The Post-Entry Performance of Irish Plants: Does a plant's Technological Activity matter?

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Allan Kearns
Department of Economics
Trinity College
Dublin 2.
kearnsa@tcd.ie

Frances Ruane
Department of Economics
Trinity College
Dublin 2.
fruane@tcd.ie

Abstract

Is Research and Development activity an important determinant of the probability that a plant will survive? We model the survival of a cohort of Indigenous plants over the period 1986 to 1996 as a function of sectoral and firm characteristics. We use a firm-level dataset provided by Forfás, the policy and advisory board for industrial development in Ireland. We conclude that R&D activity is an important factor which increases the probability of survival for that plant. Specifically, R&D active indigenous plants had a higher probability of surviving the entire period 1986-1996 than non-R&D active plants. We show that this result is robust to alternative measures of technological activity in indigenous plants.

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I: INTRODUCTION

A cohort analysis of Irish manufacturing firms concluded that research and development (R&D) spending firms had superior net job creation rates relative to non-R&D spending firms (Kearns and Ruane 1997). The same analysis suggested that an important determinant of the net job loss in indigenous firms (18.4%) over the period 1986-1996 was the closure of indigenous firms (31.2%). Did R&D spending firms have superior net job creation rates because they had a lower propensity to exit relative to non-R&D spending firms?

The exploration of the role of firm level technological activity[1] and subsequent survival is a hybrid of two literature traditions. The first of these relates to the determinants of survival itself. For example, in empirical studies, Evans (1987) found a positive relationship between the probability of survival and the size of the firm, while Dunne et al (1989) found that survival rates increase with both plant age and size. The second of these traditions started with Winter (1984). He postulated that the probability of survival of new entrant firms relative to incumbent firms in an industry, depended on which group controlled the technological development and future of an industry. Where incumbent firms were responsible for the majority of innovations in an industry, they had a relatively higher probability of survival than new entrant firms. Sutton (1991) used the theory of endogenous sunk costs to explain how incumbent firms could improve their probabilities of survival by controlling the technological environment. His theoretical analysis showed that by investing R&D, incumbent firms increased the minimum efficient scale of the industry, which decreased the probability of growth and

[1] In this paper we use the terms technological activity and R&D activity interchangeably.

survival of new entrant firms. Audretsch (1991,1995) and Audretsch and Mahmood (1995) used technological dominance to explain variations in the survival of new entrant firms in the United States. They found that control of the technological environment was empirically important in improving the probability of survival of new entrant firms and by inference decreasing the probability of survival of incumbent firms. Walsh and Konings (1997) applied a variation of this analysis to Ireland. They used a dichotomous variable to describe which subsectors in the Irish manufacturing sector were relatively more or less R&D intensive. They concluded that indigenous plants in R&D intensive industries had lower probabilities of exit relative to indigenous plants in less R&D intensive sectors.

In this paper we focus on two issues. First, we examine the determinants of the probability of survival of *indigenous incumbent* plants in the Irish manufacturing sector. We limit our study to *indigenous* plants because we are concerned with the link between R&D behaviour at plant level and the survival of the firm. In the majority of indigenous cases this link is present as the plant is the firm, in contrast with the foreign-owned sector in Ireland where all plants are subsidiaries.[2] We focus on *incumbent* plants because, invoking endogenous sunk cost theory, we would expect that technological activity undertaken by an incumbent plant will increase that plant's probability of survival. Second, we use plant-level technological data rather than sectoral level data to explore this relationship.

[2] Dunne et al (1989) concluded that the survival experiences of a subsidiary plant will be different to that of a single plant firm. The continuing survival of a subsidiary plant will be influenced by political decisions and economic performance.

We estimate two models of the probability of survival; a logit model and a Cox duration model. We estimate the survival experience of a cohort of indigenous incumbent plants (1986-1996) as a function of their technological activity and other plant and industry characteristics. We find that technological activity has a positive influence on a plant's probability of survival. This conclusion is robust to different measurements of a plant's technological activity: scale of R&D activity, R&D intensity and sales of innovative products. We find that plant size and the extent of new firm entry into an industry are also important determinants of an incumbent plant's probability of survival.

In the second section of the paper the data base is explained. The theory of plant level technological activity and superior probabilities of survival is developed in Section 3. Section 4 presents the results of a logit model which seeks to explain variations in the survival rates between firms. The results of a Cox duration model which takes account of the limitations of this logit model are presented in Section 5. The final section contains some conclusions.

II: DATA

The data set explored here is a unique combination of two sources. The R&D data are drawn from a survey of R&D performing plants, undertaken by the policy and advisory board for industrial development in Ireland (Forfás). This organisation has statutory responsibility for R&D statistics in Ireland. For the years 1986 to 1993, the biannual surveys reported data on the population of R&D performers with ten or more employees in the manufacturing and internationally-traded services sectors.[3] The employment data are drawn from the annual employment surveys

[3] Forfás estimate a response rate close to 100% for this survey.

undertaken by the same agency. Similar to the R&D data, these employment surveys cover the population of plants in the manufacturing and internationally traded service sectors.[4] The employment survey data covers all firms and in matching the two Forfás surveys, we have excluded any plant with less than ten employees through the period 1986 to 1996.

Within indigenous plants, we focus only on the incumbent plants. We do this by generating a cohort which includes all plants with ten or more employees and three or more years old in 1986. We then analyse their survival until 1996.[5] A plant is deemed to have survived if it has positive employment in 1996 exited from the cohort if it has zero employment in 1996. Where a plant has positive employment in one year followed by a report of zero employment in the following year, we deemed that plant to have exited the cohort during that year. In this way we capture the duration of the plant's life after 1986.

Table 1 in Appendix A shows the survival rates of the cohort over the period 1986-1996. The overall percentage of 2,114 plants which survive the eleven years is 69%. We can disaggregate further and explore the survival rates of plants in the high-tech relative to the low-tech sector[6]. The high-tech (low-tech) sector contains high (low) R&D intensive sectors according to the OECD classification. The probability of a plant surviving the period 1986-1996 in the high-tech sector is 73.04%, compared with the

[4] The response rate is greater than 90% for this survey (Strobl,1996).
[5] This eliminates any new entrant firms (1987-1995) from being included in our analysis. This allows us in empirical testing to focus only on incumbent firms. Our cohort is the population of indigenous incumbent plants in 1986.
[6] We have adapted the OECD classification of high-tech, medium-high, medium-low and low-tech into two sectors. High tech is the aggregation of high and medium high-tech. The low-tech sector is the aggregation of medium-low and low-tech. The OECD classification is set out in Table 1.

corresponding probability for plants in the low-tech sector of 68.35%.[7] While at this aggregate level, there is a suggestion that plants in an R&D intensive industry have a higher probability of survival, this difference is not statistically significant when we disaggregate further into the individual industrial subsectors. There is an enormous variation in the probabilities of survival between these subsectors, as evident in Table 1.[8] The range of probabilities in those subsectors in the high-tech sector is from 50.00% to 82.61%. Similarly in those subsectors which comprise the low-tech sector, the range of probabilities of survival is from 43.42% to 88.89%. How do we account for this variation in survival rates between subsectors that are classified as having the same level of technological sophistication[9]? Audretsch and Mahmood (1995) in a study of the variations of survival rates among new entrant plants emphasise the importance of plant characteristics. It is the central hypothesis of this paper that the overall classification of sectors cannot explain survival rates and that the presence or absence of research and development spend in an individual plant should be taken into account.

We divide our cohort into R&D spenders and non-R&D spenders to conduct a life-table analysis. This analysis will provide us with the estimated probabilities of survival for both groups over the period 1986-1996. In Figure 1 we have graphed both survivor functions. The probability of survival for the R&D spending plants exceeds that of the

[7] These probabilities have been estimated using life-table analysis. Life-table analysis is a technique which permits the estimation of the probability of an event (exit) occurring at different time (years) points. It allows for the fact that not all plants will have exited during the period of observation. Life-table analysis allows a cohort to be distinguished by one characteristic only and the differing probabilities to be estimated for each group. A Wilcoxon(Gehan) test for equality of the estimated probabilities of survival should be undertaken. In this case the different probabilities of survival for the high-tech and low-tech sectors are statistically insignificant at the 10% level (prob.=.1304).
[8] We disaggregate into the OECD 24 industrial subsectors.

non-R&D spending plants at every point in time 1986-1996. The probability of an R&D spending plant surviving ten years after 1986 at 85.96%, is significantly higher than the corresponding estimate for non-R&D spending plants of 66.36%.[10] Why could we expect ex ante, that R&D spending plants would have a higher probability of survival relative to non-R&D spending plants?

III: THEORY OF TECHNOLOGICAL ACTIVITY AND SURVIVAL

To develop a model of plant level technological activity and plant survival, we adapt a model first introduced by Audretsch (1991) and later developed by Audretsch and Mahmood (1995). These authors tested the hypothesis that the probability of any given firm *j*, of age *t*, remaining in industry *i*, $\Pr(Y_{it}^{j} > 0)$, is a function of the technological regime in the industry in addition to traditional industry and plant characteristics. The technological regime in an industry defines industries according to whether the majority of innovations are produced by incumbent firms or new entrant firms. We consider a model below where plant level technological activity rather than the industry's technological regime is a determinant of the probability of survival.

Successful innovative activity is the means by which firms grow and prosper. Audretsch (1991) justifies the inclusion of the probability of innovative activity as a determinant of the survival of new entrant firms because innovative activity is the means by which new firms grow and

[9] High-tech and Low-tech represent two differing levels of technological sophistication. All subsectors in each of these sectors by definition have the same level of technological sophistication.
[10] The Wilcoxon (Gehan) test shows that these different survivor functions are statistically different at the 1% level. (Prob. .0000)

attain the industry minimum efficient scale. A simple theory of the costs of production justifies this approach. A new entrant ignores its fixed costs firm in the short run and increases its output as long as its price is greater than average variable cost. However as a firm undergoes the transition from a new entrant to a young incumbent, it must consider payment of its fixed costs, as price must cover average cost in the long run. We hypothesise that growth in profitability (p) for a given scale of output becomes relatively more important a consideration than increasing scale. In this instance the probability of survival of an incumbent firm *j*, of age *t*, in industry *i* is determined by its current and expected profitability. The more profitable that the firm is, the greater its probability of survival:

$$Pr\,(Y_{it}^{j} > 0) = f\,(p_{it}^{j}) \qquad \textbf{Equation 1}$$

We can think of Equation 1 as a model of income choice in the tradition of Knight (1971).[11] Therefore we consider that the probability that a firm will decide to remain in the industry is increasing in the level of profitability the firm currently enjoys.

In turn, profitability is determined by the price-cost margin which the firm earns which in turn depends on market size and the number of firms in the industry. If we assume that the firms are Cournot quantity setters and they compete in homogeneous products, a typical profit function for a firm *j* of age *t* in industry *i* can be written as

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[11]). Jovanoic (1994) and Blanchflower and Meyer (1994) have used a model of income choice to interpret the decision of an individual to start a new firm or become the employee of an existing firm. The probability of an individual starting a new firm is greater when the gap between the expected profits from being an entrepreneur exceed the expected wage they would receive as an employee. In Equation 1 we are reversing this decision process. A firm has a current level of profitability. This is to be benchmarked against the next best income choice facing the owners if they applied their resources outside the industry.

$$p_{it}^{j} = b\left[\frac{S}{2+(n-1)}\right]^2$$ **Equation 2**

where p_{it}^{j} are the profits earned by this firm, S is the size of the market and n is the number of firms in the marketplace. In this case if we consider Equation 2 along with Equation 1, the probability of survival of this firm depends on the number of firms in the industry. This is because for a given market size, the number of firms in the industry determines the profits earned by the firm.

An extension to the standard Cournot result presented in Equation 2 is to allow for differentiated products. One firm j differentiates its products relative to its rivals. Product differentiation raises consumers' willingness to pay. Specifically, a product may be differentiated by raising its quality above the quality of competing products. If quality is important to consumers, they will be willing to pay a higher price for this higher quality product. We can introduce a parameter q into Equation 2 to measure the degree of product differentiation attributable to our firm relative to the remaining firms. If $q=1$, the products are completely homogeneous between firm j and the remaining firms. If $q=0$, the products sold by firm j are completely differentiated from the remaining firms in the industry. We obtain a modified profit function for firm j

$$p_{it}^{j} = b\left[\frac{S}{2+(n-1)q}\right]^2$$ **Equation 3**

where S and n are the size of the market and the number of firms in the market. Equation 3 states that the profits earned by any firm of a given age in any industry is determined by the degree of product differentiation and the size of the market. When a firm completely differentiates completely its products ($q=0$) relative to those sold by rivals in the industry, the firm removes the interdependence of its profits on the number of firms in the market. The firm becomes a monopolist for the differentiated product and remaining firms compete with the original homogeneous product ($q=1$). Their profits remain dependent on the number of firms in the marketplace.

Successful product innovation[12] is the source of product differentiation. Following the notation developed in Equation 3, the probability that $q=0$ is increasing in the success of a firm's technological activity, as defined by a successful innovative output (SIO)

$$\Pr\,(q=0)=f\,(SIO) \qquad \textbf{Equation 4}$$

To what extent is the positive relationship between successful innovative output (Equation 4) and profitability of a firm (Equation 3) observed in empirical studies? The general conclusion of the empirical studies to date is that relatively more technologically active firms have higher profits growth. Nas and Lappalahti (1997) report higher profits for Norwegian innovating companies when compared to non-innovating companies. The authors also conclude that these profit differences are persistent across time. Geroski (1994) observed that innovating firms earn higher profits because they have larger market shares than non-innovators. This market share is more valuable to innovating firms because they earn higher margins than non-innovators. There has not been a study of innovation and profitability for firms in the Irish manufacturing sector. However Kearns and Ruane (1997) noted that R&D spending firms in Irish manufacturing had superior employment growth to non-R&D spenders. Roper and Dundas (1996) observed for a sample of firms in the Irish manufacturing sector that employment, turnover and real export growth per annum (1991-1993) was higher for innovating than for non-innovating companies.

Through the various mechanisms outlined in Equations (1) - (4), we arrive at the central hypothesis of this paper, namely that the probability of survival of a firm *j*, of age *t*, in industry *i*, will be determined by the extent of successful innovation[13] (SIO) in this firm

$$\Pr\ (Y_{it}^{j} > 0) = f\,(SIO) \qquad \textbf{Equation 5}$$

To our model in Equation 5 we must add some more traditional industry and plant characteristics which have traditionally explained variations in the probability of survival between firms. We consider each of these variables in turn.

Plant size: The probability of survival for a firm increases with its size. Majumdar (1997) notes in a study of Indian firms that with increasing size comes more diverse capabilities, superior access to capital and a superior

[12] We could model process innovation in a similar fashion by extending the Cournot model to account for differing marginal costs. Process innovation would result in lower marginal costs for a firm relative to rivals.

[13] We proxy successful innovative output in a plant by three measures of its technological activity; scale and intensity of R&D activity in the plant and sales of innovative products.

ability to exhaust economies of scale and scope. Nas and Lappalahti (1997) focus on the ability of a firm to react to changes in its external environment. The option of downsizing in the face of an economic downturn is only available to large firms. Large firms have adequate size to consider downsizing before they consider exiting the industry. By contrast, small firms have no option to downsize, and are immediately faced with the decision to exit.

Plant age: The probability of survival increases with the age of the firm. Jovanoic (1982) termed the benefits gained from increasing experience in a market as *market entrenchment* benefits. Learning is important in exhausting economies of scale and scope and learning is a function of time. Majumdar (1997) summarises this point when noting that older firms are not prone to the *liability of newness*.

Entry: Love (1996) in a study of variations in firm exit across the British counties concludes that new firm entry is the dominant determinant of exit. There is an expected positive correlation between the extent of entry into an industry and the rate of exit of incumbent plants, i.e. the probability of survival of incumbent plants falls as the rate of entry increases. Audretsch (1995) describes the process as one of *displacement*. It occurs where informational asymmetries exist between the existing incumbent firms and potential new entrant firms. Innovative ideas occur outside of the industry which are ignored by the existing incumbents. New entrant firms enter with these innovative ideas and steal market share, eventually growing to displace the existing incumbents. Siegfried (1992) provides evidence of inefficient incumbents being displaced by new entrant firms in the United

States. Kleijweg and Lever (1996) arrive at the same conclusion in a study of Dutch manufacturing firms.

Rate of growth: Audretsch and Mahmood (1995) and Walsh and Konings (1997) model the probability of survival of a firm as determined by the rate of growth in the industry. These authors expect that the probability of survival for all firms in an industry will be higher, the greater the rate of growth of the industry. Relatively faster growing industries are thought to have elevated price-cost margins. These elevated margins are more forgiving for less efficient firms in the industry, which can still enjoy profitability despite their uncompetitive position. In slow growing industries, where intense price and non-price competition may result for a given market share, we would expect a high rate of exit among inefficient firms.

Thus we extend Equation 5 to take account of these factors. The probability of survival of an indigenous incumbent plant *j*, of age *t*, in industry *i*, in the Irish manufacturing sector will be determined as follows[14]:

$$\Pr(Y_{it}^{j} > 0) = (SIO(+), Size(+), Age(+), Ind.\ \text{Entry}\ Rate(-), Ind.\ Growth\ Rate(+))$$

Equation 6

[14] The expected influence of the variable on the probability of survival is noted as (+) or (-) in parentheses.

IV: LOGIT REGRESSION

4.1. Data

Technological activity: We use the five R&D surveys between 1986 and 1993 to measure technological activity in plants in our cohort. Given that these surveys report R&D spend for the population of indigenous R&D spenders, a plant with zero spend is considered as a non-R&D spending plant. We measure scale of R&D activity as the mean R&D spend per annum in the plant (1986-1993). The population of R&D spending firms and non-R&D spending firms remains the same for all three measures of plant level technological activity. For the R&D spending firms only, we calculate two alternative measures of their technological activities. The first measure is *R&D intensity* i.e. the mean R&D spend of the plant as a percentage of its sales. The second measure relates to innovative output. It is the mean percentage of the firm's sales which is accounted for by products developed within the firm in the last three-five years.

Plant size: We measure plant size as the employment size of the plant in 1986. We normalise this for industry minimum efficient scale (MES) in 1986, using the mean number of employees in the industry in 1986 to measure MES. This is a variation of Sutton (1991) who uses the median number of employees.

Plant age: Plant age is the age of the plant in 1986.

Entry: The industry entry rate is calculated using methodology outlined in Strobl (1996). An annual plant turnover rate by industrial subsector (using the 24 sector OECD aggregation) is calculated annually between 1986 and 1996. We then measure the number of plants entering as a percentage of this turnover. We calculated the mean annual entry rate for each of our subsectors as a measure of the extent of entry into an industry (1986-1996).

Growth rate: The industry growth rate is measured as the growth in value added by industrial subsector (1986-1995). These measures were sourced from the Census of Industrial Production. We used concordance tables to translate the CSO industry classification into the OECD industrial classification.[15]

4.2 Logit Regression Results

We use a logit regression model to estimate the probability of an indigenous incumbent plant surviving the period 1986-1996. The dependent variable captures whether the plant survived or exited over the whole period. A value of one implies the plant survived and zero for when the plant exited. We regress this dependent variable on each of our three measures of technological activity listed above as well as the plant and industry characteristics as determined in Section 2. In order to improve the explanatory power of the model we include a dummy variable to control for the industrial subsector in which the plants are located. We present the results of equations (4.1) through (4.3) in Table 3.

Equations 4.1,4.2 and 4.3 differ only in the measure of technological activity used. All of these measures of technological activity have positive coefficients and are statistically significant at the 1% level. As the scale, intensity and output of the plant's R&D activity increases, the greater the

[15] Table 2 presents summary statistics for all of the variables used in this Study.

probability that the plant survived the period 1986-1996. This is the central hypothesis of this paper.

In accordance with expectations, as the size of the plant relative to industry minimum efficient scale increases, the greater the probability of survival for the plant. For a given plant size, the higher the minimum efficient scale (MES) of the industry, the lower the probability of survival for an incumbent plant. This reflects the traditional industrial organisation result of MES as a determinant of the number of firms in an industry.

The mean annual entry rate into an industry is significant in Equations 4.2 and 4.3 at the 10% level. The positive coefficient conflicts with our expectation that the greater the extent of entry into an industry the lower the probability of survival would be for incumbents. However, an alternative view of entry and the survival of incumbents exists. The greater the extent of plant entry into the industry, the more intense the competition between new entrants for a given market share. The competition may be so intense that the vast majority of new entrant plants fail and are forced to exit, i.e. the revolving door, where an entrant arrives and subsequently exits. The remaining new entrant plants are so crippled by this early competition that they are not in a position to grow and displace the incumbents. This would result in a positive coefficient as reported in our Logit regression.[16]

The age of the plant and the growth rate of the industry are insignificant explanatory variables of the probability of survival. We do not display the results for the 24 category sectoral dummy variable for illustration

[16] In related research we are looking at the survival of new entrant plants.

purposes. In all of the equations, only four of the twenty-two subsectors have significant explanatory power.[17]

4.3 Limitation of the Logit Regression: Duration heterogeneity

The first limitation of the logit model is its inability to account for duration heterogeneity, i.e. the difference in a plant exiting our cohort in 1987 and a plant exiting in 1995. Clearly survival time is important but it cannot be introduced as an explanatory variable into the logit model. Cox and Oakes (1984, p6) note that "*inclusion of the actual failure time as an explanatory variable in a discriminant analysis (dichotomous dependent variable) would be a serious error, as the failure time is part of the response, not part of the factors influencing response*. We need to model the survival experience of plants in our cohort taking into account differences in survival times. We do not want our cohort divided up into groups determined by a dichotomous variable. We want one group of plants distinguished only by the duration of their lives after 1986.

V: A DURATION MODEL

The Cox (1972, 1975) duration model estimates the risk of exit (hazard) facing a plant in our cohort as a function of the explanatory variables already used in the Logit regression. This proportional hazards model takes account of duration heterogeneity. The hazard is the conditional probability of a plant leaving the manufacturing sector at duration *t*. The hazard rate is the rate at which a plant exits during period *t* given that it

[17] These are Clothing, Leather and Footwear, Paper and Paper Products and Furniture and other Manufacturing when compared to Food, Drink and Tobacco.

has survived until time *t*, i.e. it measures the risk of exit for a plant during the next year. We obtain a baseline hazard function, $h_0(t)$, which is estimated when all of the explanatory variables (covariates) are set to zero. It is an estimate of the risk of exit facing each plant in the cohort in each year 1986-1996. The Cox model then estimates the influence of each of our explanatory variables on this baseline hazard function. Is the hazard of a plant exiting at a moment in time increased or decreased when an explanatory variable is nonzero? A negative (positive) coefficient indicates that this baseline risk of exit at a moment in time is reduced (increased).

In order to use the proportional hazards Cox model, we must assume that the ratio of the baseline hazard function $h_0(t)$ and the estimated hazard function $h(t)$ (when an explanatory variable is included) is proportional across time. This implies the contribution of the explanatory variable to the risk of exit across time is identical. In our case, the contribution of R&D activity to the risk of exit facing a plant is the same in 1986 as it is in 1996. The implication of using this proportional hazards model is that none of our explanatory variables vary across time. They are all cross-sectional.

We express the model to evaluate many independent variables as

$$h(t) = [h_0(t)]e^{(b_1 X_1 + b_2 X_2 + ... + b_N X_n)}$$

where $h_0(t)$ is the baseline hazard function when all of the covariates are set to zero and $h(t)$ is the estimated hazard function when the value of the covariates ($x_1, x_2 ... x_n$) are nonzero.

The emphasis of this paper is on the probability of survival for an indigenous plant given its characteristics and external environment. The survival function S(t) is an estimate of the probability of surviving longer than a specified period. The cumulative hazard function $H(t)$ is related to the survival function: $H(t) = -\ln S(t)$, where

$$S_t = [S_0(t)]^p$$

and where $p = e^{bx}$. The survival function is obtained by raising the baseline survival function (this is the function when all the explanatory variables are set to zero) to the power of e^{bx}. The cumulative hazard and the cumulative survival functions approximately add to one. The difference from one will be due to the standard error of the cumulative survival estimates. Therefore the probability of surviving a given time period is one minus the probability of dying in that period.

Table 4 shows the regression results from four alternative equations. All four of these equations differ in one respect only, namely the measure of plant level technological activity used. Equation 5.1 uses a dichotomous variable which indicates whether the plant is an R&D active or non-R&D active plant. The coefficient of this variable is negative and statistically significant. This implies that the risk of exit for an R&D spending plant at a point in time (1986-1996), is less than that for a non-R&D spending plant. The only remaining statistically significant variable is the annual entry rate into the industry. The coefficient of this variable is positive. This confirms our original expectations that the risk of exit at a point in time

(1986-1996) facing indigenous incumbents is increased the greater the extent of plant entry into their industry. This is in contrast to the positive influence of entry on the probability of survival of incumbent plants concluded in our logit model.

The output from Equation 5.1 is graphically presented in Figures 2 and 3 which show the recovered hazard and survival functions. These functions have been estimated using the mean values of the covariates specified in Equation 5.1. The hazard function shows that the longer the duration considered, the greater the risk of exit in the next period. By contrast, the survival function provides an alternative viewpoint. The longer the duration we consider, the lower the probability of a plant surviving into the next period. We can further illustrate the importance of the plant being an R&D active or non-R&D active plant over this period. In Figures 4 and 5 the hazard functions and survival functions are drawn for the different groups of plants. At any point in time during 1986-1996, the risk of exit facing a non-R&D spending plant is greater than that of an R&D spending plant. Conversely, the probability of surviving into the next period is greater at every point in time for an R&D spending plant than a non-R&D spending plant.

In equation 5.2 we consider the scale of R&D activity among R&D active plants. The coefficient of R&D scale is negative and significant, i.e. the risk of exit facing an indigenous plant in our cohort is decreased as the scale of R&D activity in the plant increases. The size of the plant relative to the industry minimum efficient scale is negative, confirming our expectation that as a firm becomes large relative to the minimum efficient scale of the industry, its risk of exit decreases. The industry plant entry rate increases the risk of exit for all the incumbent plants in our cohort.

In Equation 5.3 we introduce the percentage of a plant's sales that they spend on R&D as a measure of their technological activity. This variable has the expected negative coefficient, i.e. the more intensively a plant engages in R&D, the lower its risk of exit will be. In similar fashion to Equation 5.2, both plant size relative to minimum efficient scale and the industry entry rate have the expected negative and positive coefficients respectively.

In Equation 5.4 we consider our final measure of a plant's technological activity. It is the percentage of their sales revenue which is accounted for by products developed within the firm in the last 3-5 years. The coefficient is negative, i.e. the greater the extent of sales revenue accounted for by sales of innovative products, the lower the risk of exit facing the plant. Again, the greater the extent of entry into the industry, the greater the risk of exit facing the plants in that industry. The larger the size of the plant relative to minimum efficient scale, the smaller the risk of exit facing the plant will be.

VI: CONCLUSIONS

The central hypothesis of this paper is that technological activity within plants is an important determinant of that plant's probability of survival. We outlined a theoretical model whereby the probability of a plant surviving is determined by the success of a plant's technological activity.

Using a data base of indigenous incumbent plants in the Irish manufacturing sector, we concluded that technologically-active plants have superior probabilities of survival relative to less technologically active firms. This was confirmed using life-table analysis, logit analysis and a Cox duration model. This result was consistent across the range of variables typically used to measure a plant's technological activity, namely, scale of R&D activity, R&D intensity or sales of innovative products developed within the plant.

Present work is limited by the fact that data are only available over an eleven year period. As time passes existing data bases will be augmented and the time period over which the survival experiences of indigenous incumbents can be examined will be lengthened. This should improve the quality of results. Two extensions to this study are being examined: a further evaluation of our hypothesis using a dynamic Cox regression technique and a study of technological activity and the survival of new entrant plants in the Irish manufacturing sector.

APPENDIX A

Table 1:Cohort Survival Rates Over Time by Manufacturing Subsector

Year	1986	1988	1990	1992	1994	1996	Probability of
Manufacturing Sector	Total Number of Surviving Firms from 1986 Cohort. Survival Rates (%) Underneath.						Surviving the Period.
High-Tech Sectors:							
Machinery n.e.c.	88	78	68	60	57	56	63.64
		89%	77%	68%	65%	64%	
Computer/Office Mach	14	12	11	11	10	9	64.29
		86%	79%	79%	71%	64%	
Electrical machinery	51	48	44	43	40	36	70.59
		94%	86%	84%	78%	71%	
Electronics	3	3	3	2	2	2	66.67
		100%	100%	67%	67%	67%	
Instruments	32	30	27	26	26	25	81.25
		94%	84%	81%	81%	78%	
Motor Vehicles	46	44	42	41	40	38	82.61
		96%	91%	89%	87%	83%	
Other transport	14	14	11	9	8	7	50.00
		100%	79%	64%	57%	50%	
Chemicals	22	21	18	18	18	18	81.82
		95%	82%	82%	82%	82%	
Pharmaceuticals	35	31	29	29	27	27	77.14
		89%	83%	83%	77%	77%	
High-Tech Sectors	**293**					**214**	**73.04**
						73%	
Low-Tech Sectors:							
Food/Drink/Tobacco	541	495	453	423	399	384	71.71
		91%	84%	78%	74%	71%	
Textiles	86	73	66	57	53	52	60.47
		85%	77%	66%	62%	60%	
Clothing	152	121	95	83	75	66	43.42
		80%	63%	55%	49%	43%	
Leather/Footwear	35	30	23	21	20	17	48.57
		86%	66%	60%	57%	49%	
Wood/Wood Products	102	91	83	72	66	62	62.69
		89%	81%	71%	65%	61%	
Paper/Paper Products	45	42	42	41	40	40	88.89
		93%	93%	91%	89%	89%	
Printing/Publishing	165	155	150	148	137	132	80.60
		94%	91%	90%	83%	80%	
Rubber/Plastic Prod's	81	76	69	67	65	61	75.31
		94%	85%	83%	80%	75%	
Non-Metallic Minerals	146	134	124	121	110	106	73.26
		92%	85%	83%	75%	73%	
Basic Metals	15	13	9	9	9	8	53.33
		87%	60%	60%	60%	53%	
Fabricated Metals	268	242	225	212	197	190	70.90
		90%	84%	79%	74%	71%	
Furniture/Other Manu.	173	151	136	128	121	113	65.46
		87%	79%	74%	70%	65%	
Low-Tech Sectors	**1821**					**1245**	**68.35**
						68	
Total (Cohort)	2114	1904	1728	1621	1520	1449	69.00
		90%	82%	77%	72%	69%	

Note: The survival rate or the percentage of firms surviving is the number of firms surviving after a given time period divided by the total number of firms originally in the industry in 1986.

Table 2: Summary Statistics for Regression Variables

Variable	Mean	Std Dev.	Minimum	Maximum	N
Plant Characteristics:					
(Plant Size / MES)	1.00	1.54	0.07	33.87	2114
Plant Age (Years)	21.06	18.78	3	84	2114
Industry Characteristics:					
Industry Entry Rates (%)	0.06	0.02	0.04	0.17	2114
Industry Growth Rates (%)	3.54	4.14	1.07	16.86	2114
Technological Activity:					
Scale of R&D Activity (000's)	18.56	96.83	0	1980	2114
R&D Intensity (%)	0.01	0.03	0	0.28	2114
Sales of Innovative Prods (%)	6.26	18.15	0	100	2114
Status and Duration:					
Plant Survived (1)or Died (0)?	0.69	0.46	0	1	2114
Life of Plants post 1986 (Years)	8.96	3.39	1	11	2114

Table 3: A Logit Regression of the Probability of Survival
(*p* values within parentheses)

Independent Variables[18]	Equation 4.1	Equation 4.2	Equation 4.3
Scale of R&D Spend (p)	.0036*** (.0088)	-	-
R&D Intensity (p)	-	14.5400*** (.0004)	-
% Sales Innov. Prod's (p)	-	-	.0224*** (.0000)
Age of plant in 1986 (p)	.0012 (.6663)	.0011 (.6768)	.0014 (.6188)
Plant size / MES (p)	.1166** (.0207)	.1520*** (.0017)	.1207** (.0127)
Annual Entry Rate 86-96 (i)	73.5253 (.1375)	86.0965* (.0938)	85.6525* (.1000)
Industry Growth Rate (i)	-.0859 (.1896)	-.0966 (.1450)	-.0932 (.1625)
Constant	-4.0181 (.1896)	-4.9260 (.1239)	-4.9632 (.1267)
Overall Chi Square Score	121.723	129.932	153.321
Significance Level	.0000	.0000	.0000
-2LL	2495.290	2487.081	2463.692
Overall Predicted	70.20%	70.29%	70.53%
N	2114	2114	2114

Note: Significance levels within Parentheses. *** = significant at the 1% level ** = significant at the 5% level *=significant at the 10% level.(*i)* = variable varies at industry level,*(p)* = variable varies at plant level.

[18] A sectoral categorical variable for the 24 OECD sectors was included. The variable improved the explanatory power of the model. The breakdown of this variable (23 categories) is not included for presentation purposes.

Table 4: Regression Results for the Cox Duration Model

Independent Variables	Equation 5.1	Equation 5.2	Equation 5.3	Equation 5.4
R&D Active (Yes/No) (p)	-1.0297*** (.0000)			
Scale of R&D Spend (p)	-	-0.0042*** (0.0016)	-	-
R&D Intensity (p)	-	-	-14.5508*** (0.0001)	-
% Sales Innov. Prod's (p)	-	-	-	-0.0202*** (0.0000)
Age of plant in 1986 (p)	-.0032 (0.1413)	-0.0019 (0.3822)	-0.0022 (0.3093)	-0.0024 (0.2655)
Size of plant in 1986 (p)		-	-	-
Plant size / MES (p)	-0.0611 (0.1164)	-0.0828** (0.0483)	-0.1212*** (0.0028)	-0.0989** (0.0137)
Annual Entry Rate 86-96 (i)	10.2132*** (.0000)	10.8961*** (0.0000)	11.1160*** (0.0000)	11.5028*** (0.0000)
Industry Growth Rate (i)	-.0150 (.1163)	-0.0149 (0.1211)	-0.0131 (0.1738)	-0.0140 (0.1436)
Overall Chi Square Score **Significance Level**	94.820*** (0.0000)	36.396*** (0.0000)	41.378*** (0.0000)	64.843*** (0.0000)
N	2114	2114	2114	2114

Note: *p* values within Parentheses. *** = significant at the 1% level ** = significant at the 5% level. *(p)* = the variable varies at the plant level *(i)* = the variable varies at industry level

Figures

Figure 1: The different Survivor functions for R&D Spenders relative to Non-R&D spenders using Life-Table Analysis

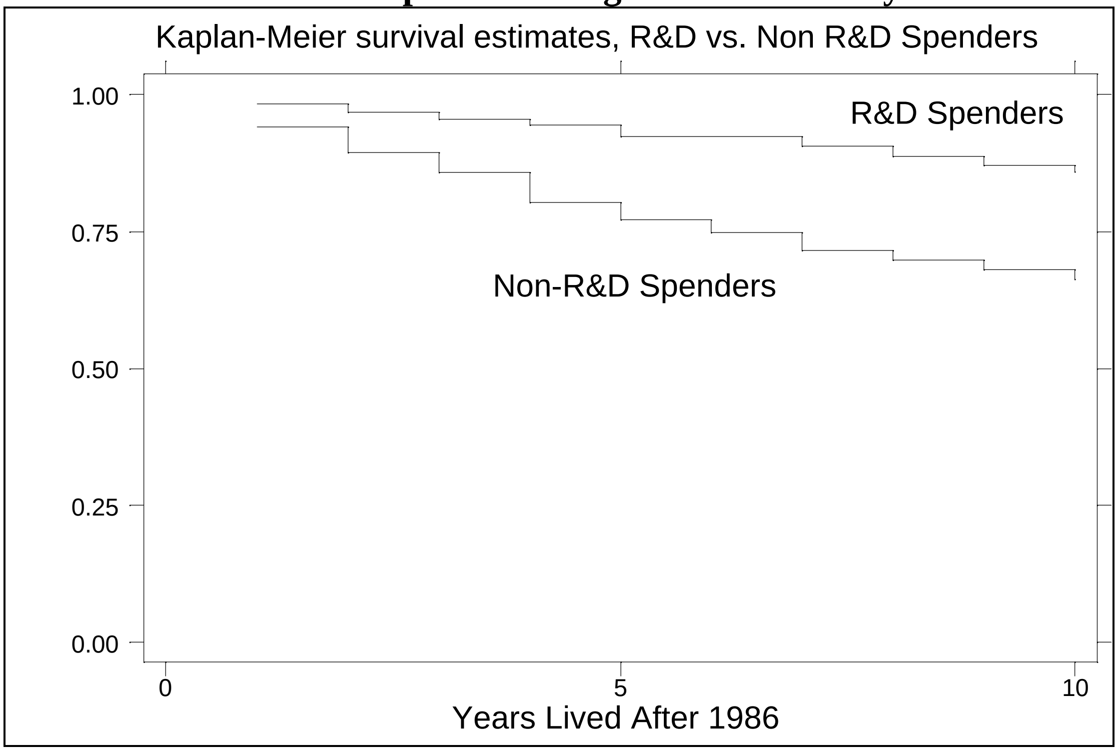

Figure 1: Over the entire duration (1986-1996) the probability of survival for R&D spending firms is greater than that of non-R&D spending firms.

Figure 2: Hazard Function based on Cox Regression (Equation 5.1)

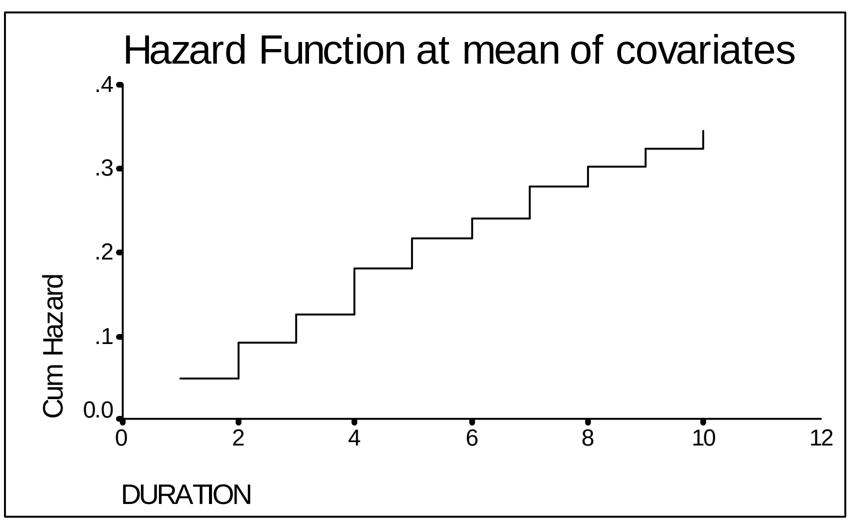

Figure 2: The longer the time period considered (duration) after 1986, the greater the risk of exit facing all of the plants. This function is estimated using the mean of the covariates.

Figure 3: Survival Function based on Cox Regression (Equation 5.1)

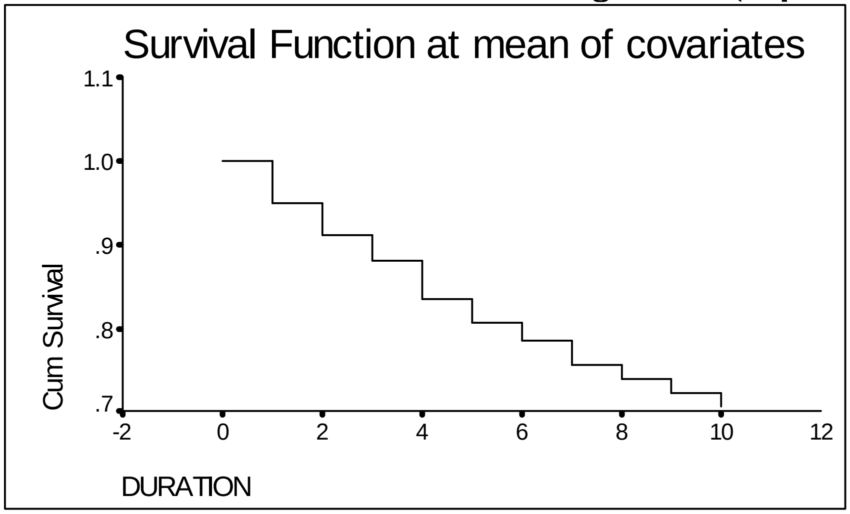

Figure 3: The longer the time period considered (duration) after 1986, the greater the the probability of survival facing all of the plants. This function is estimated using the mean of the covariates.

Figure 4: Hazard Functions based on Cox Regression (Equation 5.1) estimated for R&D Spenders vs. Non-R&D spenders

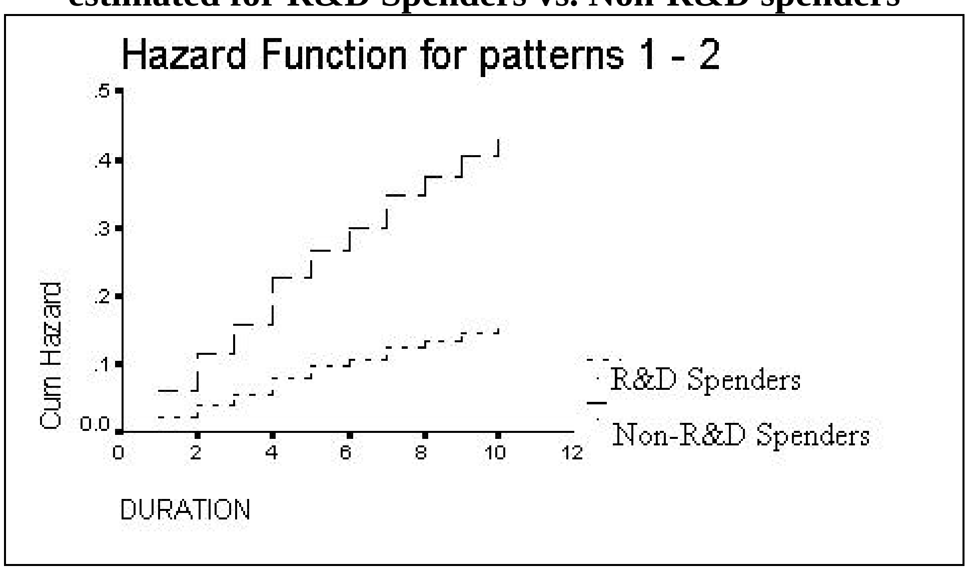

Figure 4: The longer the time period considered (duration) after 1986, the greater the the risk of exit facing all of the plants. However this risk of exit is lower for the R&D spending plants relative to the non-R&D spending plants over the entire period. This function is estimated using the mean of the covariates.

Figure 5: Survival Functions based on Cox Regression (Equation 5.1) estimated for R&D Spenders vs. Non-R&D spenders

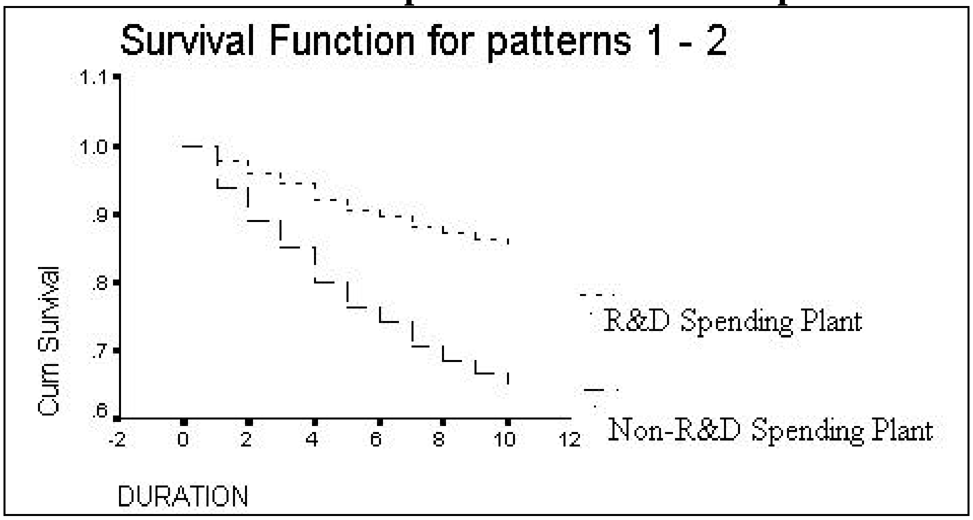

Figure 4: The longer the time period considered (duration) after 1986, the lower the the probability of survival facing all of the plants. However the probability of survival is higher for the R&D spending plants relative to the non-R&D spending plants over the entire period. This function is estimated using the mean of the covariates.

APPENDIX B

Diagnostics for the Life-Table Analysis

Wilcoxon (Gehan) statistics for the Probabilities of Survival between Industrial subsectors.

grouped by			24 SECTORAL CLASS			
Overall comparison			101.463	D.F.=21		Prob.=0.0000
Sector Names		**Total N**	**Exited**	**Survived**	**Pct Cen**	**Mean Score**
Food/Drink/Tobacco		541	153	388	71.72	60.3087
Textiles		86	34	52	60.47	-206.6163
Clothing		152	86	66	43.42	-564.3487
Leather/Footwear		35	18	17	48.57	-440.7429
Wood/Wood Products		102	38	64	62.75	-118.8039
Paper/Paper Products		45	5	40	88.89	425.1111
Printing/Publishing		165	32	133	80.61	266.2606
Chemicals		22	4	18	81.82	245.0455
Pharmaceuticals		35	8	27	77.14	125.9429
Rubber /Plastic Products		81	20	61	75.31	143.2469
Non-Metallic Products		146	39	107	73.29	93.863
Basic Metals		15	7	8	53.33	-363.9333
Fabricated Metals		268	78	190	70.9	39.8284
Machinery N.E.C.		88	32	56	63.64	-137.6364
Computer/Office Mach.		14	5	9	64.29	-97.0714
Electrical Machinery		51	15	36	70.59	81.451
Electronics		3	1	2	66.67	39.6667
Instruments		32	6	26	81.25	247.1563
Motor Vehicles		46	8	38	82.61	308.0217
Other Transport		14	7	7	50	-326.5714
Furniture/Other Manu.		171	59	112	65.5	-85

Wilcoxon (Gehan) statistics for the Probabilities of Survival between high and low-tech sectors.

	Overall comparison		2.281	D.F.=1		Prob= 0.1309
	label	**Total N**	**Exited**	**Survived**	**%**	**Mean Score**
	High tech	293	79	214	73.04	81.8737
	Low tech	1821	576	1245	68.37	-13.1735

Wilcoxon (Gehan) test for Non-R&D Spenders vs. R&D Spenders

Overall comparison statistic		79.565	D.F.	1	Prob= 0.0000
	Total N	**Exited**	**Survived**	**%**	**Mean Score**
Non-R&D Spenders	1661	591	1070	64.42	-101.285
R&D Spenders	453	64	389	85.87	371.3775

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