THE DETERMINANTS OF FIRM INNOVATIVE BEHAVIOUR: THE ROLES OF RIVALRY AND PERSISTENCE

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Abstract

This paper studies the determinants of innovative activity using an analytical framework that synthesises different views on this subject and an empirical testing that draws upon a detailed firm-level dataset from the UK computer sector. At the heart of the synthesis of different views is the idea that competition or rivalry can be defined both in terms of market power and in terms of the distribution of competencies. The latter definition also contains the clue to how and why innovation occurs and what might be its impact on post-innovation market structures and persistence in innovation. The empirical analysis finds that the determinants and dynamics of innovation and market structure are different between software and hardware firms, as is the role of persistence. Both notions of competition and the resources required for innovation explain the extent of innovative behaviour. However, persistence is important when it is the resources and costs of innovation that explain innovative behaviour. Rivalry as a determinant of innovation does not favour persistence.

Keywords: Determinants of Innovation, Market Structure and Innovation, Evolutionary Models of Technological Change, Persistence in Innovation, Computer Industry, Tobit Models.

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THE DETERMINANTS OF INNOVATIVE BEHAVIOUR: THE ROLES OF RIVALRY AND PERSISTENCE

Two notions of competition underlie much of the literature on the determinants of innovative activity. One conceptualisation of competition between firms distinguishes sharply between price-based competition and non-price competition based on some degree of market power. Rivalry among firms is the term employed to designate the latter, where firms compete with each other but on the basis on some price-making power allowed by a smaller number of competitors in the product market. Rivalry induces non-price competition among firms of which innovation is an important outcome (Schumpeter 1939, Scherer 1967). The higher profits under monopolistic rivalry and in oligopolistic markets (achieved through a restriction in outputs relative to the price competition situation) also increases the ability of firms to undertake expenditures that are inputs to innovative activity, such as R&D expenditures (Galbraith 1952, Cohen and Klepper 1996).

A more recent literature has suggested that firms compete on the basis of asymmetric or different abilities. This is a different interpretation of competition that does not rely upon the number of firms or market shares. Rather in this second notion of competition, it is the distribution of abilities of firms in a market that determines the intensity of competition and of rivalry.[1] Further it is argued that this distribution matters for explaining innovative behaviour and also post-innovation market structure. Competition selects the more able firms. Firms innovate on the basis of their cumulative learning and their unique organisational abilities. Firms that innovate accumulate considerable competencies that generate further innovation. Thus, not only does innovation occur due to competition on the basis of unequal abilities between firms, but once innovation has occurred it confers lasting advantages to innovating firms which strongly differentiate them from their rivals (Nelson and Winter 1982, Dosi 1988), thus affecting market structure even further. The characteristics of innovative behaviour stressed in this literature are the importance of cumulative learning within the firm, the presence of strong asymmetries between firms due to cumulative learning, and lastly, over time the persistence of innovating activity. Persistence and the sort of cumulative asymmetries that are posited in evolutionary models of firm growth require the domination of innovation and learning within the firm over imitation and learning by rival firms (Metcalfe and Lissoni 1993:23). Positing unequal abilities of firms is not sufficient to such an outcome. Empirical work on persistence in innovations has been equivocal, and has usually shown low probabilities for observing persistent innovative behaviour.

This paper is an empirical study of the importance of competition and persistence in explaining innovative behaviour by firms. We study the importance of rivalry and competition, defined both in terms of market shares of competitors, and the relative competence of rival firms, in explaining innovative behaviour by a firm. We also use a different empirical approach to study when persistence is important in explaining the changes in innovative behaviour. Unlike previous studies we do not ask what percentage of innovators in time *t* also innovate in time *t+1* and consequently how much of persistence is observable.[2] Instead, our search is to assess when or along what dimensions may we expect to see the importance of persistence. Given the determinants of innovative behaviour, the empirical analysis evaluates what proportion of the marginal change in the extent of innovation, due to each factor, comes from firms that are already innovating, and what proportion is due to the changes in the probability of innovating. Where the former element is dominant we can infer the importance of persistence for that determinant of innovative behaviour.

The statistical analysis in this paper uses data on the UK computer sector generated through a firm-level survey. The remainder of the paper is organised in the following way. Section 1 outlines briefly our perspective on the main determinants of innovative activity considered in the literature in this area. Section 2 outlines the data and statistical methodology employed in the paper. Section 3 contains an analysis of the results and section 4 concludes.

1. The Determinants of Innovation

1.1. Pre-innovation market structure and innovative behaviour

Different kinds of theoretical rationale have been advanced for believing that initial levels of market concentration may have an impact on the introduction of new innovations. The first is that being a price taker on the product market the competitive firm has an incentive to introduce a new process innovation because it can retain the entire difference between marginal revenue and the reduced marginal cost consequent upon the innovation. In contrast the monopolist can only sell a larger output by reducing the price of the additional units, as the monopolist faces a downward sloping demand curve on the product market. Therefore as marginal costs decrease so does the marginal revenue, which makes the impact on overall profitability due to innovation less easy to predict in imperfect markets.

The pre-innovation restriction of output under monopoly relative to competition means that the benefits of innovation are spread over fewer units of output for the monopolist when compared to a competitive firm. As Martin (1994: 359) points out, the same argument does not hold if the size of market under competition was less than the size of market under monopoly. For the same cost functions, the larger market size under monopoly would mean that the cost reduction under monopoly would now be spread over many more units of output than under competitive conditions, making the incentive to innovate higher under monopoly when the market size under monopoly is larger. With this reasoning, the influence of market structure upon the incentive to innovate depends upon market size rather than on market power alone. Careful empirical work (for example, Scott 1984) has also shown that the relation between oligopolistic market structures and innovation disappears when demand conditions and technological opportunity are controlled for.

A second rationale that favours pre-innovation monopoly as an incentive to innovate relies on a more dynamic conception where entry of new firms is allowed. Monopolies earning supernormal profits may attract entrepreneurs who might enter the market bearing new innovations whatever the market size. As Arrow (1962) argued the new entrant benefits from the higher existing profit levels under monopoly (relative to competition) as well as the cost reduction afforded by the new innovation and so has every incentive to innovate.

1.2. Complementary strategies and costs of innovation

When innovations are made a function of the costs of innovation rather than of entrepreneurship alone, there are strong reasons for believing that imperfect markets and rivalry have a decisive advantage in the generation of innovations. If there are predictable costs associated with innovation (such as R&D costs) it seems likely that firms earning supernormal profits will be the ones more able to undertake the costs associated with innovating. Firms facing monopolistic and oligopolistic structures thus may have a greater *ability* to undertake innovation. This argument was made most forcefully in Galbraith's (1952) work. More recently, Cohen and Klepper (1995) have argued that a large firm has an advantage in terms of R&D spending vis-à-vis small firms as the former can spread the costs of R&D over a larger range of output.

Another set of factors capable of determining the extent of innovation is suggested by the transactions cost literature that has emphasised the co-specialised nature of technological assets in a firm. One strategy (e.g. advertising and marketing) may thus enhance the efficiency of another (e.g. R&D spending), and so a whole range of "complementary strategies" may actually be pursued together in innovating firms.[3] That is, innovation costs of R&D will be incurred with marketing costs, with higher product design costs (Evangelista 1996) and the costs of improving the quality of human resources. Several recent studies across different national data sets have highlighted the empirical finding that innovative firms appear to pursue a wider range of strategies conjointly, when compared to non-innovative firms (Pavitt 1987, Napolitano 1991, Baldwin and Johnson 1996).

1.3. Capability gaps, post-innovation market structure and persistence in innovation

Apart from market shares that may affect the expected profitability of firms and also the ability to undertake the costs of innovation, an important aspect of competition in imperfect markets is the distribution of abilities between rival firms. For simplicity one may conceive of this dispersion of abilities as the (quantitative) gap in competence between the abilities of a firm and its rivals.[4] When, positive, the large size of this gap may be positively related to the threat of imitation by rivals, which can affect the extent of innovation that a firm is able to retain for its own benefit. Alternatively when positive, a small size of this gap can initiate a process of technological competition amongst firms. When negative, the size of this gap can initiate a process of technological catch-up and diffusion in a sector. In what follows we argue that this gap in competence is also a factor capable of influencing market structure post-innovation and persistence in innovative activity.

Imitation is likely to be rapid where competencies of rival firms are relatively similar to the competencies of the innovating firm. Once innovation has happened, rapid imitation will set into motion a period of diffusion and erode the monopolistic rents due to innovation in a manner described by Schumpeter in his early work (Schumpeter Mark 1). In the absence of substantial gaps in the competence between firms, the competition between firms approximates the text book representations which rely on representative firms each very much like the other. Further, as many studies on diffusion have indicated, diffusion is speedier the more competitive is a market. In the limit when a market is perfectly competitive, diffusion is instantaneous.

Where there is a large gap between the innovating firm and its rivals, imitation is less of a threat, and an innovating firm is able to retain its advantage and build upon its monopolistic position due to its innovating activity. It will succeed in appropriating a larger extent of the gains from innovation, in the form of larger market shares and more market power. The firm can also grow by accumulating competencies and differentiating itself ever more from its rivals. Innovating firms may characteristically have a different structure of production and organisation, and an advantage that will be reflected in the growth of the firm (Nelson and Winter 1982, Dosi 1988). In this situation, we would have the sort of large innovating firm with attendant monopoly that was described in Schumpeter's later work (Mark 2), Capitalism, Socialism and Democracy.[5] The cumulative experience of the firm will be important as a determinant of innovative activity because it enables the firm to create and retain this technological gap between itself and its rivals.[6] Persistence in innovation is possible and is likely to be intimately related to the routine undertaking of the costs and search for innovative practice that generate innovation within the firm.

An uneven distribution of competencies among firms makes the textbook picture of competition among typical representative firms an invalid representation. As many authors (Metcalfe 1998, Dosi 1988) have argued, competition in this situation of asymmetric distribution of competencies works as if it was a selection mechanism and selects one outcome (firm) over a variety (due to uneven distribution of competencies) of firms. The replicator models employed in this literature often suggest that one firm will dominate market shares if there is no new entry. Further, it is this literature that has stressed the role of persistence and positive feedback from innovation to growth to more innovation, and from innovation to firm growth to post-innovation market structure.

Despite the persuasive possibilities stressed by some of the theoretical literature (cited above), the sparse empirical literature on persistence has been equivocal. There is evidence from studies of industrial sectors that radical innovations often give rise to a cluster of innovations often within the same firm, and that firms delve into their accumulated stocks of knowledge in order to innovate. Empirical studies that have tried to assess the probability of persistent innovation have however, returned fairly low probabilities for persistence (Geroski et al 1996, Cefis and Orsenigo 1998).[7]

By focussing on the capability gap and the absence of imitation as ultimately defining the possibility of persistence we can conjecture an explanation of the results on the low probability of persistent innovation. A positive impact of innovation on growth might improve the abilities of the firm to innovate but by increasing the gap between the firm and its rivals it could also reduce the incentive to innovate due to rivalry. When the capability gap between a firm and its rivals is small, imitation is the more likely outcome, which affects the probability that any one firm will innovate again adversely. Either way the probability of persistent innovation is fairly small.

The capability gap between the innovating firm and its rivals can also explain changes in post-innovation market structure. Thus we suggested that competent rivals would cause a virtuous cycle of technological competition. But large gaps between innovators and rivals could cause innovators to retain the advantages from innovation and render market structures even more imperfect. We may expect persistence in innovation in the latter situation, but we argued not necessarily. On the related question of when we may observe persistence, we have argued that persistence in innovation must usually be associated with cumulative investments in the costs of technology, such as R&D and human resources.

To summarise this brief review: we expect pre-innovation market structure, a firm's own cumulative learning, the capability gap between a firm and its rivals, and the complementary strategies employed by the firm such as expenditures on R&D and investment in human capital to be important determinants of the firm's innovative potential. Secondly, we expect the capability gap to give us some clues about the dynamic of innovative behaviour and the role of persistence in explaining it.

2. Data, Variables and Empirical Methodology

The purpose of our empirical analysis is two-fold. Firstly, we want to understand what factors explain why some firms innovate more than others do as suggested by the review of literature in Section 1. The marginal effects due to the different factors will then allow an assessment of the importance of pre-innovation market structure and the competence of rival firms as factors influencing innovative activity above others such as R&D spending and the cumulative experience of the firm. Secondly, we also want to understand the relative importance of firms that are innovators to an explanation of the extent of innovation attributable to each of these factors. Is persistence important for factors that define rivalry or does it dominate the cost side determinants of innovation?

2.1. Data and Variables

In order to address the above objectives we consider a sample of firms that has both innovators and non-innovators, and a dependent variable that will combine information on the occurrence and extent of innovation. The data used in this paper are based on the ESRC Centre for Business Research (hereafter CBR) survey of 83 firms in the UK computer sector (hardware, diversified hardware and software/services) undertaken in 1995-96.[8] Most of this data were collected through detailed interviews with firms in different regions of the United Kingdom over a two-year period. Appendix 1 details the data used and Table A1 reports the descriptive statistics for the variables used in our analysis.

2.1.1. The dependent variable

An output measure of innovative behaviour is used as the dependent variable, and this was based upon the firms' answer to the following question: What percentage of the current sales are the result of innovations developed by your firm in the last three years (1992-95)? Since the data were collected through interviews, firms were asked to distinguish between product differentiation and innovative sales. Asking firms to first describe their innovations in products and processes made this distinction possible. Questions were also asked about what the firm thought was the innovative content of their improvements. Non-innovative firms, which did not report any sales as attributable to past innovative efforts, were recorded as zero in the construction of the dependent variable. SALES3 is thus a measure of the extent of innovation or of innovation-intensity. The measure of innovation used has the advantage of being an output measure of innovation but the disadvantage of being a subjective evaluation of a firm's innovative ability. Nevertheless we would prefer it to the more widely used input measure of innovation, viz. R&D expenditures, because the measure we use tries to discriminate between activities that are innovative and activities that are imitative. Furthermore, it is a variable that is increasingly available in innovation survey data, and lends itself to more statistical analysis than a simple count measure.

2.1.2. Explanatory variables

The first explanatory variable is a measure of pre-innovation market structure. This was the market share of every firm belonging to a particular activity field in the year 1990 (MSHAR90). The total market size of each activity field is proxied by the sum of sales of all firms assigned to the particular activity field. The variable is used in a quadratic form in the model specification as previous research (Scherer 1967) suggests that an intermediate level of rivalry is conducive to innovation. The use of a lagged variable to avoid the problem of endogeneity of market structure has however meant a reduced sample of firms for the analysis, i.e. those firms that were established after 1990 are left out of the analysis.[9]

To test the importance of accumulated firm experience and capability in the sector of activity in explaining innovative behaviour, we included a variable (AGE) which was the number of years the firm had spent in the computer business prior to 1995. This variable also captures the role of new entry in explaining innovation.

In order to assess the importance of the gap in capability we computed the difference between the firm's own productivity, in 1990, and the average productivity of all other firms in the same activity field.[10] Following Section 1.3 we may expect this gap (PRODGAP0) to be positively or negatively related to the extent of innovation depending upon whether PRODGAP0 itself is positive or negative. An additional dummy variable (DUMGAP) was introduced to pick up the influence of positive and negative observations. DUMGAP took value 1 if

PRODGAP0 was positive or equal to zero and was 0 for all negative values of PRODGAP0.

In order to test the importance of complementary activities in explaining innovative behaviour we included the following two variables as independent variables in our analysis. The first was the percentage of full time professional, scientific and managerial labour in the total full time workers of the firm. This is called PROF1. The second was the percentage of expenditures on R&D, called RD3.[11]

Two industry specific dummies were included. A dummy variable SOFT was created which took on value 1 if a particular observation came from a firm in the software/services activity group. Similarly DHARD took on value 1 if the firm belonged to the hardware sector.

2.2. Empirical methodology

We regard y* as some measure of the latent innovativeness of the firm which cannot be observed. What can be observed is the innovative content of current sales reported by firms, which depends upon y*. The dependent variable SALES3, which defines the extent of innovation, also observes the latent variable (y*). When the firm is not innovative SALES3 takes on the value 0 and so we may regard SALES3 as a censored random variable with a lower limit at 0 and an upper limit equal to 100.

$$0<y=\text{SALES3} \leq 100 \text{ when } y^*>0$$

$$= 0 \text{ otherwise.} \qquad (1)$$

Further we may postulate that:

$$y_i^* = \beta' \mathbf{x}_i + \varepsilon,$$

$$\text{when } y^*>0 \qquad (2)$$

where **x** is any (k x 1) vector of explanatory variables, and ß is the associated vector of coefficients. Following the hypotheses spelt out earlier, and the construction of independent variables elaborated in Section 2.1, we may estimate (3) using a tobit model with a lower limit at 0 and an upper limit at 100%

$y_i = \beta' \mathbf{x}_i + \varepsilon$

s.t.

when $y^*_i > 0$, $y_i = y^*_i$

when $y^*_i < 0$, $y_i = 0$ (3)

The β vector of coefficients in equation (3) do not, however, measure the effect of changes in the dependent variable (here the innovative behaviour of a firm) due to the changes in the independent explanatory factors. The marginal effects are related to the coefficient estimated in a more complicated way. This is because the tobit model has elements of the probit (the probability and changes therein of being above the limit, in our case, of being innovative) and elements of an ordinary regression (the expected level of innovation and changes therein of those who have innovated).

2.2.1. Evaluating the importance of persistence

McDonald and Moffitt (1980) have shown that the above property of Tobit models can be exploited to achieve a particular decomposition of the marginal effects due to independent factors. The authors show that the marginal effects, showing the expected actual change in y given a unit change in an explanatory variable, x_k say, can in fact be decomposed into two components as shown below:

$$\delta E(y)/\delta x_k = F(z_k)\{\delta E(y^*)/\delta x_k\} + E(y^*)\{\delta F(z_k)/\delta x_k\} \quad (4)$$

where $z_k = \beta_k x_k / \sigma$

$E(y^*)$= the expected value of y conditional upon being an innovator, i.e. from (3) when $y>0$

$F(z)$ is the cumulative standard normal distribution.

The first component of this weighted average is the effect of the expected change in the value of y (above the limit, here being an innovator) multiplied by the probability of being an innovator. The second part of the decomposition is simply the expected value of y (for firms that are innovators) multiplied by the change in the probability of being innovative.

It can also be shown that $\delta E(y^*)/\delta x_k=\beta_k A$ (5)

where $A=\{1-zf(z)/F(z)-f(z)^2/F(z)^2\}$

and that, $\delta E(y)/\delta x_k = F(z)\beta_k$, (6)

The proportion of the marginal effect that is due to $\delta E(y^*)/\delta x_k$, i.e. firms that are innovators, can now be shown to be equal to A in (5) above, and $\{1-A\}$ in contrast, is the proportion of the marginal effect that is attributable to $\{\delta F(z_k)/\delta x_k\}$, i.e. the change in the probability of innovating. These two proportions are evaluated at the point of the means of the x_k and reported in Table 5.

Statistically the use of the more restrictive Tobit model, over other models, e.g. types of double hurdle models, needs to be justified. Unlike double hurdle models which see the generation and extent of innovation as determined by two separate (if overlapping) sets of factors, Tobit models assume that the generation and extent of innovation is influenced by the same set of factors. Our justification for using the Tobit is that it is more faithful to the underlying theoretical models, which see persistence as a logical consequence of innovation and dependent on the same sorts of factors. In employing the less restrictive double hurdle models we would quickly run into problems of specification.

2.3. Treating industry differences

The computer sector consists of firms in the hardware, software and services sectors and there are significant differences between the characteristics of firms and environments in the three sub-sectors. Our activity field classification was based on the firms' selection of their fields of activity and we found it convenient to distribute firms among hardware only, software and services, and diversified firms. The last category provided hardware, software and services and offered "complete" solutions to their customers. The big differences are between firms that sell hardware only and those firms that are software/services or diversified firms. These differences emerged very clearly from the qualitative data on the competitive strategies adopted by innovators and non-innovators in the two sectors, which are briefly summarised in Table 1. Only statistically significant differences have been reported.

The statistical issue that this posed was how to treat the industry differences revealed in the Table. The standard statistical way of controlling for industry differences is to introduce a dummy variable. This involves making the rather strong assumption that the same underlying relationship between the dependent and explanatory variables is shifted up or down depending upon whether the firm belongs to the hardware or software/diversified activity field.

However, the qualitative data strongly suggested that the nature of competition and the response to it in the form of innovative activity was quite different between the two sub-sectors. In order to take account of this we divided our sample according to activity fields and ran different estimations on the same underlying variables for each group of firms. This resulted in very low numbers for the hardware sector. However, as we had expected the relationship between the dependent and explanatory variables was considerably different for two of the three activity fields.

A second problem that we encountered was the issue of segmentation of markets. The theoretical arguments we discussed in Section 1 all assume a prior knowledge of the firm and all its competitors. In doing an empirical analysis we find firms classified according to an aggregated industry code. Segmentation of markets would tend to understate a variable like MSHAR90 because we assume all other firms are rivals to the particular firm chosen.[12] Segmentation may also be reflected in a wide variance of our productivity measure, as discussed in a footnote earlier.

3. Empirical Analysis

3.1. The determinants of innovative behaviour: Tobit model results

The results of the Tobit estimation and the marginal effects are presented in Tables 2 and 3 respectively. Four different estimations are presented and these are based on the different groupings of firms. The first column reports the estimation on the group of software/services firms only, the second column includes software and services and diversified firms, the third column hardware firms only, and the last column groups all firms using dummy variables to control for industry differences.

In the aggregate, when we pool the data on all firms, and control for industry specific factors through the use of industry dummies, there is no relationship between pre-innovation market structure and the extent of innovation. In our study, this absence of a relationship is due to the different ways in which market structure impacts upon innovation in two of the three sub-sectors in our sample. In fact, when we estimate the same relationship for the three sub-sectors, we find the signs on the market structure coefficients are different, suggesting that the underlying slope relationships are quite different between the sub-sectors.

Thus, we consider the sub-sectors in the computer sector separately. In the case of software/services firms and diversified firms (columns (1) and (2) of Table 2), we find a U-shaped relationship between the extent of innovation and competition. This finding suggests that the lowest extent of innovation occurs when pre-innovation concentration of output is intermediate; but this low is achieved at a mere 8.47% of market share for software firms and 14.72% of market share for software and diversified firms. Beyond this level of market share, innovative outputs increase as market share increases. This U-shaped relationship between market structure and innovation for software/services firms is consistent with the observed importance of niche markets and small software consultancy firms as stages in the growth of software firms. Often the growth path of a typical software firm is that it starts as a consultancy, tries to establish a reputation and secure a clientele before becoming a niche player (Brady et al. 1992). Niche markets are usually very small in terms of market share. Software consultancy firms that report all their outputs as innovative represent the influence of a process of externalisation and vertical disintegration. Our data cannot distinguish between the two aspects of market structure implicit in the above discussion – the first has to do with market structure at a point of time and the second which is to do with vertical disintegration - but the U-shape relationship clearly records the two different effects.

In contrast, hardware firms (column (3) of Table 2) show that extent of innovation increases with increases in market shares. This is different from the results for the software firms but given the low market shares at which the two sub-sectors achieve their minimum it is fair to conclude that larger firms may be more innovative. This is in line with results found for the UK SME data by Cosh et al (1999). As suggested in Section 1.1 expected profitability is higher when market share is larger, in markets that are larger sized. The rapid growth of the computer sector in recent years may explain this result for pre-innovation market shares.

The influence of cumulative experience in the computer business is strongly positive and significant for software/services firms and for hardware firms. The marginal effects for the software/services group also indicates that the impact of age and experience is the second largest marginal effect explaining the extent of innovative behaviour. The results confirm the importance of firm specific learning in inducing innovative behaviour.

Of the group of variables that represent complementary strategies R&D expenditures were not statistically significant in explaining innovative behaviour in any of the three sub-sectors. This is despite the fact that mean R&D expenditures among software and diversified firms was fairly high (~14-18 % of total expenditures). The variable capturing the extent of professional and managerial employees affected innovative behaviour positively and significantly among the group of software and diversified firms but negatively and significantly among the group of hardware firms. This difference may reflect the more investment intensive nature of the hardware sector and the more human capital intensive nature of software. But it probably also reflects the influence of some large non-innovating firms in the hardware sector.

The most interesting set of results pertain to the productivity gap variables. As Section 2.1 explained we have two variables, one controlling for the positive or negative value of the productivity gap (DUMGAP) and a second variable which was simply a measure of the gap. Among the groups of software and diversified firms, the extent of the productivity gap was negatively related to the extent of innovation, suggesting that smaller gaps resulted in more innovative behaviour by firms. Further in both these groups of firms DUMGAP is not statistically significant, suggesting that innovative behaviour came from firms with positive and negative gaps, i.e. firms that were ahead or behind, but only slightly so. This suggests a process of technological competition such as that outlined in Section 1.3, due to reasonably competent rival firms. The marginal effects suggest that a £1000 unit decrease in the size of the productivity gap increased expected innovative sales by 0.7% for software firms and 0.5% for software and diversified firms.

In contrast, the hardware firms suggest a very different innovative dynamic. In this case, the size of the competence gap is positively and significantly related to the extent of innovation and further this effort comes significantly from firms that lag behind in terms of productivity (note the negatively significant coefficient on DUMGAP). This suggests a process of diffusion and catch-up, perhaps induced by the presence of large hardware subsidiary firms that are non-innovative, but whose parent firms have an international reputation for being innovative. The younger age of innovating firms in the hardware sector (see Table 4 and the discussion in section 3.2) strongly suggests such an interpretation.

3.2. Post-innovation characteristics of innovating and non-innovating firms

Table 4 presents the post-innovation (in 1995) characteristics of innovating and non-innovating firms. These characteristics are the perceptions of competition, size and age of the innovating and non-innovating firms which are noted for the two subgroups viz., the hardware, and software & diversified group of firms, separately. Here again there are important differences between the two groups of firms and these differences largely confirm our interpretation of results in Section 3.1. It can be seen that innovating software firms are somewhat larger and older, post-innovation, than their non-innovating counterparts. They seem to export larger amounts. On average it appears that innovative firms face less than half the number of competitors compared to non-innovative firms. Both these factors suggest that innovation does increase market power and market share for firms that innovate. The smaller number of competitors generally, for both innovators and non-innovators, confirms the importance of niche markets for growth in this sector. These findings together with the findings of the previous section confirm a dynamic of firms building upon the monopolistic advantage that innovation due to technological competition gives them to build distinctive capabilities and grow more. We had termed this as the Schumpeter Mark 2 pattern, elaborated by Nelson and Winter (1982) and Dosi (1988).

In contrast, in the hardware sector, innovating firms appear to face more than twice the average number of competitors, face more competition from larger firms, and also face more competition from overseas firms, relative to non-innovative firms, post innovation. Ex post innovation the market structure appears to be more competitive relative to the software sector. The characteristics of innovating and non-innovating firms, reported in Table 5, are also the opposite of what were observed for the software sector. Thus, hardware firms that are innovative tend to be younger and smaller compared to the non-innovative hardware firms. When seen along with the findings of the previous section, the suggestion is of innovation followed by rapid diffusion due to some sort of catch-up process, what we had termed the Schumpeter Mark 1 dynamics.

3.3. The relative importance of persistence

The foregoing analysis suggests the importance of the cumulative and positive feedback from innovation upon the competitive positions of firms in the software sector, relative to the hardware sector. But does this translate into the importance of persistence for all the determinants of innovation in this sector? Conversely, in the hardware sector, we found that innovators are smaller firms who also face an inordinate amount of competition. Does this mean that persistence is less important as a determinant of innovative behaviour in the hardware sector? In order to examine these questions we analyse the decomposition of the marginal effect of each determinant of innovative behaviour using the method outlined in Section 2.2 and reported in Table 5.

Across all the factors that we have considered as determining innovative behaviour the incidence of persistence was uneven. Further, there were differences between the three sectors in the incidence of persistence even for the same factor. For the factors that tried to capture rivalry and emerged as significant in the Tobit estimation, such as pre-innovation market structure and productivity gap it was the changes in the probability of innovating among firms that explained a larger proportion of the marginal effects. The capability gap, in particular, affects innovative behaviour by changing the probability of innovating. In the hardware sector large pre-innovation market shares affected innovative behaviour positively and this effect came mostly from innovating firms. However, our results for the hardware sector are much less reliable as the numbers of firms are small.

The decomposition also shows clearly that in the case of costs of innovation, be it learning in the firm or the employment of professionals, changes in innovative behaviour occur due to the efforts of firms that are innovators. Here we find that firms that are innovators explain a larger proportion of the marginal effects on innovative behaviour. The large marginal effects to these factors also suggest that the ability to undertake these costs affect the extent of innovation substantially.

Innovative behaviour is the result of a process where incentives and abilities are both important. It is fair to conclude from our results that the extent of innovation will depend upon firms already innovating, and we will observe persistence when the resources side is the dominant determinant of innovation. When competition and rivalry are the dominant factors that induce innovation, then they do so by changing the probability of innovating within a group of firms. Further it is significant that this is a result which is observable in the software sector, where some degree of cumulative benefits from innovation to growth are visible in Table 4.

4. Summary and Implications

This paper aimed to study the roles of rivalry and persistence in determining the innovative behaviour of firms. Our analytical framework tried to synthesise the insights gained from different approaches to explaining innovative behaviours. At the heart of the synthesis was the idea that competition or rivalry could be defined both in terms of market power and in terms of the distribution of competencies. The latter definition, we argued, also contained the clue to how and why innovation might impact post-innovation market structures and persistence in innovation quite differentially. Based on our synthesis we also suggested the overall probability of persistence was likely to be low, but that when it occurred persistence was likely to be related to cumulative costs of innovation.

A limited number of observations drawn from one industrial sector, and the cross-sectional rather than time series nature of our data, are weaknesses of the empirical analysis. However, despite these weaknesses, our empirical analysis appears to support our (general) conjectures about the determinants of innovative behaviour, and the possible role of persistence. Considerable differences are evident in the determinants of innovative behaviour, the effects of innovation on firm growth, and on the role of persistence between the hardware sector on one hand and software and diversified firms on the other. Pre-innovation market structure, a productivity lead over rivals, cumulative experience and investment in human capital determine innovative behaviour in the software sector. In the hardware sector market concentration, the productivity gap and age appear to determine innovative behaviour. Further, pre-innovation market structure and productivity gaps impact innovative behaviour in the two sectors in different ways.

We also found that persistence was not generally characteristic of all the determinants of innovative behaviour. To the extent that innovative behaviour was related to innovative costs and resources (professional employment, learning by firms), innovative firms accounted for a larger proportion of the marginal effects. For the other factors considered it was the changes in the probability of innovating that dominated the marginal effect. This suggests that the determinants of persistence may be directly related to the resources required for innovation but inversely related to the rivalry that induces innovation. Analysis with larger data sets drawn from other industrial sectors is needed to assess the robustness of these results.

An interesting and probably important implication of our empirical analysis is that the determinants of the extent (persistence) of innovation may be a subset of the factors that seem to influence the generation of innovation. Secondly, we have seen that the competitive strategies employed by innovating firms seem very different from the competitive strategies employed by non-innovating firms. Both of these facts suggest a different theoretical and statistical modelling of the determinants of innovative behaviour is more appropriate. Such a modelling would separate the detreminants of the generation of innovation from those of the extent of innovation. We hope this line of enquiry is pursued in future research.

APPENDIX

APPENDIX: DATA AND VARIABLES USED IN THE ANALYSIS

The evidence that is used in this paper is based on the data collected by the CBR survey of 83 firms in the UK computer sector (hardware and software/services) undertaken in 1995-96. This survey was conducted in two stages. The first stage was the sending out of a pre-interview questionnaire which asked the firms to report on factual details such as year of establishment, years of experience in the computer industry, sales, employment details, exports and R&D expenditures. In the second stage these questionnaires were followed up by detailed interviews with firms. The interview was based on a semi-structured questionnaire and addressed questions relating to innovation, competition and competitive strategies.

The sampling frame used was a random sampling frame. Some types of firms were however over sampled. The first was size, and large firms were over-sampled. The second criterion was activity fields and here we over-sampled the hardware firms. The third type of firms that were over-sampled were firms in the North and North West regions of the UK. Where we have used averages to support our conclusions such as in Tables 1 and 4, we have chosen the smaller randomly sampled data. For any analysis using MLE methods random sampling is not a requirement (Maddala 1992: 330). Table A1 provides descriptions of the variables used in the estimation and analysis of Tables 2, 3 and 5, while Table A2 reports the summary statistics of these variables.

TABLE A1: VARIABLES USED IN THE EMPIRICAL ANALYSIS

VARIABLE NAME	DESCRIPTION
SALES3	% of the current sales of a firm that are the result of innovations developed by your firm in the last three years (1992-95)
MSHAR90	Pre-innovation market share of every firm belonging to a particular activity field in 1990. The total market size of each activity field is proxied by the sum of sales of all firms assigned to the particular activity field
AGE	Number of years the firm had spent in the computer business prior to 1995
PRODGAP0	Difference between the firm's own productivity, in 1990, and the average productivity of all other firms in the same activity field (units in £000)
DUMGAP	Dummy to measure the positivity or negativity of PRODGAP0. Has value 1 if PRODGAP0 is positive or equal to zero and is 0 for all negative values of PRODGAP0
PROF1	The percentage of full time professional, scientific and managerial labour in the total full time workers of the firm
RD3	% of annual expenditures on R&D
SOFT	Has value 1 if a firm is in the software/services activity group
DHARD	Has value 1 if a firm belonged to the hardware sector

TABLE A2: DESCRIPTIVE STATISTICS FOR THE VARIABLES USED

SUB-SECTOR	SOFTWARE & SERVICES			HARDWARE ONLY			DIVERSIFIED FIRMS		
VARIABLE	MEAN	STD. DEV.	N	MEAN	STD. DEV.	N	MEAN	STD. DEV.	N
SALES3	34.15	31.23	47	20.059	31.485	17	31.333	33.672	15
AGE	11.82	7.54	49	9.235	6.088	17	13.214	8.173	14
MSHAR90	0.023	0.043	35	0.071	0.137	14	0.0782	0.0990	13
PRODGAP0	0.00	36.76	32	0.000	42.240	14	-0.0003	44.822	13
DUMGAP	0.42	0.49	32	0.41	0.51	14	0.533	0.516	13
PROF1	56.84	29.54	48	33.90	0.303	16	58.038	24.400	15
RD3	14.54	13.16	41	3.9286	3.9314	14	18.200	25.510	15

Notes

1. Thus, in a perfectly competitive model we assume all firms are identical in their ability. In such a market structure diffusion is instantaneous.

2. This is the approach for example in Geroski et al (1996).

3. This argument is strengthened when the technologies that underlie innovative activity are complex.

4. Undoubtedly there will be qualitative aspects of this difference in abilities. Thus, some firms may have competencies in marketing, others in their understanding of technology, yet both may ultimately be expressed and observed as differences in unit costs or productivity.

5. Schumpeter Mark 1 and Mark 2 have been seen as applying to different stages of the product cycle (Klepper 1996, Audretsch 1997) and have been used to explain the evolution of industry. The moot point is why do industries change from being Mark 1 into becoming Mark 2? The interpretation stressed in this paper relies upon a different nature of competition in the two situations defined largely in terms of the distribution of abilities. This of course is the outcome of continuous rivalry. I am grateful to Claudia Werker for discussion on this point.

6. Once innovation has occurred, the extent of imitability by rival firms may also vary with the nature of the innovation. Very radical innovations, or highly original ones, may be difficult to imitate. They may also give rise to a cluster of other incremental innovations by the innovating firm. The effect of such innovations is to prolong the period of post innovation monopoly.

7. It has been brought to my attention by an anonymous referee that similar results have also been found with the Cambridge ESRC

Centre for Business Research SME database by Cosh, Hughes and Wood (1999).

8. Firms were assigned to particular activity fields based on their own description of their business activity. A list of activity areas that are contained in the three different classifications is available upon request.

9. As Table A1 shows the number of cases drops from 47 to 35 when we consider MSHAR90 in the case of software. The drop for hardware and diversified hardware firms is smaller.

10. We computed average labour productivity as the ratio of total sales to total employment. As a measure of competence this is rather crude. But it was the only one that could be computed with the data available. A problem with this measure is that it is sensitive to sharp market segmentation, for example between component manufacturers and microprocessor designers in the case of hardware. The latter have a much higher productivity.

11. Employment of professional and scientific labour and level of R&D expenditures are also frequently used as measures of high tech industries.

12. A narrow definition of rivalry in the context of segmented markets could be the number of competitors a firm faces. We employ this measure to discuss the post innovation market structures facing firms in Table 4. We do not have a similar measure for 1990. We have employed the market share measure as it can be computed for 1990 and so we can avoid problems of endogeneity in our statistical model.

TABLES

Table 1: Differences in Rating of Factors and Strategies Favouring Competitiveness and Constraints to Growth

Description	Mean Scores	
	innovators	*non-innovators*
a. software/ services diversified firms		
Favourable factors		
Technical innovation and expertise	4.00	3.25**
Close relationships with clients	4.37	4.91**
Competitive prices	2.69	4.08***
Low production costs	1.93	3.20***
Established reputation	4.08	3.41*
Close relationships with hardware manufacturers	1.67	2.80**
Constraints		
Availability of highly qualified staff	2.78	1.75**
Marketing and sales skills	3.38	2.50**
b. hardware firms		
Favourable factors		
Established reputation	3.57	4.66*
Diversification of products and services	2.14	4.00*

Note: (i) All factors were ranked on a Likert scale of 1-5. The average scores must lie between 1and 5. (ii) Only factors for which differences among innovators and non-innovators are statistically significant are reported in the Table and the level of significance is indicated by asterisks. (iii) levels of significance: *** denotes 1%, ** denotes 5%, * denotes 10%

Table 2: The Determinants of Innovative Behaviour: Coefficient Values for the Tobit Estimations

Variable	(1) software and services	(2) (1)+diversified firms	(3) hardware firms	(2)+(3) All firms
constant	-1.48	5.424	-78.02***	7.09
mshar90	-1911.18***	-801.598**	789.18*	50.07
mshar90 ^{2}	8980.79***	2739.82**	5641.12*	-177.06
age	2.62**	0.58	8.56*	-0.95
prodgap0	-0.77***	-0.573**	17.61**	-0.073
dumgap	9.96	17.60	-505.36**	-1.92
rd3	-0.45	-0.21	-3.304	0.13
prof1	0.36*	0.41*	-1.37**	0.46**
soft				18.13
dhard				5.53
N	27	39	11	50
σ	23.54	30.90	12.498	35.79
log-likelihood	-105.58	-150.81	-25.05	-190.17

Table 3: Marginal Effects ($\delta E(Y)/\delta X_k$) at the Point of Means for the Tobit Estimations in Table 1

Variable	(1)	(2)	(3)	(4)
conditional mean at sample point	37.23	32.766	-0.0088	29.95
constant	-1.39	4.53	-0.008	5.39
mshar90	-1793.53	-669.34	0.79	38.1
$mshar90^2$	8427.93	2287.776	0.56	-134.76
age	2.46	0.48	0.86	-0.72
prodgap0	-0.72	-0.49	0.18	-0.55
dumgap	9.34	14.69	-0.50	-1.45
rd3	-0.43	-0.17	-0.33	0.95
prof1	0.34	0.34	-0.14	0.35
soft				13.80
dhard				4.21

Notes: (i) levels of significance: *** denotes 1%, ** denotes 5%, * denotes 10% (ii) the Tobit model has a lower limit at 0 and upper limit at 100

Table 4: Post-Innovation Characteristics of Firms

Characteristic	Software / services + diversified firms		Hardware firms	
	Innovator	*Non-innovator*	*Innovator*	*Non-innovator*
Number of serious competitors	4.58	10.09**	8.28	3.33**
Serious competitors that were larger	3.36	9.70***	7.00	1.80**
Firms' employment in 1995	44.48	19.00**	44.00	116.00
Firms' turnover in 1995 (£'000)	23780.92	1914.25	2527.14	13311.17
Age of firm in 1997	58.00	11.33	11.28	13.33
Exports as a % of all sales	21.19	7.54**	31.29	19.83

Notes: (i) Statistically significant differences in the mean scores are indicated by asterisks. (ii) levels of significance: *** denotes 1%, ** denotes 5%, * denotes 10%

Table 5: Evaluating the Importance of Persistence: Decomposition of the Marginal Effects in Table 3

Model	Variables	z	f(z)	F(z)	% of marginal response due to firms that are innovative {100A}	% of marginal response due to changes in the probability of innovating {100(1-A)}
(1)	Mshar90	-1.536	0.122	0.061	7	93
Software/	Age	1.577	0.115	0.942	79	21
services	Prodgap0	0.056	0.398	0.524	38	62
	Dumgap	0.283	0.384	0.610	43	57
	Rd3	-0.294	0.383	0.386	30	70
	Prof1	0.795	0.294	0.788	56	44
(2)	Mshar90	0.402	0.368	0.655	46	54
(1)+ diversified	Age	0.264	0.386	0.603	42	58
firms	Prodgap0	0.026	0.399	0.512	37	63
	Dumgap	0.364	0.374	0.641	45	55
	Rd3	-0.093	0.393	0.464	36	64
	Prof1	0.699	0.312	0.758	54	46
(3)	Mshar90	8.75	0.000	0.999	1	99
hardware	Age	7.60	0.000	0.999	1	99
only	Prodgap0	-4.226	0.000	0.001	1	99
	Dumgap	-18.398	0.000	0.000	1	99
	Rd3	-1.007	0.246	0.156	19	81
	Prof1	-3.401	0.001	0.003	1	99

Notes: (i) The market share variable is computed as a composite variable. $Z=\beta_1 x+\beta_2 x^2$. This is evaluated at the point of means for the market share variable. The coefficient values are read from Table 2 (ii) z=(mean of x)β/σ. The information on β and σ can be read from Table 2. F(z) is the cumulative standard normal density and f(z) is the ordinate of the standard normal curve. $A=\{1-zf(z)/F(z)-f(z)^2/F(z)^2\}$ (iii) The software used for estimation of the Tobit model was LIMDEP (v.7). Missing observations were skipped in the analysis. This has meant only firms with no missing observations on any determinant of innovative behaviour were included in the analysis. An implication of this procedure is that the mean values used in the decomposition reported in the above table are not the same as the average values for each variable reported in Table A1 (iv) the decomposition breaks down for hardware firms due to the small number of observations. Values of F(z) and f(z) have not been reported..

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