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Innovation and Collaboration in the Geographic Information Systems (GIS) Industry: Evidence from Canada and the United States.

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Abstract

This paper examines the role of collaborative technical activity in the innovation performance of Canadian and US companies in the geographic information systems (GIS) industry. This young but rapidly growing sector produces specialized hardware and software for cartographic applications (computer mapping). Evidence from a sample of 384 companies suggests that innovation is strongly dependent upon in-house R&D. The results also suggest that a firm's propensity to operate within a collaborative network varies directly with its R&D-intensity. A description of the main benefits and costs of collaboration is presented. Although there is no statistical association between innovation and the incidence of external collaboration, the evidence suggests that R&D partnerships contribute to the innovation process in a number of important ways. The key contribution lies in the speed of product commercialization. A related finding is that collaborators tend to generate radical innovations more frequently than less successful and/or non-collaborators.

Keywords: collaborative R&D, innovation, geographic information systems (GIS), new industries.

Introduction

There is now a good deal of empirical work on the role of external collaboration in the innovation performance of high-technology firms (Freeman, 1991; Greis et al., 1995; Hagedoorn, 1995; Woiceshyn and Hartel, 1996). Although the recent literature does not reveal a clear consensus regarding the benefits or costs of collaboration (Bruce et al., 1995; McGee and Downing, 1994), there is growing evidence that knowledge-sharing agreements are especially prevalent within new or emerging industries (Arora and Gambardella, 1994; Dodgson, 1993; Mowery, 1998). Prominent examples of the latter include biotechnology, optoelectronics, advanced materials, robotics, and computer software (Cornish, 1997). Several authors note that R&D-based partnerships can stretch the knowledge-horizons of the enterprise (Carr, 1995; Cutler, 1991; Haour, 1992; Rothwell, 1992). Significantly, these partnerships can create new techno-market opportunities that otherwise might not be available to firms working in isolation (Jones-Evans and Kirby, 1995; Malecki 1997; Sverker et al., 1998; Von Hippel, 1987).

To date, however, rather little attention has been given to industries that operate along the hazy interface between manufacturing and service activity. The geographic information systems (GIS) industry is a notable example, in that this sector is fast-growing, R&D-intensive, technology-driven, and difficult to define with standard industrial classification (SIC) codes. Firms in the GIS domain include manufacturers of specialized computer hardware (e.g. global positioning systems, digital scanners), developers of geographical software (e.g. computer mapping programs), data providers (e.g. value-added information packagers), technical consultants (e.g. software troubleshooters), or any combination of the preceding (Hartung, 1997). The chief entry barrier to this industry is human capital (i.e. education, technical training, and computer literacy), as illustrated by Dobson (1993), Mark (1999), and several others (see Goodchild and Rhind, 1991).

This paper explores the recent growth and development of the commercial GIS sector in Canada and the United States. To the best of our knowledge, this sector has not been systematically investigated at an empirical level prior to now. Special attention is given to the role of inter-firm technical collaboration in product/service innovation. A brief description of the origins, size, nature, and growth of this sector is offered at the outset. This overview is followed by an exploration of two main questions. First, to what extent is innovation a function of in-house R&D? Second, what are the main characteristics of collaborators versus non-collaborators? Data for the inquiry come from a sample of 384 firms that responded to a postal survey in the Fall of 1996. Supplementary data come from personal interviews with a subsample of 131 firms. Before looking at the survey results, however, it is first necessary to outline a brief research context for the paper. Why is the GIS sector worth exploring? And, why might one expect to find technical collaboration among firms in this industry?

Research Context

The term 'GIS' refers to a computer system (hardware or software) that is designed to process, manipulate, display, and/or quantitatively model geographically referenced data (Dobson, 1993). Although GIS users can be found across a wide range of sectors, the main buyers of GIS products include public agencies (e.g. government census bureaus), resource companies, utilities, educational institutions, and the marketing departments of major corporations (Hartung, 1997). A common denominator among GIS users is that there is usually a strategic need to examine geographic phenomenon (often in time-series), typically with a view to exploring interactive relationships for modeling purposes (e.g. comparative statistics, trend-based forecasting, scenario construction, and so on).

Although the GIS sector has existed since the early 1960s, the commercialization of this industry did not take place until the mid-1980s (i.e. worldwide GIS sales were well below $0.5 billion prior to 1985, compared to over $7 billion today). According to Frost and Sullivan (1994, 1996), sales from the GIS industry are projected to expand at a compounded growth rate of nearly 20% per annum over the next 10 years. As shall be shown later, moreover, a striking feature of this industry is its strategic orientation toward innovation (new product and/or service development). An additional feature of this sector is that most firms exhibit occupational profiles that strongly emphasize scientific, technical and/or professional workers (Dobson, 1993).

At least two further characteristics of the GIS industry should be emphasized. First, GIS producers typically operate in an environment of continuous technological change. Most GIS products depreciate quickly, creating a need for sustained innovation (Berry and Taggart, 1994). The same holds true for a wide array of GIS consulting services, in that best-practice technical solutions are often in a state of constant flux (Mark, 1999). Second, major computer corporations such as IBM and Intel do not operate directly in the GIS domain. Instead, these corporations provide platforms that support GIS applications. This means, in effect, that substantial market niches exist for small and medium-sized GIS firms. Although the GIS industry is dominated by three large players (Environmental Science Research Institute, Intergraph Corporation, and MapInfo), recent rates of new company development have been remarkably high. In the US and Canada, for example, almost half of the current population of GIS companies consists of firms that first started business in the late 1980s (Hartung, 1997). Part of the recent boom in new company formation can be traced to an upswing in demand for customized GIS outputs (i.e. systems that are tailored to the needs of specific users). Given that the three market leaders are unwilling and/or unable to offer customized systems to all but their largest customers (Frost and Sullivan, 1996), the recent proliferation of niche players is not too surprising.

On this note, a recurring theme in the recent literature on new or emerging industries is that collaborative R&D among complementary firms can improve the innovation performance of network members (Carlsson, 1987; Malecki and Tootle, 1996; Sverker et al., 1998). A related theme is that internal R&D and external collaboration represent complements rather than substitutes (Arora and Gambardella, 1994; Mowery and Rosenberg, 1989). These are potentially important themes as far as the GIS sector is concerned, if only because most firms in this industry operate with fewer than 20 employees (Hartung, 1997). Very small firms in this size category often lack the in-house skills to design, develop, and/or successfully commercialize radically new products or services without external help (Freeman, 1991; Greis et al., 1995; Rothwell, 1992). Collaborative R&D has been identified as a potentially useful vehicle for bypassing the internal weaknesses that often afflict small producers (Boardman, 1995; Carr, 1995; Cutler, 1991; Hogan, 1995; Pilorget, 1993; Tyson, 1993). At the same time, of course, collaborative activity can also entail significant commercial risks (see Bruce et al., 1995). Risks of special relevance to small firms in the GIS sector include 'technological raiding' (loss of proprietary knowledge), delayed product development as a result of incompatible management styles, and the possibility that collaborators may become future competitors.

This said, there is good reason to suspect that inter-firm collaboration for innovation purposes is a widespread practice within the GIS sector. Aside from purely technical considerations (e.g. the need to circumvent scale-related problems), there are a number of 'social' factors that should also be considered. For instance, many GIS firms employ university graduates from disciplines such as geography, engineering, and/or computer science. These graduates interact at professional conferences, seminars, trade shows, and related gatherings on a frequent basis (many of these people also co-author academic research papers for GIS Journals). Significantly, impressionistic evidence from a set of pilot inquiries conducted for this project revealed that trust-based relationships are often forged in response to repeated interactions at industry and/or academic meetings. These relationships appear to function as facilitators of network development (i.e. formal or informal systems of knowledge exchange).

A second factor that needs to be considered is that the 'newness' of the GIS sector, together with the relatively small number of university departments that produce graduates with GIS expertise, is suggestive of a young cohort of skilled professionals that operate in a close-knit information network. Any given GIS graduate that works for a GIS company is likely to know (either socially or professionally) a significant number of other graduates operating in other GIS firms. While the role of socially-based contact networks in the context of interfirm technical collaboration is hardly a 'new' topic (see Malecki 1997), we contend that this is an important factor as far as the GIS sector is concerned.

Finally, it should be mentioned that the GIS sector does not represent a big component of any national economy in terms of direct employment, value-added, exports, or output. In the US, for example, total employment in this sector is currently estimated at less than 300,000, whereas global sales for 1998 were only around $7 billion (i.e. the entire sector is smaller than Microsoft). While these figures are not suggestive of a large industry at this point in time, the growth potential of the GIS sector is widely believed to be considerable. By the time this paper goes to press, for example, there is a strong chance that most readers will have been exposed to a number of GIS applications (whether they were aware of it or not). For instance, readers that recently reserved an air-ticket via the internet or by phone were probably dealt with by a customer service person that explored travel options via a GIS package that is embedded within the airline's reservation software system. As a further example, readers that use any of the US Government's statistical information services will note that public data can be obtained (and mapped) on a regional and/or county-specific basis. These are relatively simple examples of GIS. More sophisticated applications are being used by crime analysts in US cities (Calkins, 1991), epidemiologists in disease-prone regions (Townsend, 1991), and utility companies in both developed and developing nations (Mahoney, 1991). The key point is that this small but fast-growing sector has been delivering critical analytic capability to a wide range of user groups at a variety of geographic scales (local, regional, national, and global). How is this achieved?

Methodology and Results

As a first step toward answering this question, self-administered survey instruments were mailed to 698 GIS companies in Canada and the US in the Fall of 1996 (we are not distinguishing between Canadian and US firms in this paper). The target number of 698 came from a telephone survey of the known population of 1219 firms operating in the GIS area, 698 of which agreed to participate in the survey. Of these 698 firms, 384 provided valid responses (giving a 31 percent response rate for the total population, and a 55 percent response rate for those firms that had agreed to participate during the telephone solicitation phase).

Several tests for nonresponse bias were conducted, including t-tests for 'early' versus 'late' respondents across a set of key variables (employment size, R&D spending, and innovation performance). T-tests were also conducted for respondents versus nonrespondents across variables such as employment size, product focus, and date of establishment (using published data from industrial directories). Despite a lower response rate than we had originally hoped for, none of the tests for nonresponse bias pointed to significant differences at p = 0.05 or less. In short, we believe that we have a reasonably representative sample (and one that includes the commercial core of the industry in terms of North American market share).

Table 1. Descriptive statistics for the sample.

Characteristics	Median	Mean
Total employment	11	86.9
Company age (years)	12	14.3
Years in GIS business	6	8.0
Research-intensity *	10	15.0
Export-intensity **	2	14.1
1985 sales (n = 130) ***	725	8177
1990 sales (n = 202)	800	8034
1995 sales (n = 323)	700	7104

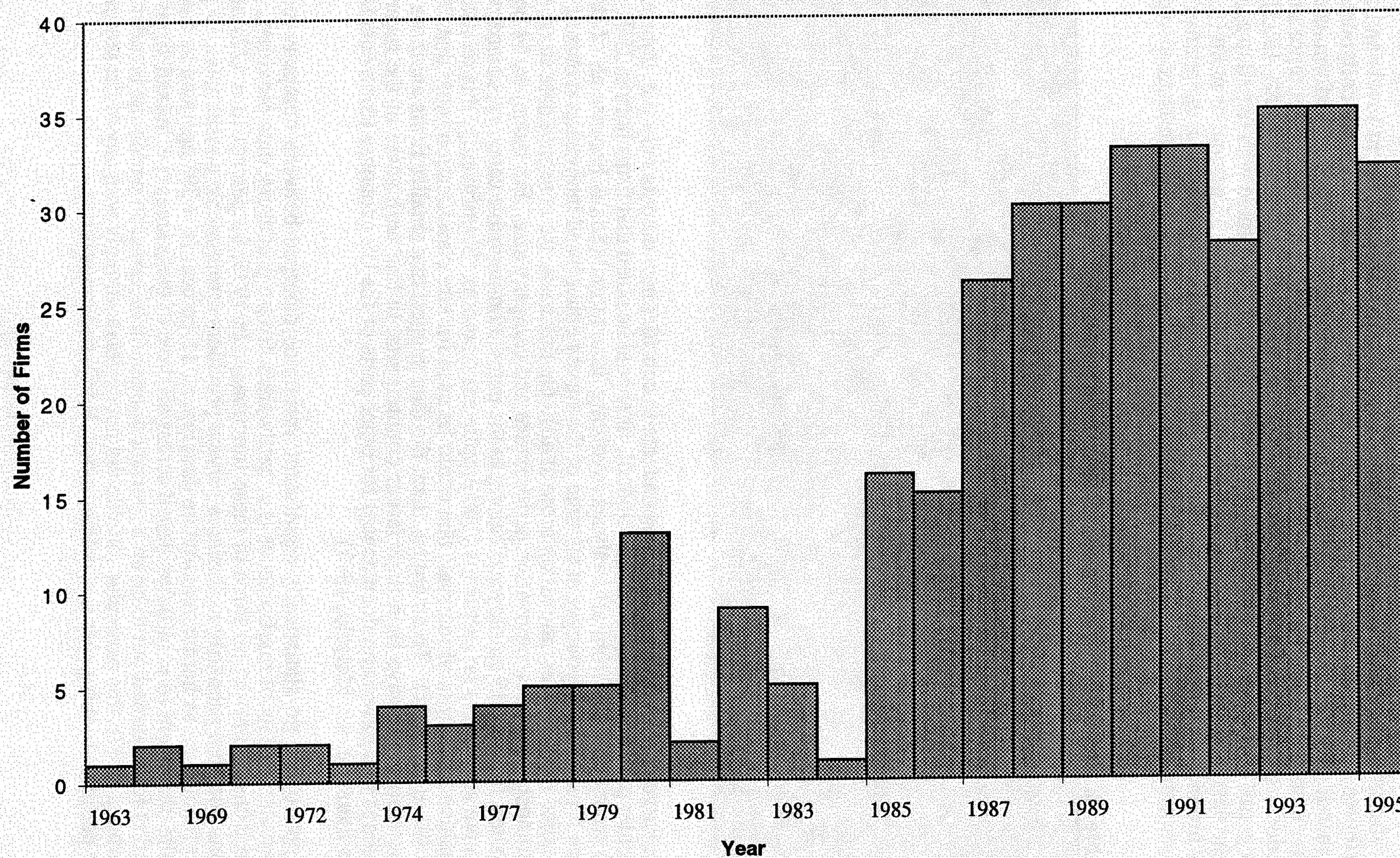
* *R&D spending as a % of total sales in 1995*
** *Export sales as a % of total sales in 1995*
*** *US$ (000s): Note: there are 61 missing cases for the sales variable.*

A snapshot of the main characteristics of the sample is shown in Table 1. These data reveal that the 'typical' GIS firm is small (median employment = 11 workers), young (average age = 14 years), research-intensive (an average of 15 percent of sales go toward R&D), export-oriented (almost 50 percent serve foreign customers), and modest in terms of total sales (median 1995 revenues were around $700,000). Table 1 also reports mean and median sales across three time periods (1985, 1990, and 1995). These data underscore the fact that rates of new firm formation within this sector have been fairly high. For example, only 130 of the survey firms earned GIS-related revenue in 1985 (median sales = $725 thousand). Within this particular sample, fully 101 firms (26 percent of all respondents) entered the GIS market after 1990. Clearly, then, we are dealing with a relatively young sector. Figure 1 shows that a substantial majority of the survey firms did not earn any GIS-related revenue until after 1984.

An interesting feature of the sample as a whole (not tabulated in this paper) is that an estimated 33 percent of the total workforce consists of university-educated graduates (e.g. > 20,000 Bachelors, > 7000 Masters, > 1000 PhDs, and > 2000 employees with professional degrees). Outside the nucleus of the industry (i.e. the Big 3), these graduates are fairly evenly distributed across the remaining size-classes, such that the typical GIS firm has an impressive educational profile (30 percent of the workers hold Masters degrees, 10 percent are doctoral graduates, while 7 percent hold professional degrees). One reason for this pattern is that GIS firms are almost invariably R&D-intensive. In this particular sample, for instance, R&D expenditures (expressed as a proportion of total sales) ranged from a low of 4 percent to a high of 55 percent (the median is 10 percent).

Although the sample spans a wide range of size categories (see Figure 2), no statistically

Figure 1
First year that the firm received GIS-related revenues



significant differences were uncovered between company employment levels and a variety of attributes, including export propensity, R&D-intensity, and external collaboration (R&D partnerships). A notable exception to this pattern concerns innovation performance (Table 2). Here, innovation performance was defined as the proportion of 1995 output represented by GIS products or services that had been developed over the last 5 years [1991-1995]. The two categories of innovation performance (high versus low) were defined with regard to a natural break in the data, with 'high' corresponding to a new product share of 35 percent or more (the median in this instance was 41 percent). We offer this dichotomy simply to illustrate the relative distribution of innovation performance across the various size categories (parametric tests are also presented).

Table 2. Innovation-intensity and company size.

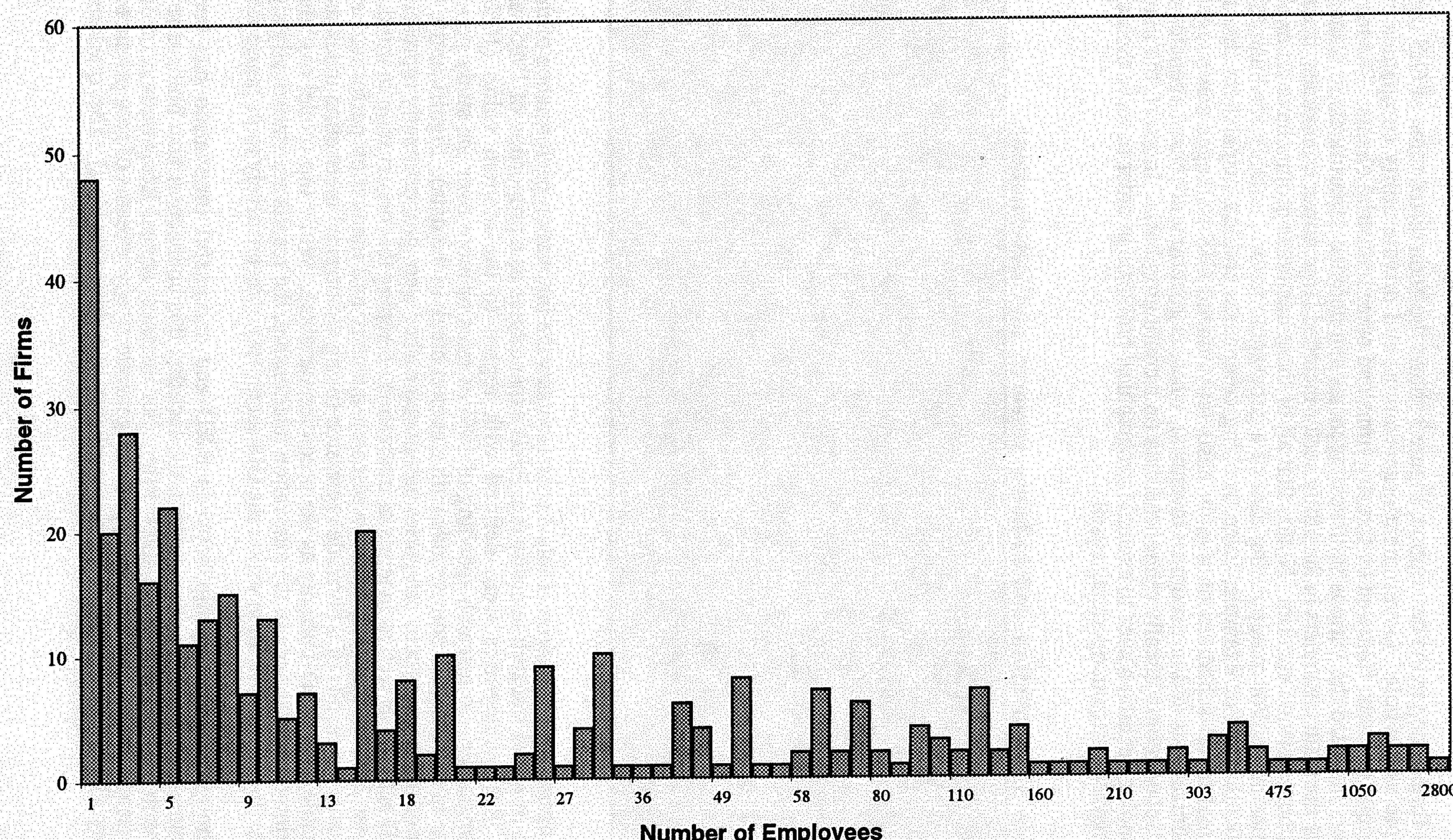
Size class (employment)		1-19	20-49	50-99	100 or >	Total
Innovation-intensity	High	82	24	12	16	134
	Low	68	23	14	36	141
Total		150	47	26	52	275

Chi-square = 9.00 p = .02 (missing cases = 23)
Pearson's r = -0.1891 p = .01

The survey instrument required respondents to consider new outputs only (i.e. improved versions of older products/services were excluded). It should be noted that firms born in 1991 or later (n = 86) were excluded from all analyses involving 'innovation' (this is because all of the firms that were 5 years old or younger at the time of the survey either listed innovation scores of 100 percent or failed to supply an innovation score at all). On this basis, the censored data suggest an inverse relationship between innovation performance and company size. For example, 54 percent of the smallest firms (1-19 employees) belong to the innovation-intensive category, compared to only 31 percent among the largest firms (100 employees or more). Significantly, this relationship is not sensitive to the mix of intervals that could be used for size classification (note that Pearson's r = -0.1891 at p = 0.01). To an extent, then, the data suggest that smaller firms are more likely to be innovation- intensive than their larger counterparts, in line with some of the recent empirical findings that have been documented for other parts of the US economy (for a concise review of this literature, see Malecki, 1997).

Interestingly, no statistically significant variations emerged between company size and four characterizations of market focus (i.e. hardware/software producers, data providers, consultants, and firms exhibiting all three of these functions). In 1995, 32 percent (n = 122) of the survey firms operated primarily as business service providers (professional consultants), 19 percent (n = 69) functioned as hardware/software developers, 11 percent (n = 39) operated as data providers, while 38 percent (n = 140) functioned across all three of these areas (i.e. 'mixed' firms). Although market focus turned out to be an important dimension of variation within the broader dataset (see Hartung, 1997), this particular variable did not correlate strongly with any of the key attributes that are pertinent to this paper (i.e. collaboration, R&D, and innovation).

Figure 2
Firm Size of Survey Respondents



As a further step in the description, Figure 3 shows the main distribution of GIS customers for the sample as a whole. Government organizations and private utility companies emerged as the principal markets, followed by forestry firms and other industrial clients. The main government buyers included the various statistical agencies and defence departments in Canada and the US, while the main customers in the utility sector included large power companies, trucking firms, and telephone service vendors. Notice that all of these customer groups have an explicit interest in monitoring and/or manipulating data of a geographic nature, notably for business management applications. For example, large trucking companies employ dispatchers that need to design optimal travel schedules on a daily basis (customized GIS packages can suggest options that minimize costs and/or maximize revenues), whereas government census agencies are called upon to display geographically referenced data on a continuing basis. In short, the main users of GIS technology exhibit a need to examine geographical problems in order to serve their customers more efficiently (or to cut operating costs).

Table 3. Innovation and in-house research and development.

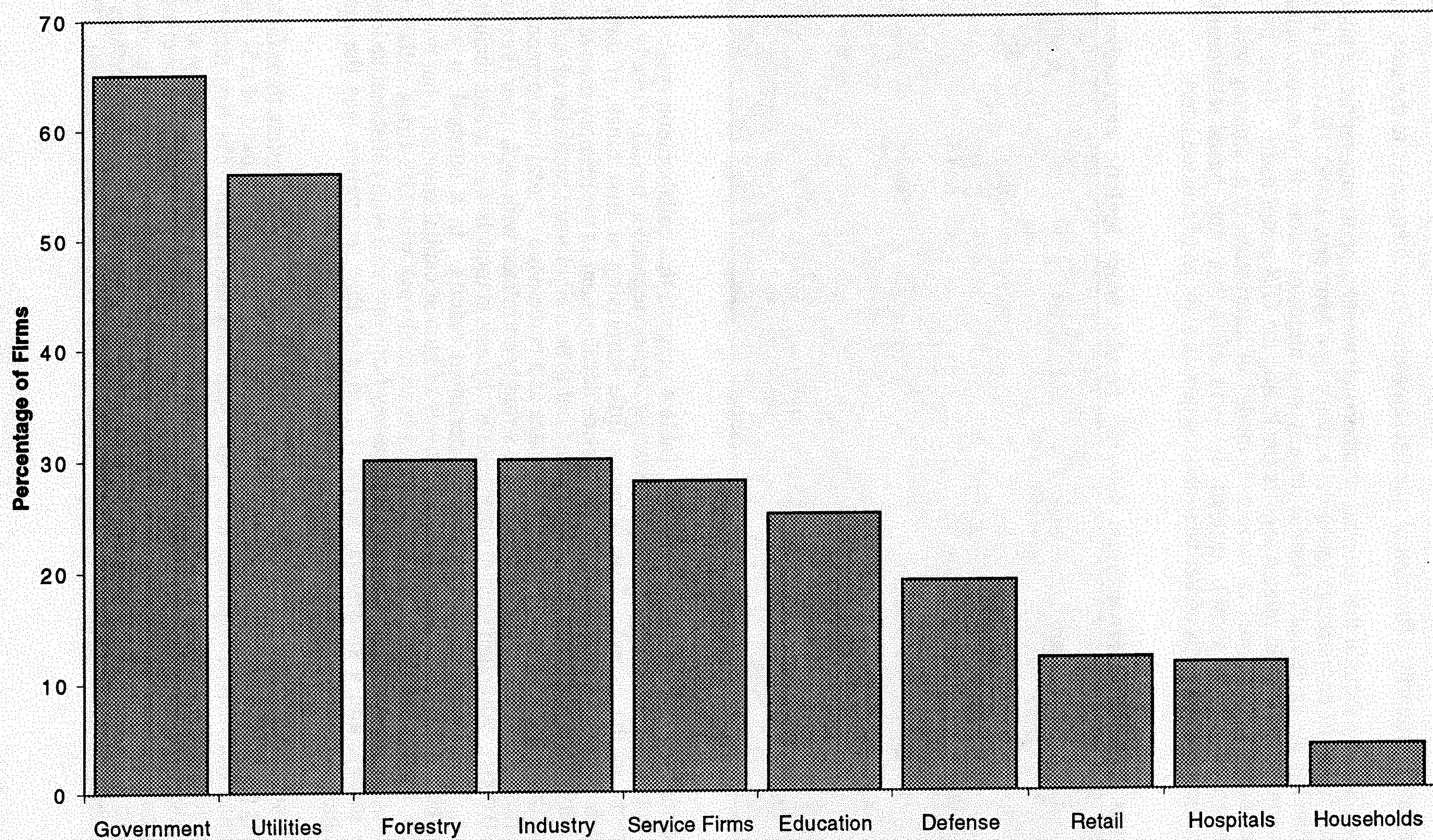
Research-intensity		High	Low	Total
Innovation-intensity	High	87	40	127
	Low	57	72	129
Total		144	112	256

Chi-square = 15.37 p = .0001 (missing cases = 42)
R^2 = 0.2987 (parameter = 0.3857) t = 6.66 (p = 0.001)

Set against this backdrop, Table 3 crosstabulates the innovation performance of the survey firms with in-house research intensity (i.e. R&D expenditures as a proportion of 1995 sales). Here, the two R&D categories were defined with regard to the median value (10%), with 'high' corresponding to research spending of 10% of sales or more over the study period (the median value in this instance corresponds with a natural break in the data). Significantly, firms across all four of the market focus categories mentioned earlier were proportionally represented in terms of R&D activity, as well as in terms of innovation. Keeping this observation in mind, Table 3 shows a clear 2 x 2 relationship between research-intensity and innovation performance. Table 3 also presents the results of a bivariate regression (using the original innovation index as the dependent variable, and R&D-intensity as the predictor variable). While our model explains only a small portion of the variance in the innovation relationship, the results are statistically significant at p = 0.01. In short, innovation within the GIS sector responds positively to in-house R&D.

Although the relationship between R&D and successful innovation has been empirically documented for many other sectors, the fact that this connection also holds true for very small firms in the GIS industry is noteworthy. For instance, annual R&D outlays of only around $80 thousand per firm (on average) appear to generate steady streams of new products or services for many GIS companies (including consultants and data providers). The question thus arises: is

Figure 3
Principal sources of revenue for the survey firms



innovation primarily a function of internal research? Or, is there more to the story than this?

It was initially thought that external collaboration would support innovation via pooled R&D and/or other forms of cooperative technical activity (see Mowery, 1998). External collaboration was defined as the existence of formal (legally structured) or informal (non-contractual) R&D-based linkages with firms in related sectors (including the GIS sector itself). Here, the term 'informal' does not refer to casual or incidental modes of interaction (e.g. chatting with colleagues at a conference or trade show). Instead, the term refers to a trust- based relationship that includes specific technical goals and/or well-defined task allocations (discussed later).

Table 4. R&D partnerships: selected results from logistic regression. *

R&D Partnerships (yes/no) by:	Exp (B)	p	prediction rate
(1) R&D-intensity	8.79	0.0017	76.5%
(2) Educational-intensity *	9.32	0.0014	69.2%
(3) Innovation-intensity	0.14	0.6510	11.7%

* *These are separate (bivariate) logistic regression models.*
** *University/college graduates as a percentage of total employment*

In contrast to our initial expectations, Table 4 suggests that collaboration (yes/no) and innovation are not even weakly connected (our bivariate logistic regression model correctly classified only 12 percent of the cases). This seems a little surprising at first blush, if only because most collaborators identified new product/service development as the primary motive for collaborative activity. This said, R&D-intensity turned out to be a significant predictor of collaboration, as did workforce quality (i.e. university graduates as a percentage of total employment). Both of these metrics pertain to human capital and are strongly correlated with each other (Pearson's $r = 0.7868$; $p = 0.0001$). Although several other logistic regression models were tested, including multivariate ones, Table 4 shows only the most pertinent results. In a nutshell, it would appear that collaboration is associated with high levels of human capital intensity, but not with innovation itself. At this juncture, then, one might reasonably ask why GIS firms collaborate in the first place. After all, fully 30 percent of the survey firms operated with collaborative links at the time of the survey, and a substantial majority indicated that innovation was the main motive for establishing inter-firm partnerships.

Although the survey uncovered a wide mix of motives for collaboration, three factors stood out as being particularly important. These factors were identified on the basis of a 5- point Likert scale, ranging from 1 [not important at all] to 5 [critically important]. The first factor pertains to the development of entirely new technology (mean score = 3.44). Fully 67 percent of the collaborating firms identified this factor as being either a very important or critically important reason for initiating partnerships. The second factor pertains to speed of product development (mean score = 3.11). A majority of the collaborating firms entered partnerships with a view to accelerating the innovation process (product or service commercialization). The third factor pertains to product/service efficiency (mean score = 2.85). Here, a majority of the collaborating firms felt that pooled R&D would result in better product or service performance. Overall, 55 percent of the collaborating firms indicated that their partnerships had contributed significantly to one or more of these three objectives, suggesting a positive connection between collaboration and the innovation process (though not necessarily innovation itself).

Table 5. Attributes of successful, less successful and non-collaborators.

	Successful n = 64	Less Successful n = 53	Non-Collaborators n = 123
	**		
Innovation Intensity	61.7% -------------	38.7%	46.9%
		**	
Research Intensity	18.9%	16.5% ---------------	9.8%
	I_____________	_____________	_____________I
	**		
		**	
Sales Growth (1985-1995)	845% ---------------	300% ---------------	520%
	I_____________	_____________	_____________I
	**		
BA/BSc Graduates*	41%	54%	56%
	I_____________	_____________	_____________I
	**		
	**		
MA/MSc Graduates*	24% -----------------	11%	12%
	I_____________	_____________	_____________I
	**		
		**	
Doctoral Graduates*	9% -----------------	2% -----------------	3%
	I_____________	_____________	_____________I
	**		
	**		
Professional Graduates*	14% -----------------	7%	10%

* *university/college graduates as a percentage of total employment*
** *significantly different group means at p = 0.05 or <*

As a further step in the analysis, Table 5 compares successful versus less successful collaborators across a number of dimensions, including innovation performance, R&D-intensity, sales growth, and workforce education. Firms that flagged a positive impact of collaboration upon overall business performance (rated along a 5-point scale) were classified as 'successful' collaborators (n

= 64). The resulting dichotomy was found to be robust, in that over 90 percent of the firms that were allocated to the successful category indicated an interest in cultivating new or expanded collaborative links in the future, compared to only 23 percent among firms in the less successful group (the comparable percentage for non-collaborators was 18 percent). The results indicate that successful collaborators outperform their less successful counterparts across three important attributes, including innovation-intensity, sales growth, and workforce quality (i.e. the number of university/college graduates holding advanced degrees, expressed as a percentage of total employment). Among successful collaborators, for instance, the average innovation score exceeds 60 percent, compared to only 39 percent among less successful collaborators (these means are significantly different at $p = < 0.05$). The data also suggest that successful collaborators operate with significantly higher proportions of post-BA/BSc graduates than less successful and/or non-collaborators.

Table 5 also points to a number of important contrasts between non-collaborators and less successful collaborators. For example, non-collaborators score higher on the innovation index, despite having lower R&D-intensity. An implication here is that R&D productivity is stronger among non-collaborators than among less successful collaborators. The latter, as a group, exhibit weaker sales performance than the remainder of the sample. The question thus arises: why are there significant differences between these three groups in terms of the variables that have been discussed thus far? The following section offers a number of tentative answers.

Discussion

Some of the results shown earlier suggest that GIS firms can innovate successfully on the basis of modest in-house R&D expenditures. The results also suggest that collaborative activity is more prevalent among R&D-intensive firms. Although collaboration does not necessarily cause innovation, many externally-networked firms obtain significant product-related benefits from their partners.

Interestingly, on-site interviews with 131 of the survey firms teased out qualitative data that could not be readily obtained from the postal questionnaires. For example, most of the collaborating firms were found to operate without contract-based agreements. Instead, most partnerships were found to involve trust-based relationships between people that know each either on a social and/or professional basis. While most collaborative ventures are organized on a task-specific level (i.e. partnerships dissolve upon project completion), a majority of the interviewees stated that certain types of new product and/or service options require collaborative work. It would appear that many GIS firms draw upon specialized technical expertise that is distributed across informal business networks (i.e. previous and/or potential partners), such that, in effect, a single small firm can become a much larger entity over the duration of a specific project. This pattern of behavior would go some way toward explaining why so many small GIS firms can survive alongside the three industry leaders (recall that the GIS sector is an oligopoly).

Significantly, personal interviews also revealed that many of the R&D partnerships documented earlier include (or overlap with) marketing agreements for product distribution. From a geographical perspective, it is interesting to note that collaborative links were found to span a range of spatial scales (from local [50 percent] to national [64 percent] to global [16 percent]). For example, several of the more innovative firms identified local partners (collaborators located in the same metropolitan area), national partners (collaborators located in different States/Provinces), and global partners (collaborators located outside North America). In short, collaborative activity is not simply a local phenomenon.

Perhaps one of the most striking impressions that emerged from the interviews was that successful collaborators appeared more likely to introduce radically new GIS technologies than less successful and/or non-collaborators. While this impression confirmed what most respondents ranked as one of the top motives for collaboration in the first place, the original survey instrument was not crafted with a view to assessing the commercial, strategic, and/or technological significance of specific types of new offerings (e.g. radical versus incremental). On this note, superior product/service attributes would certainly go some way toward explaining why successful collaborators were found to exhibit faster rates of sales growth than the remainder of the sample (Table 5). Interestingly, McGee and Dowling (1994) note that R&D-based collaboration can actually reduce a firm's rate of sales growth if appropriate management expertise is lacking. Our evidence supports this view, in that successful collaborators outperform less successful collaborators, while non-collaborators are situated in the middle (Table 5). Although McGee and Dowling (1994) suggest that differences in management competence are at the heart of this type of relationship, we can confirm this only to the extent that there is a clear rank order in terms of the educational characteristics of our three groups of survey firms. Specifically, successful collaborators employ significantly higher proportions of graduates with advanced university degrees than both non-collaborators and less successful collaborators. In addition, the fact that non-collaborators perform better than less successful collaborators implies that collaboration may actually be a strategic mistake unless appropriate levels of management competence are in place.

In this regard, interviews with less successful collaborators revealed that many of the CEOs and/or managers in this group spent a good deal of time trying to correct flaws in the operation of their partnerships, such that, in several cases, collaborative efforts were associated with serious opportunity costs. More specifically, time spent on attempting to salvage failing partnerships might better have been spent on more productive activities. This may explain, in part, why so many of the less successful collaborators were found to exhibit weaker business performance than non-collaborators.

In contrast to producers of hardware or software, consultants and data providers expressed minimal problems in terms of external collaboration. Within this segment of the sample, interviewees consistently defined 'innovation' as a process involving the development of radically new types of services (i.e. technical solutions or procedures). Interestingly, service-based firms that scored highly on our innovation index indicated that business survival depends upon the continuous development of new streams of technical expertise, often in anticipation of client needs rather than as a reaction to market demand. A notable feature of innovators on the service side of the industry is that competitive advantage appears to flow mainly from the creation of new strands of expertise in highly specialized areas (e.g. spatial statistics, computer cartography, remote sensing).

It should also be mentioned that interviewees across all segments of the industry indicated that at least 50 percent of all company employees perform research-related and/or information-intensive functions on a regular basis (e.g. product/service development, market analysis, data acquisition, academic Journal scanning, software design, customer analysis (e.g. surveys), conference attendance/participation, Website construction, and so on). In collective terms, this tiny sector appears to resemble a large academic research unit -- the main difference being that commercial outputs are critically important. This heavy emphasis upon research (broadly defined) goes some way toward explaining why the occupational/educational structure of the industry as a whole is heavily oriented toward professionally and/or academically qualified workers that hold advanced university degrees.

Finally, our interviews revealed that most GIS firms prefer to locate in metropolitan areas that contain dense clusters of producers in similar or related industries. Evidence from the postal survey (not presented here) uncovered several distinct clusters of GIS activity (the three largest being Los Angeles, Washington DC, and Denver). Although a full explanation for this clustering cannot be presented here (see Hartung, 1997), on-site interviews revealed three sets of factors that warrant brief mention. First, the local technological environment (as well as quality of life considerations) was seen as especially important. Specifically, fast access to leading research universities and/or government agencies, as well as fast access to customers and potential collaborators, emerged as a central factor. Second, access to a first class communications infrastructure (airports, highways, telecommunications) was seen as critical. In short, the GIS industry is concentrated in growth regions that contain well developed stocks of technological resources. These regions, not surprisingly, also happen to be good places to live from a quality of life perspective. Third, virtually all of the more innovation-intensive firms within the sample as a whole (as well as the subsample that was interviewed) were members of regional clusters of GIS activity. An implication here is that Porter's (1990) much-publicized model of competitive advantage may apply quite strongly to the GIS sector. Specifically, innovation appears to be especially pronounced within regions that contain dense clusters of firms operating in similar or related industries.

Conclusions

The commercial GIS industry represents a relatively new sector that is innovation-oriented, R&D-intensive, and fast-growing. A substantial proportion of producers in this sector operate with R&D-based links to complementary firms. Most research-oriented partnerships are structured to promote new technology development and/or technology transfer, often with marketing agreements in place. Formal contracts are rare, whereas implicit or trust- based arrangements are common. There is a positive relationship between successful innovation and in-house R&D. There is also a positive relationship between in-house R&D and collaboration propensity. Although external collaboration is not a significant predictor of innovation performance, there is a general perception among successful collaborators that pooled R&D generates important benefits. These benefits include faster product development, better product performance, and enhanced opportunities for the creation of entirely new GIS technologies. On the negative side, firms that failed to capture major benefits from partners cited hostile appropriation of expertise as a problem (i.e. collaboration can change into competition). Many of these firms also noted that scarce management time had been allocated to the task of correcting problems and/or rebuilding relationships within ventures that perhaps ought not to have been initiated in the first place. On this note, we suspect (but cannot prove) that less successful collaborators are positioned in a lower-performance category than other firms because of a lack of appropriate management expertise.

It would appear that innovation in this industry is not driven primarily by the largest companies, though the latter are certainly 'innovative' by most yardsticks. There is, in fact, an inverse relationship between innovation-intensity and company size, suggesting a key role for small firms as far as new product/service development is concerned. This finding must be tempered by the possibility that not all innovations are equal in terms of their technological and/or commercial significance. The task remains to design, develop, refine and empirically test an innovation index that might accurately mirror the innovation contribution of different types of firms within this industry. For now, we are left with the impression that smaller firms are more innovative than their larger counterparts (especially if they collaborate with other firms). We are also left with the possibility that this suspicion may reflect the criteria that were employed to define innovation in the first place.

Setting issues of definitional validity or clarity aside, our findings raise a number of questions that merit further attention. First, it would appear that GIS firms continue to build R&D-based partnerships with other firms, despite the absence of a significant connection between innovation and the incidence of collaboration. Qualitative evidence from our follow-up interviews revealed that successful collaborators typically generate commercially superior innovation streams than most other firms. Second, the small versus large firm debate (innovation propensity) is far from resolved, and this is true for many sectors. It would seem that one of the only convincing ways to resolve this debate would be to perform detailed tracking studies of firm-specific innovations over time. Again, it would seem that an assessment of the significance of particular sets of innovations would be instructive. Finally, performance differences between firms might ultimately reflect local or regional differences in the quality of available technological resources. All three of these issues are currently being explored by the authors.

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