Does Venture Capital Investment in Start-Ups Drive Incumbent Innovation? Evidence from the Computer, Semiconductor, and Pharmaceutical Industries*

by

Setio Anggoro Dewo, Joshua S. Gans *and* Joseph Hirschberg**

4th July, 2005

This paper undertakes an empirical examination of venture capital funding to start-up firms in semiconductors and biotechnology to examine the impact of this on incumbent R&D strategy. Contrary to claims and theoretical predictions that the rise in start-up R&D activity would drive incumbents to become more innovative, our data does not find any significant relationship between the two. This leads us to question whether expectations of a large strategic effect from start-up activity are warranted.

Keywords. start-up, incumbent, R&D strategy, strategic complements, venture capital, biotechnology.

* We thank the Intellectual Property Research Institute of Australia and the Australian Research Council for financial support. Thanks also to Scott Stern for helpful comments. Responsibility for all errors lies with the authors. All comments to J.Gans@unimelb.edu.au. The latest version of this paper is available at www.mbs.edu/jgans.

** Universitas Indonesia – Fakultas Ekonomi (Setio), Melbourne Business School (Gans) and Department of Economics (Hirschberg), University of Melbourne.

1. Introduction

In the past two decades, venture-backed start-up firms have emerged as important drivers of innovative activity across many industries; accounting now for more than 15% of industrial innovation (Kortum and Lerner, 2000). They have also been heralded as drivers of the perennial "gale of creative destruction." (Schumpeter, 1943) That is, there is a strong expectation that start-up innovation has and does put pressure on incumbent firms to innovate more intensively (Gilbert and Newbery, 1982). This is because, in the absence of technological competition, incumbents are overly concerned about cannibalising existing assets and product lines (Reinganum, 1983). By providing that competition, incumbents overcome their concern for cannibalisation and innovate more intensively. For this reason the increase in start-up activity has been applauded – not only for their creativity – but for their flow-on strategic effects on established firms.

Existing studies of the relationship between incumbent and start-up innovation have usually taken place at a product level. Christensen (1997) examines the disk drive industry and finds that new entrants consistently displace incumbents in both technological and market leadership. However, in other industries, the relationship appears more nuanced. In biotechnology, start-up companies often join with incumbent pharmaceutical companies in licensing agreements, alliances or outright acquisition (Orsenegio, 1989; Lerner and Merges, 1998). Such cooperative activities forestall product competition and may diminish the intensity of innovation racing; potentially, to the point where greater start-up competition *diminishes* incumbent incentives to innovate (Gans and Stern, 2000).

Nonetheless, a gap exists in that no empirical study has looked at to the relationship between research and development intensity of venture-backed start up firms and that of incumbent companies.[1] The goal of this study is to fill this gap by examining

[1] The activities of venture-backed start-up firms have attracted considerable attention recently by empirical researchers. Recent studies have analysed the drivers that determine commercialisation strategy of venture-backed start up firm (Gans, Hsu and Stern, 2002); venture-backed start up firms' commercialisation strategy (Hsu, 2000); corporate governance of venture capitalist (Sahlman, 1990); venture-backed firms' IPO (Barry et al., 1990 and Megginson and Weiss, 1991); long run certification role (Megginson and Weiss, 1991; Lerner, 1993; Gompers, 1996; Gompers and Lerner, 1997 and Munsters and Rad, 1994); the

empirically the strategic interaction between research and development intensity by start up firms and research and development intensity by incumbent companies. In so doing, we propose to test whether the strategic interactions of incumbents and start-ups follow the qualitative predictions of the theoretical literature. While some examination of strategic interactions amongst incumbents exists (Grabowski and Baxter, 1973; Henderson, 1993; Lerner, 1997), our study is novel in that it takes into account start-up and incumbent interactions across several key industries.

Our focus is on explaining the research and development expenditures of incumbent firms across three industries: (i) computers and office equipment; (ii) electronics and electrical equipment; and (iii) pharmaceuticals. We associate each with a *narrower* industry classification associated with start-up innovation. The associated industries are computer hardware, semiconductors and biotechnology, respectively. These industries were selected for two reasons. First, they are leading industries in R&D activity in which venture capitalists have important role. Second, each are regarded as technologically intensive in terms of product development (Bygrave and Timmons, 1992).

For each industry, we identify the largest firms and examine the time series of their R&D expenditures over the past few decades. Taking into account their potential strategic interactions, we explore the relationship between changes in incumbent R&D and the growth of start-up innovation in the incumbent's industry. In so doing, we generate several interesting findings. First, and most importantly, there is no evidence of a significant relationship amongst the R&D activities of incumbent and start-up firms. For the vast majority of incumbents, start-up R&D activity is not significantly correlated with incumbent R&D expenditures. This includes strategic interaction between pharmaceutical firms and biotechnology start-ups; the focus of a more micro-level study

---

importance of well-developed stock markets and IPOs for venture capital financing (Black and Gilson, 1998); security design (Repullo and Savarez, 1998 and Cumming, 2000); interaction between financing activities and innovation (Santarelli,1995); empirical analysis of venture capital contracts (Kaplan and Stromberg, 2000); professionalization of start up firms (Hellman and Puri, 2002); venture capital contracting under asymmetric information (Trester, 1998); moral hazard in venture capital financing (Bergemann and Hege, 1998); characterising efficient contracts (Marx, 1998); venture-run performance of venture-backed IPO (Brav, 1997); post IPO operating performance (Jain and Kini, 1994); venture capitalist's reputation and capitalists spur innovation (Kortum and Lerner, 1998 and Gans, Hsu and Stern, 2002).

by Cockburn and Henderson (1994) that also failed to find evidence of racing. This indicates a lack of racing between them or alternatively a lack of any common driving force of technological opportunity.

The remainder of this paper is organised as follows. Section 2 reviews the relevant literature on technological competition. Section 3 describes data that we use in this study. Section 4 states our estimation procedure while Section 5 presents our main empirical result. A final section concludes.

2. Theoretical Predictions

The theoretical literature on innovation racing is well developed. While the analysis of the incentives to innovate in competitive as opposed to monopolistic markets began with Arrow (1962) it was not until the work of Loury (1979) that the strategic analysis of R&D competition became the focus of attention. He developed a model whereby competing firms commit to a level of R&D expenditure on innovative activity each period with a greater expenditure increasing the likelihood that they develop an innovation (and secure a patent) prior to their rivals. He found that the R&D expenditures of individual firms were *strategic substitutes* with those of other firms. That is, the marginal return to R&D expenditure for a firm was falling in the level of expenditure by other firms.

Lee and Wilde (1980) relaxed an assumption of the Loury model that had firms committing to a given level of R&D expenditure in each period and instead assumed that R&D expenditure was chosen in each period. For our purposes here, the important implication of this change was that R&D expenditures of firms became *strategic complements* with one another. That is, the marginal return to R&D expenditure in a given period increased with the level of expenditure chosen by rival firms. As it was generally supposed that R&D expenditures could in fact be varied from period to period and were not fixed following an initial decision, this approach became established as the canonical model of innovation racing.

The interaction that we focus on here, however, is the strategic interactions between incumbent firms in an industry and start-ups that enter that industry. In a seminal paper, Gilbert and Newbery (1982) took an 'auction approach' to innovation – similar in spirit to Loury's model but without a dynamic effect – and found that incumbent firms have greater incentives to innovate than start-ups. The reason for this was that if an incumbent were to innovate first and secure a patent it could preclude entry and preserve its monopoly profits (π^m). In contrast, an entrant could only hope to gain a foothold in a more competitive market (earning π_s^c). Thus, to the incumbent the return from innovating prior to the entry was the monopoly profits of the industry less the profits it would earn under competition (π_i^c). As industry profits under monopoly exceed those under competition (i.e., $\pi^m > \pi_s^c + \pi_i^c$), this return necessarily exceeded the return an entrant could hope to make. Hence, the unique equilibrium involved the incumbent engaging in sufficient R&D activity so as to pre-empt entrant innovation.

The Gilbert and Newbery approach – while identifying the important difference between incumbent and start-up pre-emption incentives – was, however, a static model. Reinganum (1983) embedded the possibility of pre-emption into the Lee and Wilde stochastic racing model and demonstrated that incumbent and entrant innovation remained strategic complements. However, she also demonstrated that while incumbent innovation might be spurred on by the possibility of pre-empting entrant innovation, it was also limited by a concern that such an innovation might cannibalise an incumbent's existing assets and product lines. That is, an incumbent would earn $\underline{\pi}^m$ in each period no innovation was generated. This was an effect identified by Arrow (1962) that he termed the *replacement effect*. The idea was that, even in the absence of start-up innovation, if an innovation was generated sooner rather than later, the incumbent's increase in profits would be $\pi^m - \underline{\pi}^m$. In contrast, a start-up would have no rents to cannibalise if it innovated sooner and hence, may have a greater willingness to pay for the innovation. Reinganum showed that for drastic innovations (where $\pi_i^c \approx \pi_s^c \approx \pi^m$), the entrant may have greater overall innovation incentives than the incumbent.

At this point, it is useful to consider in more detail, why strategic complementarity is the prediction of the traditional patent racing model. Gans and Stern (2000) demonstrate that the larger are the negative effects of rival innovation on a firm's profits, the greater are its incentives to innovate to avoid such negative effects. To see this, recall that a greater level of R&D expenditure in a given period by say, the start-up, will increase the probability that the incumbent earns π_i^c rather than its continuation payoff of V_i; that represents the present value of the expected profits of the firm if the innovation race were to continue. The higher the level of start-up R&D expenditure, the higher the return to the incumbent of raising its own level of R&D as this reduces the likelihood of that negative effect being incurred. A similar logic holds for the start-up who earns no rents if the incumbent innovates first.

However, as Gans and Stern (2000) point out, the fact that rival innovation negatively impacts on the profits of a firm is critical in driving the strategic complementary result. While this will naturally be the case for start-ups who, if pre-empted by incumbents, have few opportunities to earn further rents, this may not be reasonable for incumbent firms. As Gans and Stern develop, the negative impact of start-up innovation on incumbent profits is a direct result of the fact that start-up innovation precipitates product market entry by them and the consequent dissipation of monopoly rents. They demonstrate that, in fact, start-up firms are more likely to be acquired or license their innovation to the incumbent as there are mutual gains from trade in terms of saving the costs of product market entry as well as preserving market power in the industry. If such licensing were to occur following start-up innovation, the start-up would be paid an amount τ that is greater than profits it would earn from product market entry, while the incumbent would earn $\pi^m - \tau$. In this situation, it is entirely possible that $\pi^m - \tau > V_i$ meaning that the incumbent benefits from earlier start-up innovation rather than is harmed by it. In particular, this condition will hold when the returns from product market entry by the start-up are negative (i.e., $\pi_s^c < 0$) or alternatively if start-up intellectual property rights are weak (each of which causes a reduction in τ). This is likely to be the case if an innovation is not drastic or if the sunk costs of product market entry are prohibitively high. Thus, as the impact of start-up innovation on incumbent profits may be positive, incumbent R&D expenditure may be *decreasing* in the level of start-up innovation.

The possibility of strategic substitutability between the incumbent's R&D expenditures and those of start-up's rests on the possibility that cooperative options (licensing or acquisition) are chosen over competitive ones (i.e., product market entry). Gans, Hsu and Stern (2002) provide the only empirical analysis of this issue in the context of start-up innovation. They found that cooperative options were widespread but that the choice of cooperation over contracting was driven by a number of environmental factors. Consistent with the Gans and Stern (2000) model, they found that stronger intellectual property rights and a greater importance of incumbent complementary assets (i.e., high start-up product market entry costs) were associated with cooperation. In addition, start-ups who were funded by private venture capitalists were more likely to cooperate than those funded by say government programs. Their results suggest that industry-based characteristics of the commercialisation environment play an important role in the cooperation/competition choice and hence, in the nature of the strategic relationship between incumbent and start-up innovation.

The economics literature of innovation racing and commercialisation strategy suggests that while the strategic relationship between incumbents and start-ups will depend on characteristics specific to an industry that relationship may be positive or negative between start-ups and individual incumbent firms. In contrast, the literature does provide a general prediction that incumbents will engage in innovation racing with their industry rivals. For this reason, we focus our attention on industry specific interactions between individual incumbents and start-up activity in their industry broadly defined. Nonetheless, we also will take into account the R&D expenditures of rival firms in the same industry as a potential control both for their own rivalry as well as potential similarities in their activities that is driven by changes in technological opportunities.

3. Data

We examine the drivers of R&D expenditures by 31 incumbent firms across three broad industry classes: (i) computers and office equipment; (ii) electronics and electrical equipment; and (iii) pharmaceuticals – in the period 1979 to 1997. The choice of the sample period reflects the availability of consistent data for both incumbent and start-up firms.

Among Fortune 500 firms ranked by sales performance, there are 23 incumbents in the computers and office equipment industry, 33 in the electronics and electrical equipment industry and 15 pharmaceutical companies. Our dataset for these companies was from *Compustat* and a complete series (in terms of key variables such as R&D expenditures, sales and profit) was only available for 8, 15 and 8 companies, respectively. These form the 31 incumbents that are the focus of this study.[2] Note that our sample comprises the largest firms in those industries.

The data source for start-up firms comes from *Venture Economics* (1979 to 1997). This provides data on the level of funding given to start-up firms that we take as a proxy for their R&D expenditures. Many start up firms received funds from venture capitalists for multiple years based on its stage of financing. Since our study focuses on amount of research and development expenditures of start-up firms in total, *not* start-up firms individually, then we treat a firm with financing in multiple stages in the same year as a one firm. Furthermore, for a firm that received financing in more than one year, we treat every transaction as a distinct firm. Accordingly, we have 7,010 start-up firm financing observations for period 1979-1997.

The time series data on total research and development expenditures at the aggregate level for the incumbent companies follow a consistent positive trend, while research and development expenditures of venture-backed start up firms are more variable. Figures 1 and 2 illustrate these looking at aggregate expenditures in our sample. Notice that the proportion of total R&D expenditure on the sample by start-ups is around 10 percent over the life of the series. Small but important enough to have a potential impact on incumbent strategic behaviour.

---

[2] Those companies are: (1) in computer and office equipment: Data General, Digital Equipment, Hewlett-Packard, IBM, SCT, Unisys, Wang and Western Digital; (2) in electronics and electrical equipment: AMP, Cooper Industries, Emerson Electric, GE, Intel, Litton, Molex, Motorola, Raychem, Raytheon, Rockwell International, Texas Instruments, Thomas & Bretts, Vishay Intertechnology and Whirlpool; and (3) in pharmaceuticals, Abbott Laboratories, American Home Products, Bristol Myers Squibb, Merck, Pfizer, Schering-Plough and Warner-Lambert.

Figure 1. Aggregate R&D expenditures by Incumbents

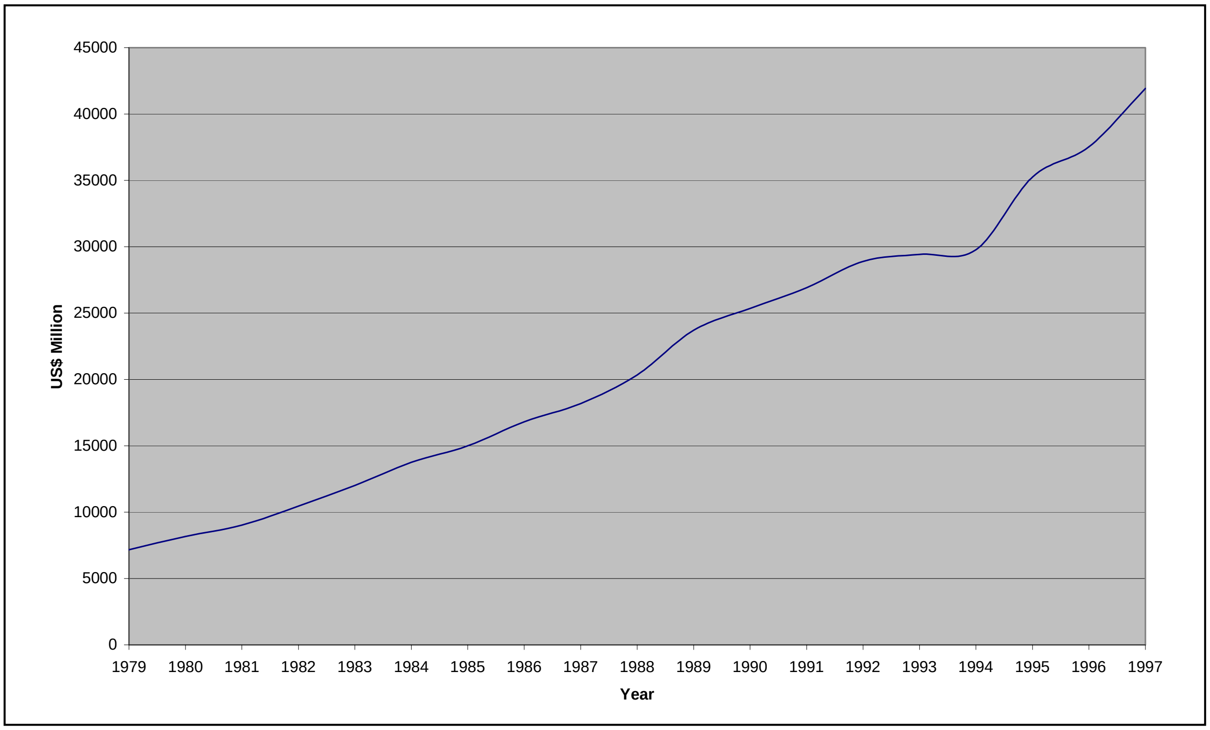
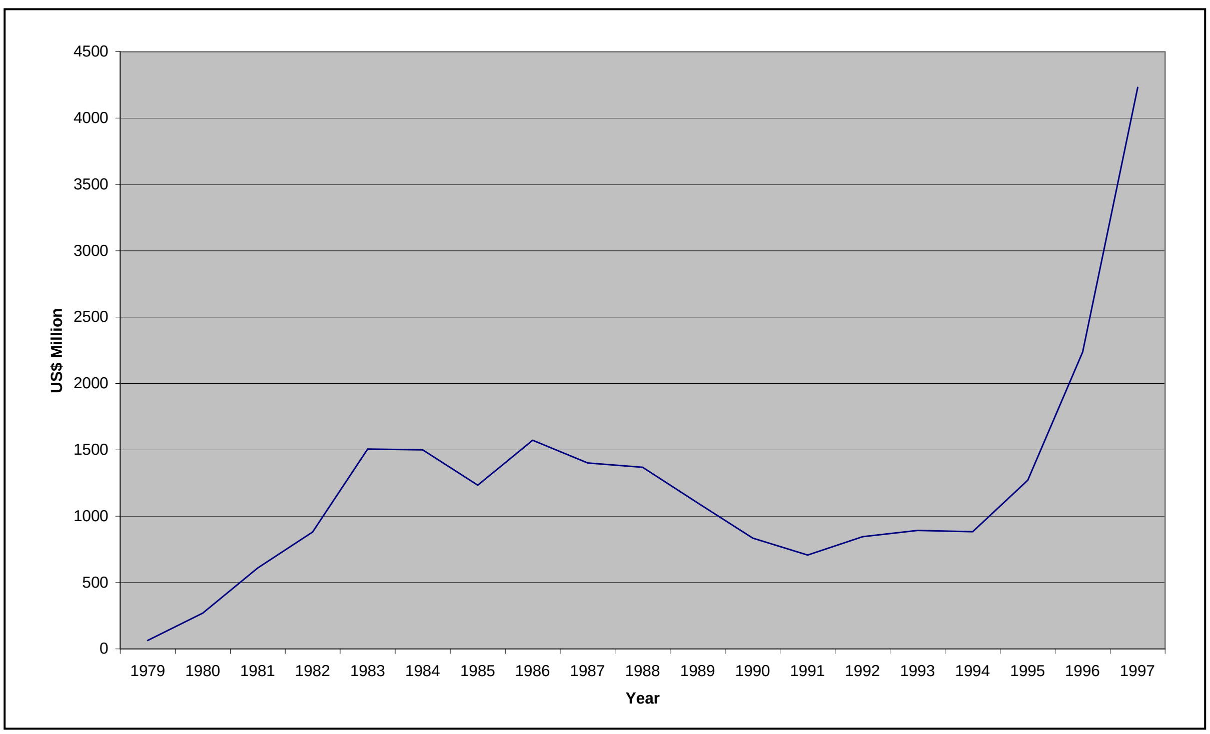


Figure 2: Aggregate R&D expenditures by Start-Ups



Definition of Variables

This study focuses on the individual incumbent behavior in managing its research and development performance. We use research and development intensity ($RDINTENS_{i,t}$: R&D expenditures divided by sales for firm *i* in year *t*) as a proxy to represent individual incumbent research and development activity; a variable commonly used in empirical studies of innovative activity.

As the focus of the analysis is on the impact of the R&D expenditures of start-up firms on incumbent R&D strategies, we develop an index ($RDINDEX_{J,t}$) based on the venture capital finance flowing into industry *J* in year *t*. We interpret a higher value for this index to be representative of more intense is start-up research and development activity at the industry level. However, as start-up innovation in computer hardware and semiconductors likely relates to innovation both in computers and office equipment and electronics and electrical equipment, the $RDINDEX_{J,t}$ for these incumbents is aggregated across computer hardware and semiconductors. Thus, our analysis below considers two groups of start-ups: computer related and biotechnology.[3]

Finally, we need to control for common drivers of the levels of incumbent R&D expenditure and the start-up R&D index for each broad industry. In this regard, we control for the degree of technological opportunity by utilising the average R&D intensity of all incumbents (other than *i*) under the same two digit SIC code (defined as $CRDINDEX_{i,t}$). Second, in order to account for that part of R&D intensity that may be due to normal business practice and avoid bias, profit intensity (as a proxy for the incumbent's returns from innovation commercialization) is included as a control. The variable, $PROFINTENS_{i,t}$ is defined by dividing after tax profit by sales for firm *i* in year *t*.

It should be noted that we take these key variables and test whether the time series are stationary. Using an Augmented Dickey Fuller test we were able to reject the hypothesis of a unit root in each time series. Nonetheless, as will be described below, in accordance with theory, we examine the impact of changes in the index of start-up

[3] However, we continue to distinguish between incumbents across the three broad classes: especially as they relate to competitive interactions amongst one another and any controls used.

expenditures on changes in R&D intensity of individual incumbent firms, thereby, further reducing any concerns regarding autocorrelation.

4. Estimation Procedure

We now turn to describe our estimation procedure. To test the prediction that start-ups and incumbents engage in innovative racing, we test the null hypothesis that there is no strategic relationship between research and development activities of incumbent and research and development activities of start up firms and research and development efforts of competitors. This is done by considering the following estimation equation:

$$DY_{i,t} = \gamma_i + \theta_{1,i} DX_{J,t-1} + \theta_{2,i} Z_{i,t-1} + \theta_{3,i} DCY_{i,t-1} + \upsilon_{i,t} \qquad (1)$$

where

$$DY_{i,t} = \mathrm{RDINTENS}_{i,t} - \mathrm{RDINTENS}_{i,t-1},$$
$$DX_{i,t-1} = \mathrm{RDINDEX}_{J,t-1} - \mathrm{RDINDEX}_{J,t-2},$$
$$Z_{i,t-1} = \mathrm{PROFINTENS}_{i,t-1}, \text{ and}$$
$$DCY_{i,t-1} = \mathrm{CRDINTENS}_{i,t-1} - \mathrm{CRDINTENS}_{i,t-2}.$$

Thus, for each incumbent firm we are trying to explain the drivers of the changes in its R&D intensity from year to year. Our chief focus is on start-up innovation levels and changes in this but we also control for the profit intensity of the incumbent in the previous period as well as the average level of R&D intensity by firms other than the incumbent in the same industry. The lagged structure is to take into account the notion that strategic changes in R&D expenditures may take some time following an observation of R&D elsewhere as well as the re-investment of profits. We continue to use the one year lag structure for all presented results below but the qualitative outcomes did not change for various alternatives up to 3 years.

Since we use time series data, it may be inappropriate to assume that the error terms are serially independent. Accordingly, we assume that $\upsilon_{i,t}$ has an AR(1) structure:

$$\upsilon_{i,t} = \rho \upsilon_{i,t-1} + \varepsilon_{i,t} \qquad (2)$$

where $\rho \in (-1,1)$ is the coefficient of auto-covariance and $\varepsilon_{i,t}$ is a random error term distributed i.i.d with 0 mean and variance, $\sigma^2_{\varepsilon_{i,t}}$. This is a reasonable assumption in that R&D activity generally has a cumulative nature and in this way our estimation procedure allow for that.

Finally, in estimating (1) and (2) we utilise the seemingly unrelated regression (SUR) method. Ordinary least squares (OLS) for this sample size would make it difficult to obtain precise estimates of the coefficients in (1) for each incumbent. Moreover, the error terms for an incumbent may be contemporaneously correlated with those for incumbents in the same industry.[4] Given this, it is more efficient to estimate all equations jointly, rather than to estimate each one separately using OLS (Zellner,1962)[5]. In using SUR, we can test and isolate firm-specific variables influencing the interaction between R&D intensity of incumbent companies and R&D expenditures of venture-backed start up firms.[6]

5. Empirical Results

We are now in a position to report our main empirical finding: namely, that our index of venture capital funds to start-up firms, overall, appears not to have a significant impact on incumbent R&D expenditures. Table 1 reports our main regression result. As alternative specifications yielded the same qualitative outcomes, we focus on that table alone.

Note first that our controls are in general significant and of the expected sign. In particular, our proxy for technological opportunity and innovation competition between incumbents (the average R&D intensity of other incumbents in the industry) are highly significant and positive for half of the incumbents studied and a positive coefficient for the remainder. For this reason, we state results with those controls included as these were the most robust to minor changes in specification.

[4] Indeed, tests on OLS results not reported here demonstrated that this was the case.
[5] In fact, this study has similarity to Zellner (1962)‘s study. First, both studies study investment behaviour at the firm level. Second, both studies face contemporaneous correlation between error terms of each firm.
[6] Of course we account for the fact that under our AR(1) error specification, the residual covariance matrix is difference from the standard SUR.

The key result is on the index of venture capital expenditures for start-up firms; our proxy for their aggregate level of research activity in similar technologies. The results on this coefficient are mixed with no consistent relationship between start-up and incumbent R&D across incumbent firms. For incumbents in the computer industry, one firm (SCT) had a positive and significant correlation with start-up expenditures while two had significant but negative correlations (Unisys and Data General). For the remainder, all but Digital Equipment, had insignificant but negative coefficients.

A similar pattern of insignificance occurred in the electronics industry with only Texas Instruments (positive) and Intel (negative) have significant correlations with start-up innovation. The Intel example is interesting as there is anecdotal evidence that it is a firm that favourably deals with start-up entrepreneurial firms in markets of ideas (Gans and Stern, 2003). This pattern is consistent with that evidence in that when established firms can more easily deal with start-ups in procuring the results of innovative activity, we expect there R&D activities to be strategic substitutes (Gans and Stern, 2000).

In the pharmaceutical industry, an industry said to be heavily impacted upon by start-up innovators, the coefficients for most incumbents were negative (the exceptions being American Home Products and Johnson and Johnson) but only two were significant (American Home Products and Merck). Thus, biotechnology start-ups as a whole do not appear to be putting pressure on large pharmaceutical firms to raise their R&D game. One reason for this is heterogeneity in the degree of intellectual property protection that may impact on a more disaggregated project or product based analysis than that done here (Gans, Hsu and Stern, 2002; Gans and Stern, 2003). Interestingly, however, this result is consistent with Cockburn and Henderson’s (1994) micro-level study of strategic interaction between pharmaceutical firms and biotechnology start-ups. They too failed to find evidence of a strategic influence on pharmaceutical firms arising from start-up activity.

These results may arise from the linear structure of the model. We did consider alternative specifications involving a common intercept, common coefficients for control variables, control variables with polynomial (square and cubic), inter-firm restrictions on coefficient of control variables, restriction within individual incumbents and structural break with year 1995 as a break year because there are a big jumps of research and development spending by venture-backed start up firms in this year. However, this did not give rise to any consistent pattern of strategic interdependence either across firms or within firms in a given industry class.

Of course, the aggregated nature of our industry and start-up activity classifications may account for the lack of a consistent finding. Only a more micro-level study could unpack that as an issue. In addition, it may be the incumbents and start-up firms are pursuing more complementary research programs but even in that case some strategic interaction may have appeared.

6. Conclusion

This study represents a first cut examination of strategic interaction between start-up innovative activity and the R&D strategies of incumbent firms. While many commentators have suggested that start-ups would put pressure on incumbent firms to raise R&D expenditures and innovate more aggressively (especially over the 1980s and 1990s; the period of our sample), we have not been unable to uncover evidence of such a relationship.

That said, given their aggregated nature our findings should be interpreted cautiously. However, there is no clear strategic pattern of impact of aggregate start-up activities on the overall R&D strategy of established firms. This suggests that simplistic views of their impact on the overall nature of technological competition need to be examined properly and that more nuanced theories about the interaction of these firms in markets for ideas may generate a clearer picture. Delineating this is left for future research.

Table 1: Seemingly Unrelated Regression Results

Table 1.4 Seemingly Unrelated Regression results

	Fixed	Z(-1)		DX(-1)		DCY(-1)		Adjusted
	Effects	Coefficient	SE	Coefficient	SE	Coefficient	SE	R-squared
Computer industry								0.792413
DE	-0.002094	2.024166***	0.323101	0.007402	0.005149	0.139405**	0.181699	
DG	-0.000150	25.37952***	4.668681	-0.013987*	0.007253	0.533446	0.251613	
HP	-0.003058	-0.646810	0.948449	-0.005352	0.005232	0.553688***	0.181214	
IBM	-0.004286	0.309971***	0.043936	-0.002053	0.004980	0.307887***	0.114417	
ST	0.001212	15.77683***	2.295004	0.022532**	0.009889	0.168092	0.317294	
UC	-0.000955	2.210344***	0.305836	-0.006758**	0.002571	0.228608***	0.083878	
WL	0.065177	-5.506946	15.32503	-0.017068	0.014547	1.488667***	0.419432	
WD	-0.003778	2.473093	3.353015	-0.000468	0.013323	0.228755	0.520527	
Electronics Industry								0.621479
AMP	-0.001669	10.73423***	2.136918	-0.001897	0.003390	0.514947***	0.186425	
CI	0.007570	-0.668446***	0.207238	0.001315	0.001097	0.152113**	0.081084	
EL	0.001628	0.633772	0.902174	0.000667	0.000693	0.065137	0.057099	
GE	0.002400	-0.211044**	0.112536	0.002060	0.001964	0.017455	0.060662	
IC	0.036082	0.730640	0.702300	-0.037998**	0.016828	1.222821	1.707596	
LI	0.024882	-1.107502**	0.625334	-0.003932	0.004669	0.648585**	0.324584	
MO	0.002020	-12.94141	12.29265	-0.005666	0.004300	0.112133	0.354946	
MOTR	0.037181	1.303216***	0.357154	-0.005025	0.004807	1.312474***	0.398592	
RCM	0.094189	5.693361	4.159124	0.010381	0.009526	2.534307***	0.575423	
RTN	0.021544	-1.726025**	0.889981	0.003004	0.002595	0.414161**	0.173347	
RWL	0.012957	-1.840150***	0.343830	0.011255*	0.005843	0.227870	0.519105	
TI	-0.016556	40.07200***	5.196423	0.008028***	0.002402	0.165534	0.212368	
TB	-0.046465	8.005040***	0.587796	0.011553	0.007895	1.001429	0.553907	
VI	-0.035847	-28.31541	20.85151	0.004311	0.007077	0.938304	0.661708	
WPL	-0.012548	3.076005	0.406355	0.001746	0.001675	0.317637	0.103257	
Pharmaceutical industry								0.686415
AHP	0.015693	-1.206628**	0.484061	0.003822*	0.002264	0.190897**	0.083770	
AL	0.004258	-0.554860	0.674930	-0.001848	0.002011	0.094143	0.158852	
BMS	0.011784	0.435535**	0.182589	-0.002213	0.003512	0.223728**	0.125392	
JJ	0.005967	0.020643	0.093756	0.000218	0.001810	0.079998	0.050297	
MRC	0.022765	0.719893***	0.259830	-0.008266*	0.004515	0.593574***	0.153332	
PFZ	-0.003265	-0.062165	0.048043	-0.000303	0.000951	0.153100***	0.035382	
SP	0.012176	0.174707	0.534371	-0.001894	0.002643	0.132303	0.083258	
WLB	0.011352	0.255826***	0.085338	-0.002113	0.002309	0.178911***	0.067820	

* denotes statistically different from zero at the 10% level.

** denotes statistically different from zero at the 5% level.

*** denotes statistically different from zero at the 1% level.

DX(-1) denotes first difference of RDINDEX(-1)

Z(-1) denotes PROFINTENS(-1) on level

DCY(-1) denotes first difference of average of all competitors' research and development intensity under the same four digit SIC code

RDINDEX data source is Venture Economics

References

Acharya, R. (1999), *The Emergence and Growth of Biotechnology*, Cheltenham, Edward Elgar.

Acs, Z.J., and D.B. Audretsch (1988), "Innovation in Large and Small Firms: An Empirical Analysis." *American Economic Review*, 78 (4): 678-690.

Acs, Z.J. and D. B. Audretsch. (1987). "Innovation, Market Structure and Firm Size." *The Review of Economics and Statistics* 69 (4): 567-574.

Allen, T.J. (1977). *Managing the Flow of Technology*. Cambridge, MA, MIT Press.

Appiah-adu, K., and A. Ranchhod (1998). "Market Orientation and Performance in the Biotechnology Industry." *Technology Analysis and Strategic Management* **10**(2): 197-210.

Barry, C.B., Muscarella, Chris J., Peavy III, John W., and Michael R. Vetsuypens (1990). "The Role of Venture Capital in the Creation of Public Companies: Evidence From The Going Public Process." *Journal of Financial Economics* **27**: 447-471.

Baum, J.A.C., T. Calabrese and B.S. Silverman (2000). "Don't Go It Alone: Alliance Network Composition and Startups' Performance in Canadian Biotechnology." *Strategic Management Journal* **21**: 267-294.

Bergemann, D., and U. Hege. (1998). "Venture Capital Financing, Moral Hazard and Learning." *Journal of Banking and Finance* **22**: 703-735.

Black B.S., and R.J. Gilson. (1998). "Venture Capital and the Structure of Capital Markets: Banks versus Stock Markets." *Journal of Financial Economics* **47**: 243-277.

Bound, J., C. Cummins, Z. Griliches, B.Hall and A. Jaffe (1984). Who Does R&D and Who Patents? *R&D, Patents and Productivity*. Z. G. (ed.). Chicago, University of Chicago Press**:** 21-54.

Brav, A., and P.A. Gompers (1997). "Myth or Reality? The Long-Run Underperformance of Initial Public Offerings: Evidence from Venture and Non-venture Capital-backed Companies." *Journal of Finance* **52**(5): 1791-1821.

Bygrave, W.D. and J.A. Timmons. (1992). *Venture Capital at the Crossroads*. Boston, Harvard Business School Press.

Chandler, A.D. (1997). The Computer Industry: The First Half Century. *Competing in the Age of Digital Convergence*. D. B. Yoffie. Boston, Harvard Business School Press.

Christensen, C.M. (1997). *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. Boston, Harvard Business School Press.

Cockburn, I and R. Henderson (1994). "Racing to Invest? The Dynamics of Competition in Ethical Drug Discovery." *Journal of Economics and Management Strategy*, 1994, **2**(3), pp. 481-519.

Cohen, W.M., R.C. Levin, and D.C. Mowery (1987). "Firm Size and R&D Intensity: A Re-Examination." *Journal of Industrial Economics* **35**(4): 543-565.

Cohen, W. M. and D.A. Levinthal (1990). "Absorptive Capacity: A New Perspective on Learning and Innovation." *Administrative Science Quarterly* **35**: 128-152.

Dasgupta, P. and J. Stiglitz (1980). "Uncertainty, Industrial Structure and the Speed of R&D." *Bell Journal of Economics* **11**: 1-28.

Degnan, S.A. (1999). "The Licensing payoff from US R&D." *Research Technology Management* **42**(2): 22-25.

Dell, M., and C. Fredman (1999). *Direct from Dell*. New York, Harper Business.

Fisher, F.M., and P. Temin (1973). "Returns to Scale in Research and Development: What Does the Schumpeterian Hypothesis Imply?" *Journal of Political Economy*: 56-70.

Gans, J.S., D.H. Hsu and S. Stern (2002). "When Does Start-up Innovation Spur the Gale of Creative Destruction?" *RAND Journal of Economics*, 33 (4): 571-586

Gans, J.S., and S. Stern (2000). "Incumbency and R&D Incentives: Licensing the Gale of Creative Destruction." *Journal of Economics and Management Strategy* **9**, Issue 4: 485-511.

Gans, J.S. and S. Stern (2003), "The Product Market and the 'Market for Ideas': Commercialization Strategies for Technology Entrepreneurs," *Research Policy*, 32 (2): 333-350.

Gompers, P. A. (1996). "Grandstanding in the Venture Capital Industry." *Journal of Financial Economics* **42**: 133-156.

Gompers, P. and J. Lerner (1997). "Conflict of Interest and Reputation in the Issuance of Public Securities: Evidence from Venture Capital." *Working Paper*, Harvard Business School.

Grabowski, H. G. (1968). "The Determinants of Industrial Research and Development: A Study of Chemical, Drug and Petroleum Industries ." *Journal of Political Economy* **76**: 292-306.

Grabowski, H. G. and N. D. Baxter (1973). "Rivalry in Industrial Research and Development." *Journal of Industrial Economics* **21**: 209-235.

Hambrick, D.C., I.C. MacMillan, *et al.* (1983). "Business Unit Strategy and Changes in the Product R&D Budget." *Management Science* **29**: 757-769.

Hay, D.A. and D.J. Morris (1991), *Industrial Economics and Organization, Theory and Evidence*, New York, Oxford University Press

Hellman, T., and Manju Puri (1999). "Venture Capital and the Professionalization of Start-up Firms: Empirical Evidence." *Working Paper*, Graduate School of Business, Stanford University.

Ho, M. (1998). “Biotechnology.” *Institutional Investor*: 15-16.

Hsu, D. (2003). “Do Venture Capitalist Affect Commercialisation Strategies at Start-ups?” *Journal of Finance*, (forthcoming).

Hubbard, R.G., A.K. Kashyap, *et al.* (1995). “Internal Finance and Firm Investment.” *Journal of Money, Credit and Banking* **27**(3): 683-701.

Hubbard, R.G. (1998), Capital Market Imperfections and Investment, *Journal of Economic Literature* **36**:193-225

Hundley, G., C.K. Jacobson, *et al.* (1996). “Effects of Profitability and Liquidity on R&D Intensity; Japanese and US Companies Compared.” *Academy of Management Journal* **39**(6): 1659-1674.

Jain, B. and O. Kini (1994). “The Post-issue Operating Performance of IPO Firms.” *Journal of Finance* **49**: 1699-1726.

Jensen, G.R., and J.M. Johnson, The Dynamic of Corporate Dividend Reductions, *Financial Management* **24**:31-51

Jolly, V. K. (1997). *Commercializing New Technologies*. Boston, Harvard Business School Press.

Kaplan, S.N., and P. Stromberg (2000). “Financial Contracting Theory Meets the Real World: An Empirical Analysis of Venture Capital Contracts.” *Working Paper*, no. 7660, NBER: Cambridge, MA.

Katz, M.L., and C. Shapiro, R&D Rivalry with Licensing or Imitation, *American Economic Review* **77**(3): 402-420

Kortum, S., and J. Lerner (1998). “Does Venture Capital Spur Innovation.” *Working Paper*. Harvard Business School.

Kortum, S and J. Lerner. 2000. “Assessing the Contribution of Venture Capital to Innovation.” *Rand Journal of Economics*, 31, pp. 674-92.

Lee, T. and L. Wilde. (1980). “Market Structure and Innovation: A Reformulation.” *Quarterly Journal of Economics* **194**: 429-436.

Lerner, J. (1993). “Venture Capitalist and the Decision to Go Public.” *Journal of Financial Economics* **35**(3): 293-316.

Lerner, J. (1997). “An Empirical Exploration of a Technology Race.” *RAND Journal of Economics* **28**(2): 228-247.

Lerner, J. and R.P. Merges (1997). Patent Scope and Emerging Industries: Biotechnology, Software and Beyond. *Competing in the Age of Digital Convergence*. D. B. Yoffie. Boston, Harvard Business School Press.

Link, A. N., Terry. G. S., and S. R. Woodbery (1988). “Firm Size and R&D Spending:Testing for Functional Form.” *Southern Economic Journal* **54**(4): 1027-1032.

Marx, L.M. (1998). “Efficient Venture Capital Financing Combining Debt and Equity.” *Review of Economic Design* **3**: 371-387.

Megginson, W.C., and K.A. Weiss (1991). “Venture Capital Certification in Initial Public Offerings.” *Journal of Finance* **46**: 879-893.

Munsters, J. A. and A. T. Rad. (1994). “Initial Public Offerings and the Role of Venture Capitalists in the Netherlands.” *Journal of International Financial Markets, Institutions & Money* **4**(3-4).

Oliver, R. W. (2000). *The Coming Biotech Age: The business of Bio-materials*. New York, McGraw-Hill.

Pavitt, K., M. Robson, and J. Towsend (1987). “The Size Distribution of Innovating Firms in the UK:1945-1983.” *Journal of Industrial Economics* **35**(3): 297-316.

Reinganum, J.F. (1983). “Uncertain Innovation and the Persistence of Monopoly.” *American Economic Review* **73**(4): 741-748.

Reinganum, J.F. (1989). On the Timing of Innovation. *Handbook of Industrial of Organization*. R. Schmalansee. and R. D. Willig. Amsterdam, North Holland. **Vol.1:** 849-908.

Repullo, R., and Javier Savarez (1998). “Venture Capital Finance: A Security Design Approach.” *Working Paper*, No. 9804, CEMFI.

Rivette, K.G. and D. Kline (2000). *Rembrandts In The Attic*. Boston, Harvard Business School.

Rosen, R.J. (1991). “Research and Development with Asymmetric Firm Size.” *The Rand Journal of Economics* **22**(3): 411-429.

Sahlman, W. (1990). “The Structure and Governance of Venture Capital Organizations.” *Journal of Financial Economics* **27**: 473-522.

Santarelli, E. (1995). *Finance and Technological Change, Theory and Evidence*. London, Macmillan Press.

Scherer, F.M. (1965). “Firm Size, Market Structure, Opportunity and the Output of Patented Inventions.” *American Economic Review* **55**: 1097-1123.

Scherer, F.M. (1984). *Innovation and Growth*. Cambridge, The MIT Press.

Schumpeter, J.A. (1943). *Capitalism, Socialism and Democracy*. London, Unwin University Books.

Schwert, G.W. 2002. “Stock Volatility in the New Millenium: How Wacky is Nasdaq?” *Journal of Monetary Economics*, 49, pp. 3-26.

Sim, C.A. (1972). “Money, Income and Causality.” *American Economic Review* **62**(1): 540-552.

Soete, L.L.G. (1979). “Firm Size and Inventive Activity: The Evidence Re-considered.” *European Economic Review* **12**: 319-340.

Torrisi, S. (1998). *Industrial Organisation and Innovation*. Cheltenham, Edward Elgar.

Trester, J.J. (1998). “Venture Capital Contracting under Asymmetric Information.” *Journal of Banking and Finance* **22**: 675-699.

Warshofsky, F. (1994). *The Patent Wars: The Battle to Own the World's Technology*. New York, John Wiley.

Zellner, A. (1962). "An Efficient Method of Estimating Seemingly Unrelated Regression Equations and Tests for Aggregation Bias." *Journal of the American Statistical Association* **57**: 348-368.