supply chain can improve the focal firm's performance and results. From a transaction-cost based point of view typical risks in innovation networks and how networks address these can be analysed in order to explain, why firms remain in the network despite of the risks associated. Notably, transaction cost and also network-based approaches to analysing innovation cooperation and innovation networks are not always suitable to address strategic advantages that result from innovation cooperation. Therefore, a complementary analysis from a strategic management perspective (e.g. based on the market- and/or resource-based views) seems advisable that addresses for example issues of network governance (e.g. Gassmann and Fuchs, 2001) and that also relates to acquisitions. Economic theory has proposed a number of reasons for acquisitions (see e.g. Morris and Hay, 1991; Milgrom and Roberts, 1992; Jansen, 2001). For example under the assumption that the stock market is efficient, motives for takeovers can be increased market power, reduced advertising and other promotional expenditure or efficiency gains which could not be realised without the acquisition. Other explanations that have been proposed for acquisitions are managerial takeovers, allocational takeovers, acquisitional takeovers or conglomerate mergers aimed at risk reduction (Morris and Hay, 1991). Here, allocational takeovers refer to acquisitions which are motivated by a reallocation of assets to managers who make more efficient uses of them. This situation is possible if the assumption of fully-efficient firms is not made any more.

One of the reasons, why acquisitions may be a very appropriate means for innovation are studies into the obstacles to innovation, especially in larger firms. This body of literature (e.g. Hauschildt, 2004) points out that firms may not be able or willing to carry out specific types of innovation. Obstacles to innovation may emerge in the sense that larger firms are not able to carry out specific innovations. One of the main reasons fort his can be that some innovations are organisationally radical (e.g. Henderson and Clark, 1990) either because firms do not have absorptive capacity (Cohen and Levinthal, 1990) or because such innovations require intensive learning and intellectual deliberation within the firm (Levinthal and March, 1993). Absorptive capacity can be lacking either because different or new skills of technologists or researchers of the larger firm are required (and essentially represent a problem of lacking human capital or lacking capabilities) or it can be that radically different organisational structures for R&D are required (for a reconceptualisation of the absorptive capacity concept and construct, see also Lane et al., 2006). Another important reason for an incapability to carry out specific innovations are certain ideological views or conservative attitudes in a firm, which Wheelwright and Clark (1992) refer to this as a ‘Product A filter’. Whilst such attitudes or views may be subjective from an external point of view, they may objectively deter innovation within the firm. Finally, a third reason why firms are incapable of certain innovations is that specific departments or individuals may attempt to avoid power redistribution as a result of an innovation being carried out or high risk aversion of individuals or departments (but not the firm as a whole).

Next to not being able to carry out specific innovations, firms may also simply not be willing to carry out specific innovations which they consider as being too risky for the firm as a whole. This may for example be due to uncertainty with regard to its profitability. Also, firms may object simply against the timing of an innovation. Another set of reasons may relate to large firms not wanting to irritate customers with too many innovations of which longer-term only few survive. Thirdly, firms may not be willing to carry out innovations that imply the destruction of valuable assets or would render obsolete important competencies. Fourthly, objection may exist because of missing or limited fit of an innovation to existing products of the firm. If this means that individuals or departments objectively feel incapable of succeeding with such an innovation, than rejecting to carry it out in the first place may be individually rational. Fifthly, an innovation may economically radical either in terms of reducing cost or by increasing performance so much that existing products of the firm become uncompetitive. In such a case, a firm may decide not to carry out the innovation in order not to cannibalise existing products' sales.

Especially this last point is important since it may imply that large firms tend to favour incremental over radical innovations. For example, for the EDA industry, Sangiovanni-Vincentelli (2003) claims, that start-up firms have largely realised incremental innovations and that the level of radical innovation in this industry may be too low, which refers back to the argument made in the previous that innovation networks are needed for radical innovation (Bingham, 2003).

Jovanovic (1992) models the behaviour of small firms as drawing stochastically information on the market. Based on this information, the firms adjust their behaviour and their strategies. Those firms capable of learning based on new information are able to grow whilst those incapable cannot survive on the market. This can explain why larger firms acquire small firms that have managed to survive for some time on the market. Larger firms in acquiring a surviving small firm gain information that has been translated in appropriate strategies. Especially in fast changing industries in which per definition the level of information generation is high, such acquisition behaviour may help to economise on the firm's resources by letting other firms carry out exploration and by then picking the survivors and in doing so acquiring an amplified signal from the market on which more easily decisions can be based. Linking this with the work of Utterback (1996) on the emergence of dominant designs and the subsequent focus on process innovation in an industry and the model of Klepper (1996) one can also conclude that smaller firms are particularly likely to emerge in areas where the dominant design has not yet been established. If these areas are those where information production is highest and where consequently acquisitions are most likely to occur, then this innovation may be more radical than argued by Sangiovanni-Vincentelli (2003) and Bingham (2003), at least in the EDA industry.

The previous considerations on acquisitions show that these can be another efficient means for firms to carry out innovation by acquiring successful start-ups in the industry. In summary, there is evidence for the suitability of both approaches innovation networks as well as acquisitions to realise (in particular radical) innovation in high-tech industries. For example, allocational takeovers may an important reason if small start-ups frequently come to a point when they do not realize their potential due to lack of complementary assets such as distribution channels or because of too slow growth. The focus of the remainder of this paper is on acquisitions and in particular on what characteristics of the acquiring firms (and here in particular those related to R&D) determine the acquisition of innovative or entrepreneurial start-ups as concerns the average annual value of acquisitions, the number of (private and/or public) acquisitions and the technological value of acquisitions as measured based on prior patenting. The reasons for doing so is that initial exploratory interviews with experts in all three industries analysed (biotech, semiconductor and EDA) have indicated, that innovation cooperation is largely confined to pre-competitive research, which significantly limits the scope of any analysis of innovation cooperation, as compared to acquisitions.

Desyllas and Hughes (2005) analyse the association of R&D and patenting with acquisitions in a sample of broadly defined high technology industries. They find that decreasing returns from exploiting a firm's existing knowledge base and the choice between making or buying R/D are main drivers for the acquisition of innovative firms. The exploratory interviews in the biotech, EDA and semiconductor industries also provide evidence, that many of the acquisitions in these high-tech industries are related to R&D aspects. This could be related to the obstacles to innovation in larger firms discussed earlier. Hauschildt (2004) and Henderson (1993) provide examples for situations in which firms may not be able to carry out specific types of innovation. One response of firms to not being able to carry out an innovation at acceptable cost can be the acquisition of start-ups in order to make up for their missing capabilities (e.g. Markides and Geroski, 2005). This paper therefore analyses empirically a set of larger firms in the three industries to explore what determines the acquisition of innovative or entrepreneurial start-ups as concerns the average annual value of acquisitions, the number of (private and/or public) acquisitions and the technological value of acquisitions as measured based on prior patenting of the acquired start-ups. The main research question of this paper is therefore, if the relationship between own R&D and patenting with acquisitions is substitutive or not.

3. Methodology and empirical research context

Data for the analysis was collected at the SFB 541 at Humboldt University from the SDC Platinum and Worldscope Disclosure databases. It comprises the largest firms in the EDA, biotech and semiconductor industry during the period of 1981 until 2004.[1] In order to compare the three industries which have widely different industry concentration levels, all firms making up approx. 80 per cent of the market by sales value were included, resulting in 14 EDA, 50 semiconductor and 21 biotech firms being analysed. Data was collected on a number of variables concerning various firm characteristics (leverage, sales, R&D expenditure, liquidity, patents granted and firm location). Patents of a large firm are both, a measure of absorptive capacity and one of R&D productivity. Patents of an acquired start-up can be used to assess the extent of its technological base. Using a five-year timeframe prior to the acquisition year to measure the level of technological knowledge is somewhat arbitrary, yet this approach has been utilised in the literature before (Clooydt et al., 2006) and is also considered a suitable balance between the declining value of knowledge and patent protection which increases with every year a patent ages and the increasing level of knowledge stock with every additional year included to measure the level of technological knowledge. It was not possible to use operating margin and cash flow as measures for profitability, since these

[1] In the semiconductor industry, which had the lowest industry concentration, only the years 2001 to 2004 are analysed in the first instance.

were highly correlated with R&D intensity. Therefore, sales growth was used as a joint proxy for profitability and industry opportunity.

To model influences on the average annual value of acquisitions, two well-established models for panel data exist, namely random and fixed effects (Johnston and DiNardo, 1997). The difference between the fixed effects and the random effects model is based on whether the time-invariant effects are correlated with the regressors (which is the case for the fixed effects) or (in case of the random effects model) not. For these models, the specification is:

$$u_{it} = c_i + \varepsilon_{i,t} \quad (1)$$

$$s_{it} = \alpha + \beta' \mathbf{X}_{it} + c_i + e_{it} \ , \quad (2)$$

where $i = 1, \ldots$, N units under observation, and $t = 1, \ldots, T$ time periods for which data were collected. S_{it} denotes an acquisition-related dependent variable for firm i in period t, $\mathbf{X}_{it}$ represents a set of independent variables, β' a vector of coefficients, c_i unobserved individual heterogeneity and e_{it} an idiosyncratic error that satisfies $E[e_{it}|\mathbf{X}_{it}, c_i] = 0$. The model is estimated through GLS assuming no correlation between e_{it} and c_i. For the fixed effects model, other than the random effects model, the assumption is that the individual effect c_i is correlated with the time-variant independent variables $\mathbf{X}_{\mathrm{it}}$. This means that although the basic specification given in (1) and (2) remains, the interpretation differs, in that the disturbance c_i is a constant (and thus represented by a dummy variable) for each unit of analysis, i.e. here for each specific firm. The fact that the disturbance is a constant in the fixed effects model implies that all time-invariant variables will be dropped during the estimation.

To decide which of the two models (random or fixed effects) is more appropriate, Hausman and Hausman-like tests (in cases where the Hausman test itself is not applicable) are used. If the Hausman test is significant, then the fixed effects model is more appropriate. Since the number of (private and/or public) acquisitions and the technological value of acquisitions as measured based on prior patenting of the acquired start-ups are all count data, negative binomial models are estimated for these as independent variables. The Hausman test is involved analogously to determine whether fixed or random effects are appropriate.

4. Results

To address the hypotheses developed in the previous section, panel estimations for negative binomial and multiple regression models are applied to identify significant associations for the level at which large firms acquire (i.e. the number of acquisitions per year and the average value per acquisition and year, as far as available) and to what degree it acquires technological patents (as measured by the total number of patents granted to the acquired firms in the acquisition year and the five years prior to it). The next three section summarise the results for each industry separately.

4.1 EDA industry

Tables 1 to 4 summarise the results in the EDA industry.[2] Concerning the factors associated with the average annual value of the acquisitions made by firms in the EDA industry, Table 1 shows that sales has a significant positive association with the value of acquisitions, whereas if a firm is headquartered in Asia have a significant negative association. Next to the acquisition value, the total number of acquisitions is also a measure of acquisition intensity and the results for this measure are reported in Table 2.

TABLE 1
Random effects GLS model for EDA industry, dependent variable: EDA average annual value of acquisitions (mn €)

Variables	Random effects estimates
Financial leverage (total assets to total equity)	-6.8481 (11.7189)
Current ratio	0.2594

[2] In the EDA industry, the results for a model including the logarithm of Tobin's Q as an additional measure for profitability and economic opportunities yield very similar results but are not reported here due to size limitations.

(current assets to current liabilities)	(5.1601)
Sales growth (% over previous year)	-0.2083 (0.1917)
Sales (natural logarithm of net sales in 1000 €)	24.5336 (7.1548)***
R&D intensity (R&D expenditure to net sales in %)	1.2023 (1.0475)
Missing R&D intensity data (dummy; 1 = missing)	25.0810 (25.1617)
Patenting intensity (Patents granted by application year to net sales)	-231065.9 (212743)
Missing Patenting intensity data (dummy; 1 = missing)	52.4118 (23.0073)**
Company headquartered in Europe (dummy; 1 = yes; base category: United States)	70.52536 (87.1526)
Company headquartered in Asia (dummy; 1 = yes; base category: United States)	-23.7969 (14.1068)*
Constant	-248.9254 (86.3693)***
R^2 within R^2 between R^2 overall	0.0776 0.3867 0.1543
No. of observations (individuals)	93 (14)
Wald Chi² p-value	1063.75 < 0.001
Hausman specification test Chi² p-value	 3.17 0.5291

Notes: Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$; heteroskedasticity-robust standard errors in parentheses; unbalanced panel data with observations per group: min = 3; max = 11; average = 6.6

As can be seen from Table 2, concerning the number of acquisitions made a significant association with the same sign as for the value of acquisitions is found for sales. However, for the R&D intensity the association is now significant and negative. This means that firms with a high R&D intensity tend to acquire on average more than those with low R&D intensity.

It needs to be noted, that for some acquisitions the value is not disclosed which means that the data is less complete with regard to acquisition values. Desyllas and Hughes (2005) argue that acquisitions of private firms should be more strongly related to the acquisition of innovation than those of large firms, since private acquisitions refer more often to smaller and more specialised start-ups that are specialised in technological niches. This is addressed in Table 3.

TABLE 2

Negative binomial model for EDA industry, dependent variable: acquisition of public or private companies (total number)

Variables	Random effects estimates
Financial leverage (total assets to total equity)	-0.3772 (0.3185)
Current ratio (current assets to current liabilities)	-0.0869 (0.1256)
Sales growth (% over previous year)	0.0022 (0.0034)
Sales (natural logarithm of net sales in mn €)	0.3154 (0.1295)**
R&D intensity (R&D expenditure to net sales in %)	-0.0489 (0.0231)**
Missing R&D intensity data (dummy; 1 = missing)	-30.1041 (1411434)
Patenting intensity (Patents granted by application year to net sales)	233.5289 (586.8052)
Missing Patenting intensity data (dummy; 1 = missing)	-0.0714 (0.5024)
Company headquartered in Europe (dummy; 1 = yes; base category: United States)	-0.1113 (0.6071)
Company headquartered in Asia (dummy; 1 = yes; base category: United States)	-0.9158 (0.7010)
Constant	12.5456 (847.3765)
Log-likelihood	-115.9448
Log (r)	16.5696
Log (s)	1.9576
No. of observations (individuals)	105 (14)
Wald Chi²	24.03
p-value	< 0.01
Hausman specification test	
Chi²	0.02
p-value	1.0000

Notes: Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$; unbalanced panel data with observations per group: min = 3; max = 13; average = 7.5; Likelihood-ratio test vs. pooled: Chi² = 4.47, p-value >= Chi² = 0.017

Table 3 provides results for the factors that are associated with the acquisition of private firms. As can be seen the association for R&D intensity is of the same direction as for the total number of (public and private) acquisitions. However, the significant association for sales becomes insignificant whilst at the same time, the number of private acquisitions is significantly positively associated with sales growth.

TABLE 3

Negative binomial model for EDA industry, dependent variable: acquisition of private companies (total number)

Variables	Random effects estimates
Financial leverage (total assets to total equity)	-2.8701 (1.9182)
Current ratio (current assets to current liabilities)	0.0980 (0.2094)
Sales growth (% over previous year)	0.0139 (0.00736)*
Sales (natural logarithm of net sales in mn €)	0.3240 (0.2716)
R&D intensity (R&D expenditure to net sales in %)	-0.1399 (0.0680)**
Missing R&D intensity data (dummy; 1 = missing)	-10.8502 (138.3239)
Patenting intensity (Patents granted by application year to net sales)	.27406 (2290.472)
Missing Patenting intensity data (dummy; 1 = missing)	-7.9485 (86.9365)
Company headquartered in Europe (dummy; 1 = yes; base category: United States)	1.5511 (1.0238)
Company headquartered in Asia (dummy; 1 = yes; base category: United States)	-0.8607 (1.51296)
Constant	7.50119 (27.6340)
Log-likelihood Log (r) Log (s)	−25.9013 19.9601 12.5728
No. of observations (individuals)	105 (14)
Wald Chi² p-value	9.37 < 0.4976
Hausman specification test Chi² p-value	 0.10 0.9998

Notes: Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$; unbalanced panel data with observations per group: min = 3; max = 13; average = 7.5; Likelihood-ratio test vs. pooled: Chi² = 0.00, p-value >= Chi² = 1.000

Next to distinguishing between the acquisition of private and public firms, a more direct way to assess the innovativeness of the acquired start-ups is to evaluate their patent stock. This is done in the model reported in Table 4 for which the dependent variable is the number of patents acquired by the start-up in the five years prior to acquisition and in the acquisition year itself. The approach of using a five-year timeframe prior to the acquisition year has been pursued in the literature before (Clooydt et al., 2006) and strikes a balance between the declining value of a start-up's knowledge stock and increasing levels of knowledge stock with every additional year included. Notably, for private acquisitions, a significant negative association is also found for financial leverage (proxying the financial status of the firm) as is a significant positive association of the number of acquisitions of private firms with sales growth as a proxy for the acquiring firm's profitability.

As can be seen in Table 4, the main factors significantly associated with the number of patents that have been granted to the acquired firm until including the fifth year prior to the acquisition are sales (positively) and if the company is headquartered in Europe (positively).

TABLE 4

Negative binomial model for EDA industry, dependent variable: patents granted to acquired firm in acquisition year and 5 years prior to acquisition

Variables	Random effects estimates
Financial leverage (total assets to total equity)	0.0080 (0.3610)
Current ratio (current assets to current liabilities)	-0.4682 (0.3307)
Sales growth (% over previous year)	-0.0062 (0.0063)
Sales (natural logarithm of net sales in mn €)	0.6306 (0.1909)***
R&D intensity (R&D expenditure to net sales in %)	0.0362 (0.0302)
Missing R&D intensity data (dummy; 1 = missing)	-18.7229 (16963.51)
Patenting intensity (Patents granted by application year to net sales)	-12930.34 (8960.437)
Missing Patenting intensity data (dummy; 1 = missing)	-0.1970 (1.0853)
Company headquartered in Europe (dummy; 1 = yes; base category: United States)	1.7016 (0.8246)**
Company headquartered in Asia (dummy; 1 = yes; base category: United States)	0.2057 (1.2498)
Constant	-9.87835 (3.2020)***
Log-likelihood	-125.1155
Log (r)	12.1500
Log (s)	15.3276
No. of observations (individuals)	105 (14)
Wald Chi²	19.43

p-value	< 0.0351
Hausman specification test	
Chi²	9.98
p-value	0.1900

Notes: Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$; unbalanced panel data with observations per group: min = 3; max = 13; average = 7.5; Likelihood-ratio test vs. pooled: Chi² < 0.001, p-value >= Chi² = 0.499

4.2 Biotech industry

As concerns the results for the biotech industry, the variation in sales growth (based on the pooled data across all years) is generally stronger (mean approx. 114%, minimum -100% and maximum approx. 5500%) for biotech than for the EDA industry (mean ca. 33%, minimum -31% and maximum 717%). The average sales across all years are however slightly larger for EDA (mean 629,000 USD, minimum 226,000 USD and maximum 9 million USD) than for the biotech industry (mean 562,000 USD, minimum approx. 60,000 USD and maximum approx. 10 million USD). Comparing both industries with semiconductors, it becomes clear, that for the latter average sales are considerably larger (mean approx. 3.4 million USD, minimum approx. 95,000 USD and maximum approx. 31 million USD). As concerns sales growth, it averages to 164% in the semiconductor industry and the variation (minimum -99%, maximum 9868%) is even stronger than in the biotech industry which is consistent with the high revenue fluctuation well established for the semiconductor industry (e.g. Levy 1994). Looking at R&D intensity and patenting intensity, the pooled average for the biotech industry is 164% for R&D intensity with the minimum being 0% and the maximum being 4070%. The average patenting intensity for the biotech industry (patents per thousand USD sales) is 0.0003 with the minimum being 0 and the maximum being 0.0167. Compared to this, in the EDA industry, the average R&D intensity is 47% with the minimum being 7% and the maximum being 2760%. The average R&D intensity is pushed upwards by very high outlier values for one firm (Magma Design Automation). For most other firms in the EDA industry, the R&D intensity is in the range of 10-15%. As concerns patenting intensity, the mean value is of similar order of magnitude as for biotech, namely approx. 0.0002 with the minimum being 0 and the maximum being 0.088 patents per thousand USD sales. Comparing biotech and EDA with the semiconductor industry it becomes clear, that for the latter patenting intensity (mean approx 0.00007, minimum 0 and maximum 0.0006 patents per thousand USD sales) is about one to two orders of magnitude lower than for EDA and biotech, both of which have similar average, minimum and maximum values for the number of patents per thousand USD sales. This result is however consistent with the low effectiveness of patents as an appropriation mechanism in the semiconductor industry, i.e. the semiconductor industry patents less frequently in relation to sales (Cohen, Nelson et al. 2001). Concerning the R&D intensity of the semiconductor industry (mean approx. 14%, minimum approx. 1% and maximum approx. 46%) it is found that it is similar to and even slightly higher that of the EDA industry (after accounting for outlier values in the latter) which is consistent with earlier findings (Sangiovanni-Vincentelli, 2003). Also the R&D intensity in both the EDA and semiconductor industries is considerably lower than for biotech which mirrors the considerable uncertainty of research-related investments in the latter. Given this uncertainty, an analysis of the relevance of external R&D sourcing through acquisitions is of particular relevance for the biotech industry. In this respect, as concerns the value of acquisitions Table 5 shows that for the biotech industry it is significantly positive associated with the liquidity of the acquiring firm, its size as measured by sales and is significantly negative associated with a firm being located in Europe, i.e. European firms do, all else being equal acquire at significantly lower prices than firms in the US.

TABLE 5
Random effects GLS model for Biotech industry, dependent variable: average annual value of acquisitions (mn €)

Variables	**Random effects estimates**
Financial leverage (total assets to total equity)	-0.9459 (4.3625)
Current ratio (current assets to current liabilities)	4.4728* (2.5697)

Sales growth (% over previous year)	-0.0040 (0.0353)
Sales (natural logarithm of net sales in mn €)	68.5278 (32.0973) **
R&D intensity (R&D expenditure to net sales in %)	0.0875 (0.0585)
Missing R&D intensity data (dummy; 1 = missing)	18.1410 (41.7690)
Patenting intensity (Patents granted by application year to net sales)	19758.9 (13497.21)
Company headquartered in Europe (dummy; 1 = yes; base category: United States)	-163.5689 (74.9174) **
Company headquartered in Asia (dummy; 1 = yes; base category: United States)	-16.7617 (121.5723)
Constant	-728.7524 (360.3179)**
R^2 within	0.0199
R^2 between	0.3584
R^2 overall	0.0755
No. of observations (individuals)	242 (21)
Wald Chi²	23.70
p-value	< 0.01
Hausman specification test	
Chi²	14.21
p-value	0.1638

Notes: Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$; heteroskedasticity-robust standard errors in parentheses; unbalanced panel data with observations per group: min = 5; max = 17; average = 11.5

Table 6 provides the results for the biotech industry for the acquisition of public or private firms. What can be seen is that leverage has a significant positive acquisition with the number of acquisitions as has sales as a measure for firm size.

TABLE 6

Negative binomial model for Biotech industry, dependent variable: acquisition of public or private companies (total number)

Variables	**Random effects estimates**
Financial leverage (total assets to total equity)	0.0644 (0.0387)*
Current ratio (current assets to current liabilities)	-0.0147 (0.0350)
Sales growth (% over previous year)	-0.0003 (0.0005)
Sales (natural logarithm of net sales in mn €)	0.2406 (0.1097)**
R&D intensity	-0.0012

(R&D expenditure to net sales in %)	(0. 0023)
Missing R&D intensity data (dummy; 1 = missing)	-25.4788 (593358.8)
Patenting intensity (Patents granted by application year to net sales)	-101.9886 (650.8131)
Company headquartered in Europe (dummy; 1 = yes; base category: United States)	-1.1855 (0.9060)
Company headquartered in Asia (dummy; 1 = yes; base category: United States)	-0.7799 (1.0897)
Constant	0.0687 (4.3030)
Log-likelihood	-183.0504
Log (r)	3.9710
Log (s)	0.3007
No. of observations (individuals)	246 (21)
Wald Chi²	17.02
p-value	< 0.05
Hausman specification test	
Chi²	15.46
p-value	0.1161

Notes: Significance levels: * p < 0.1; ** p < 0.05; *** p < 0.01; unbalanced panel data with observations per group: min = 5; max = 17; average = 11.7; Likelihood-ratio test vs. pooled: Chi² = 26.77, p-value >= Chi² < 0.01

Table 7 shows that if only the number of acquisitions of private companies is considered, no significant effects can be identified. This is likely due to the fact, that only very few of the acquisitions in the biotech industry are private companies. For the biotech industry, only 1 private acquisition occurs across the period analysed (1980 to 2006 in the case of this univariate analysis) per acquiring company in the sample (versus 1.9 and 1.2 private acquisitions per acquirer in the semiconductor and EDA industries, respectively).

TABLE 7

Negative binomial model for Biotech industry, dependent variable: acquisition of private companies (total number)

Variables	Random effects estimates
Financial leverage (total assets to total equity)	0.0440 (0.1609)
Current ratio (current assets to current liabilities)	0.0970 (0.0795)
Sales growth (% over previous year)	-0.0061 (0.0060)
Sales (natural logarithm of net sales in mn €)	0.4674 (0.3061)

R&D intensity (R&D expenditure to net sales in %)	-0.0130 (0.0104)
Missing R&D intensity data (dummy; 1 = missing)	-11.8387 (229.5436)
Patenting intensity (Patents granted by application year to net sales)	0.9215 (2.0102)
Company headquartered in Europe (dummy; 1 = yes; base category: United States)	-0.9347 (1.3335)
Company headquartered in Asia (dummy; 1 = yes; base category: United States)	0.6036 (1.2138)
Constant	6.4700 (536.8714)
Log-likelihood	-52.9497
Log (r)	15.2528
Log (s)	0.3683
No. of observations (individuals)	246 (21)
Wald Chi²	8.25
p-value	0.5091
Hausman specification test	
Chi²	2.30
p-value	0.8061

Notes: Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$; unbalanced panel data with observations per group: min = 5; max = 17; average = 11.7; Likelihood-ratio test vs. pooled: Chi² = 2.34, p-value >= Chi² = 0.063

As can be seen in Table 8, for the number of patents granted to the target prior to acquisition, a significant positive association is found for financial leverage and sales whereas the headquarter of the acquired company being located in Europe is significantly negatively associated with the number of patents granted to the target prior to acquisition.

TABLE 8

Negative binomial model for Biotech industry, dependent variable: patents granted to acquired firm in acquisition year and 5 years prior to acquisition

Variables	Random effects estimates
Financial leverage (total assets to total equity)	0.1418 (0.0770)*
Current ratio (current assets to current liabilities)	0.0270 (0.0479)
Sales growth (% over previous year)	-0.0006 (0.0006)
Sales (natural logarithm of net sales in mn €)	0.3991 (0.1398)***
R&D intensity (R&D expenditure to net sales in %)	-0.0015 (0.0034)
Missing R&D intensity data	-24.3442

(dummy; 1 = missing)	(623039.9)
Patenting intensity (Patents granted by application year to net sales)	-0.1617 (1.2568)
Company headquartered in Europe (dummy; 1 = yes; base category: United States)	-1.9166 (1.0180)*
Company headquartered in Asia (dummy; 1 = yes; base category: United States)	-0.1725 (0.7421)
Constant	-8.3222 (2.0427)***
Log-likelihood	-265.3305
Log (r)	12.9170
Log (s)	17.6537
No. of observations (individuals)	246 (21)
Wald Chi²	20.17
p-value	< 0.0169
Hausman specification test	
Chi²	0.00
p-value	1.000

Notes: Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$; unbalanced panel data with observations per group: min = 5; max = 17; average = 11.7; Likelihood-ratio test vs. pooled: Chi² = 0.00, p-value >= Chi² = 1.000

4.3 Semiconductor industry

The analysis of the semiconductor industry covers only the period 2001 to 2004, since in 2000 the industry experienced its worst recession and therefore including 2000 and prior years may have introduced a structural break because of the significantly changing sales figures which would have made interpretation of the results very difficult.

Furthermore, in the case of the semiconductor industry, using the acquisition of private firms as a proxy for technology-based acquisitions or acquisitions for innovation reasons was difficult since the on average larger size of the acquired firms meant that the targets were very rarely private firms. Given that such an imbalance causes problems for the estimation algorithms, it was therefore decided to use as a proxy for technology-based acquisitions in the semiconductor industry those acquisitions that refer to semiconductor technology in a narrow sense (i.e. semiconductor materials, lithography, design technology, production and microelectronic products, such as ICs, RAM, ROM, etc.).

Table 9 shows that firm size and whether a company is headquartered in Europe is significantly positively and whether it is headquarters in Asia is significantly negatively associated with the average annual value of a firm's acquisitions. Furthermore, patenting intensity is almost significantly positively associated with the latter.

TABLE 9
Random effects GLS model for Biotech industry, dependent variable: average annual value of acquisitions (mn €)

Variables	Random effects estimates
Financial leverage (total assets to total equity)	-7.2363 (19.2843)
Current ratio (current assets to current liabilities)	-2.4407 (8.5893)
Sales growth (% over previous year)	-0.0043 (0.0377)
Sales (natural logarithm of net sales in mn €)	8.6631 (4.4960)*
R&D intensity (R&D expenditure to net sales in %)	-1.7461 (2.8021)
Missing R&D intensity data (dummy; 1 = missing)	-106.6142 (130.1437)
Patenting intensity (Patents granted by application year to net sales)	873597.2 (537848.5)
Company headquartered in Europe (dummy; 1 = yes; base category: United States)	10.2147 (122.394)**
Company headquartered in Asia (dummy; 1 = yes; base category: United States)	-111.2905 (49.3561)**
Constant	42.1127 (70.5316)*
R^2 within	0.0141
R^2 between	0.4513
R^2 overall	0.1699
No. of observations (individuals)	173 (49)
Wald Chi²	27.81
p-value	< 0.01
Hausman specification test	
Chi²	4.99
p-value	0.17251

Notes: Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$; heteroskedasticity-robust standard errors in parentheses; unbalanced panel data with observations per group: min = 2; max = 4; average = 3.5

Table 10 provides the results for the total number of acquisitions. As can be seen, both, sales as a proxy for size and a firm's headquarter being located in Asia are significantly positively associated with the total number of acquisitions in the semiconductor industry.

TABLE 10

Negative binomial model for Biotech industry, dependent variable: acquisition of public or private companies (total number)

Variables	Random effects estimates
Financial leverage (total assets to total equity)	-0.0583 (0.1234)
Current ratio (current assets to current liabilities)	-0.0660 (0.0989)
Sales growth (% over previous year)	0.0001 (0.0001)
Sales (natural logarithm of net sales in mn €)	0.0378 (0.0080)***
R&D intensity (R&D expenditure to net sales in %)	-0.0011 (0.0189)
Missing R&D intensity data (dummy; 1 = missing)	-0.2294 (1.1432)
Patenting intensity (Patents granted by application year to net sales)	64.3500 (1158.096)
Company headquartered in Europe (dummy; 1 = yes; base category: United States)	0.4375 (0.4895)
Company headquartered in Asia (dummy; 1 = yes; base category: United States)	-1.0194 (1.0897)**
Constant	0.9594 (0.9394)
Log-likelihood	-266.8162
Log (r)	2.2200
Log (s)	0.7835
No. of observations (individuals)	195 (50)
Wald Chi²	35.89
p-value	< 0.001
Hausman specification test	
Chi²	10.15
p-value	0.1184

Notes: Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$; unbalanced panel data with observations per group: min = 3; max = 4; average = 3.9; Likelihood-ratio test vs. pooled: Chi² = 15.78, p-value >= Chi² < 0.0001

Table 11 shows that for more narrowly technology oriented acquisitions in the semiconductor industry, only being headquartered in Asia has a significant positive effect, whilst the association for firm size (i.e. sales) is almost significant.

TABLE 11
Negative binomial model for Biotech industry, dependent variable: acquisition of private companies (total number)

Variables	Random effects estimates
Financial leverage (total assets to total equity)	-0.5891 (0.2692)**
Current ratio (current assets to current liabilities)	0.0329 (0.1289)
Sales growth (% over previous year)	-0.0002 (0.0002)
Sales (natural logarithm of net sales in mn €)	0.0173 (0.0106)
R&D intensity (R&D expenditure to net sales in %)	-0.0195 (0.0248)
Missing R&D intensity data (dummy; 1 = missing)	-23.2471 (235116.9)
Patenting intensity (Patents granted by application year to net sales)	2356.245 (1581.317)
Company headquartered in Europe (dummy; 1 = yes; base category: United States)	0.0481 (0.4992)
Company headquartered in Asia (dummy; 1 = yes; base category: United States)	0.9855 (0.5431)*
Constant	1.4418 (1.1568)
Log-likelihood	-151.4412
Log (r)	2.6874
Log (s)	1.2114
No. of observations (individuals)	195 (50)
Wald Chi²	14.41
p-value	0.1549
Hausman specification test	
Chi²	3.29
p-value	0.5109

Notes: Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$; unbalanced panel data with observations per group: min = 3; max = 4; average = 3.9; Likelihood-ratio test vs. pooled: Chi² = 2.19, p-value >= Chi² = 0.070

As can be seen in Table 12, for the number of patents granted to the acquired firms in the prior five years, only being an Asian company has a significant positive association.

TABLE 12

Negative binomial model for Biotech industry, dependent variable: patents granted to acquired firm in acquisition year and 5 years prior to acquisition

Variables	Random effects estimates
Financial leverage (total assets to total equity)	-0.2188 (0.2666)*
Current ratio (current assets to current liabilities)	0.0640 (0.1303)
Sales growth (% over previous year)	-0.0002 (0.0002)
Sales (natural logarithm of net sales in mn €)	0.0110 (0.0120)
R&D intensity (R&D expenditure to net sales in %)	-0.0218 (0.0259)
Missing R&D intensity data (dummy; 1 = missing)	-14.5466 (4532.405)
Patenting intensity (Patents granted by application year to net sales)	-425.6298 (2115.386)
Company headquartered in Europe (dummy; 1 = yes; base category: United States)	-0.0684 (0.5455)
Company headquartered in Asia (dummy; 1 = yes; base category: United States)	1.2262 (0.5343)**
Constant	-3.2367 (0.9987)***
Log-likelihood	-274.4532
Log (r)	-0.2654
Log (s)	4.1186
No. of observations (individuals)	195 (50)
Wald Chi²	12.64
p-value	= 0.2448
Hausman specification test	
Chi²	4.13
p-value	0.5312

Notes: Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$; unbalanced panel data with observations per group: min = 3; max = 4; average = 3.9; Likelihood-ratio test vs. pooled: Chi² = 14.35, p-value >= Chi² < 0.0001

5. Conclusions and future research

Overall, the results show that the patenting and R&D intensities of firms are only rarely associated significantly with firms' acquisition activities. This holds for measures of acquisition activity in general (such as the total number of acquisitions or the average annual value of acquisitions), as well as for more narrow measures of technology acquisition (such as the number of private or technology-related acquisitions or the number of patents granted to the target firms prior to acquisition). The most consistent predictors found are significantly positive associations of sales (as a proxy for firm size) and of leverage which are associated with four different measures for acquisition intensity in the three different industries analysed. Beyond that, geographical influences could also be identified, as summarised in Table 13.

TABLE 13
Summary of results across industries

Measure	EDA	Biotech	Semiconductors
Average annual value	Leverage (+) Sales (+) Europe (+)	Sales (+) Asia (-)	Sales (+) Europe (+) Asia (-)
Total no. of acquisitions	Leverage (+) Sales (+)	Sales (+) R&D intensity (-)	Sales (+) Asia (+)
No. of private/ technology-related acquisitions	-	Growth (+) R&D intensity (-)	Asia (+)
No. of patents granted to targets before acquired	Leverage (+) Sales (+) Europe (-)	Sales (+) Europe (+)	Asia (+)

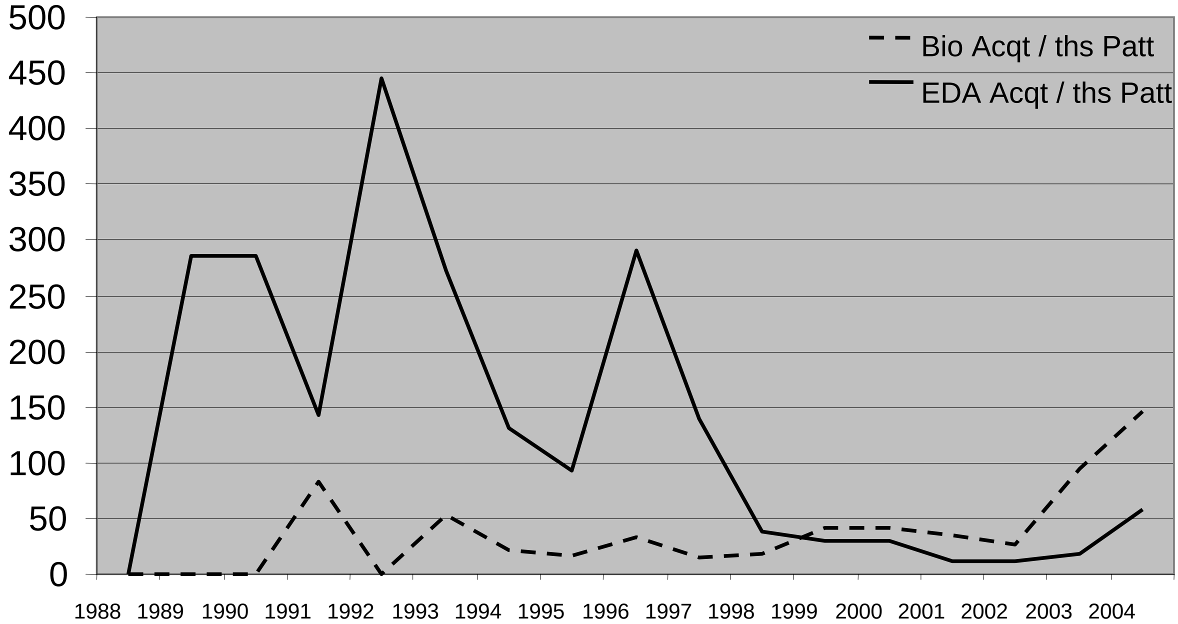
The findings do not generally support the notion that acquisitions compensate weakening exploitation indicated by lower patenting intensity or that acquisition of innovation is a substitute for own R&D. The latter seems to apply specifically to the biotech industry, where a significant negative association is found of R&D intensity and the number of acquisitions. Therefore, as concerns the main research question of this paper, neither a substitutive relationship with acquisitions can be identified for the acquiring firms' patenting intensity, nor for their R&D intensity except for the latter in the biotech industry. In the EDA and semiconductor industries acquisitions seem to be more strongly related to size of the firm and its financial conditions.

In line with the reasoning of Desyllas and Hughes (2005) the effect sizes for R&D intensity are higher in absolute values for the acquisition of privately held firms only, i.e. a unit reduction of R&D intensity leads to higher increase of the number of acquired companies. Whilst the effects are not significant, this can be cautiously interpreted as a stronger substitutive relationship between R&D spending on the one hand with private acquisitions on the other hand which could indicate that the latter are a better substitute for own R&D and patenting than are public acquisitions (assuming that with larger sample sizes a significant association could be ascertained). Given the findings on acquisitions indicate that cooperation and innovation networks are potentially very relevant for firms to address issues of weakening exploitation and reduced resource inputs to innovation activities, but that their role may differ according to the industry concerned. Future research should explore further such potential differences between industries.

Related to this, Gans et al. (2002) argue that small firms and start-ups are more likely to commercialise themselves (rather than licensing or aiming for acquisition), the lower the control over intellectual property (IP) rights, the higher transaction costs for finding a suitable partner for licensing or acquisition and the lower sunk costs associated with product market entry are. Looking at the industries analysed in this paper, EDA has high control over IP rights, which favours licensing or acquisition, but also low sunk cost (favouring product market entry). Compared to this, the semiconductor industry is characterised by low relevance of patents and high sunk cost, which again does not provide clear guidance to entrants as to the commercialization strategy to choose. Finally, in the biotech industry control over IP rights is high, as are sunk cost, which strongly suggests licensing or acquisition as a commercialisation strategy. Given that commercialisation relates to new products and processes and thus innovation, one can derive from this analysis, that any relationship of R&D (e.g. in terms of expenditure or patenting) should in tendency be stronger in the biotech industry, than in the EDA and semiconductor industries, where positive and negative drivers for commercialisation through licensing or acquisition balance each other out more strongly.

Figure 1 looks at this from a slightly different perspective, trying to compare the extent of own R&D (“make” in terms of patents) with that of acquired R&D (“buy” in terms of acquisitions.) Given that acquisition as a commercialisation strategy for start-ups and entrants should be more prevalent in the biotech industry, one would expect the ratio of acquisitions to own patenting be higher there, compared with other industries, such as e.g. EDA. However, Figure 1 shows, that this situation only emerged very recently, and that for a long time, the ratio of acquisitions to own patenting was actually considerably higher in EDA.

Figure 1
Summary of results across industries



However, the average number of acquisitions per thousand patents across all years is 41.11 for the biotech and 34.86 for the EDA industry, which is consistent with the model by Gans et al. (2002). Nevertheless, the difference is not very large, and therefore other factors influencing the choice of commercialisation strategy (thereby explaining when acquisitions are a predominant technology sourcing strategy) could be examined in future research.

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