Small Firm Survival and Technological Activity

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ABSTRACT. The paper investigates the post entry performance of small firms competing under different technological environments. Small firm survival is compared over technical and non-technical products and over stages of differing technological activity. The empirical results, in the context of the product life-cycle framework, show that small firms enjoy a higher probability of survival in stages of high technological activity, and in products that are more technical in nature. Technological activity is also seen to affect the shape of the hazard rate function, implying that the relation between technological activity, age and small firm survival may be complex.

1. Introduction

Technological activity and firm attributes such as size and age are widely recognized as important determinants of firm entry, exit and survival.[1] While there have been several studies that focus on firm entry and exit, the issue of firm survival and hazard rates has only recently received attention in the literature. As Audretsch and Mahmood (1995) point out, a major reason is the lack of data that are (i) longitudinal, (ii) at the firm or establishment level and (iii) for sufficiently dissaggregated product categories rather than broad 3 or 4 digit SIC levels. This study uses a unique dataset that traces firm entry, exit and survival at annual intervals within specific product markets to address the issue of small firm survival within differing technological environments. i.e. the study investigates whether a small firm has a better chance of surviving in a high-tech or a low-tech environment.

Section 2 is a brief description of the relevant empirical literature and Section 3 highlights the stylized facts developed in the evolutionary framework. Section 4 deals with data and measurement issues. The results are presented in Section 5, followed by conclusions in Section 6.

2. Review of empirical evidence

The technological environment within which the firm operates is recognized as one of the major determinants of firm entry, exit and growth and survival. Theoretical models and stylized facts developed by Nelson and Winter (1978), Gort and Klepper (1982), Jovanovic (1982), Acs and Audretsch (1990), Jovanovic and MacDonald (1994a, b), and Malerba and Orsenigo (1995), consider the impact of technological activity chiefly on entry and exit of firms, while Audretsch (1991), Mahmood (1992), Audretsch and Mahmood (1995), Agarwal and Gort (1996), and Agarwal (1996, 1997a) study the relation between firm survival and technological activity. Audretsch (1991) finds an increase in small firm survival within an entrepreneurial regime, defined by a high small firm innovation rate relative to total innovation rate, while Audretsch and Mahmood (1995) find survival of all firms negatively affected by a high technological environment. Mahmood (1992) investigates the difference of hazard rates across low and high-tech industries, and finds them to be different. Agarwal (1996) addresses the complex relation between technological activity and firm survival, and the results of her study show that technological activity can both help and hinder survival. While entrant survival is higher in a high-tech environment, the hazard function – the probability of failure conditional on age – is also higher, reflecting the adverse effects of technical uncertainty and obsolescence of incumbent knowledge.

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Several studies have also addressed the issue of firm size and age as two of the chief determinants of firm survival. Jovanovic (1982) models firm growth and survival as a function of the efficiency level of the firms. Firms learn about their own efficiency levels only after they enter the market. Thus, it may take a firm some time to learn about its ability to compete. Once firms learn about themselves, the model predicts that firm survival will increase with age and size (level of output produced) of firm. Supporting evidence to this hypothesis has been found by various researchers. Dunne, Roberts and Samuelson (1988) use *Census of Manufactures* data for the 1972–1987 period and find a positive relation between firm age and survival throughout the observed age range. Baldwin and Gorecki (1991) consider entry in Canadian manufacturing industries within the 1970–81 period, and find high infant mortality among entrants, but that a significant percentage of the entrants are still alive after a decade. Hazard rates generally decline with age. Phillips and Kirchhoff (1989) use Small Business Administration data and find small firm survival rates more than double for firms that grow, and increase with age. Audretsch (1991) studies 11,000 firms from manufacturing over a ten year period using Small Business Administration data. His results too confirm the hypothesis that survival of firms increase with age. Mahmood (1992) finds that start-up size reduces hazard rate in both types of industries. The general consensus of these studies is that survival increases with age and decreases with size. Agarwal and Gort (1996) and Agarwal (1996, 1997a) find that while size is negatively related to survival, the relationship between age and survival may not always be monotonic. Using data on product market life cycles and over an extended age span, they are able to track senility points – when hazard rates increase with age.

Given the complex nature of relationship between size, age and survival, this study focuses on how small firms in particular perform over time and across differing technological environments, i.e. it investigates the post entry performance of small firms as a function of its age and technological activity. The technological environment within which the firm functions is measured in two distinct ways. Using the evolutionary approach first used by Gort and Klepper (1982), the study distinguishes between high tech and low tech stages of the product life-cycle. The life cycle stages are similar to the concepts of entrepreneurial and routinized regimes developed by Nelson and Winter (1978) and used by Audretsch (1991, 1995). Secondly, a distinction is made in terms of high-tech and low-tech products based on the level of technological activity measured by percentage of high-tech personnel employed.

3. Stylized facts in the evolutionary framework

Gort and Klepper (1982) and Jovanovic and MacDonald (1994a, 1994b) offer the theoretical basis for the evolutionary hypothesis, where the underlying innovative activity causes events in the product market to follow a path dependent on preceding events. Gort and Klepper distinguish between 5 stages in the evolution of product markets based on net entry. Stage 1 is the early period of few firms, immediately following a product innovation. Stage 2 is a period of increasing number of firms, when innovations in the market stem from outside rather than incumbent sources. Stage 3 is an interim period, when the number of firms in the product market peaks, followed by a shake-out stage 4. Innovations in stage 4 stem chiefly from within industry sources and the competitive intensity is highest in this stage, causing inefficient firms to exit the market. Stage 5 is the final stage where net entry is seen to be roughly zero. These evolutionary stages can be used as proxies for the underlying changes in technological activity and competitive intensity. The early stages (Stages 1 and 2) represent a period of high technological activity and uncertainty since the ratio of new to incumbent information is high, while later stages (Stages 3 through 5) show relatively lower levels of technological activity as the product market is more established.[2]

In a study of the evolutionary trends of key industry variables, Agarwal (1997b) finds that patenting activity declines over the later years of the product life cycle, and for most products, the decline in technological activity occurs in the period when number of firms contract. The theoretical models developed in Jovanovic and MacDonald (1994a, 1994b) lend support to the evolutionary framework described above. As mentioned earlier, these stages in the product market evolution also correspond to the concept of technological regimes (entrepreneurial and routinized) used in the empirical work conducted by Audretsch (1991, 1995) and Audretsch and Mahmood (1995). Agarwal and Gort (1996) and Agarwal (1996, 1997a) use the stages to investigate the impact of evolution of product markets on survival of firms.

4. Data, measurement issues and empirical analysis

The empirical analysis uses historical data developed for 33 product markets. Data on small firm entry, survival, and exit are extracted from a historical database developed using information in *Thomas Register of American Manufacturers*,[3] an annual publication that was first printed in 1906. The products in this study are a sub-set of the products used by Gort and Klepper, who chose the products on the basis of three criteria so as to include a broad range of type of products (consumer, industrial and military) which were basic innovations and had adequate data on net entry. 31 of the original 46 products are used,[4] and two new products – Contact lenses and Video cassette recorders – that gained prominence in the last two decades, are included to incorporate recent innovations and maintain representativeness of the sample.

Small firms are identified based on the asset size[5] of the firm, as listed by the *Thomas Register* at the time of its entry into the market. The products in the data set are classified as technical and non technical based on the study conducted by Hadlock, Hecker and Gannon (1991).[6] They used the ratio of R&D employees to total personnel to distinguish between technical and non technical industries. Of the 33 products in the data set, 21 are classified as technical and 12 as non technical products. The list of all the products in the analysis is given in the Appendix. The year of commercial introduction of the product market, the corresponding SIC code, and the technological index of the product are also included.

Life-table analysis is used to calculate survival and hazard rates of small firms across high-tech and low-tech stages and products. The Wilcoxon test of homogeneity is used to test if significant differences exist across technological categories.[7] Kernel estimation is a powerful non-parametric technique used to identify regularities in hazard rate patterns without forcing a particular structure by imposing parametric restrictions. It is widely used by statisticians, but since its use in the economic literature is limited, a brief explanation is warranted (See Silverman (1986) for details on kernel estimation techniques). In essence, if the relation between two variables $\{X_i, Y_i\}_{i=1}^{n}$ is given by

$$Y_i = m(X_i) + \varepsilon_i \tag{1}$$

where m is the unknown regression function, then the kernel estimate of m has the form

$$\hat{m}_\lambda(x) = \sum_{i=1}^{n} W(x, X_i; \lambda) y_i \tag{2}$$

where $W(x, X_i; \lambda)$ is the weight sequence for kernel estimates that depends on the kernel function K_o and the smoothing parameter or bandwidth λ. The weights are derived from a single function that is independent of the design:

$$W(x, X_i; \lambda) = \frac{K_o\left(\frac{x - X_i}{\lambda}\right)}{\sum_{i=1}^{n} K_o\left(\frac{x - X_i}{\lambda}\right)} \tag{3}$$

Symmetric probability functions (usually gaussian density) can be used as kernel functions. In general, the shape of the kernel is not considered to be of crucial importance, since there is no significant change in efficiency across different kernel functions. The bandwidth λ however, is an important factor in kernel estimation since it determines how much influence any one data point will have on the shape of the function. Higher values of λ imply more smoothing, while lower values may cause the function to be under smoothed. Optimal values of λ can be determined using criteria based on minimizing the mean squared error (MSE).

5. Empirical results

The section first addresses the issue of small firm survival and technological activity. An exposition of the relationship between small firm survival and age within different technological environments is presented using hazard rates. In what follows, firm

TABLE I
Small firm survival rate and technological activity

	Number of firms	Survival rate (in percentages)		
		1 year	5 year	10 year
Stage				
Low-tech	863	92.00	63.87	44.58
High-tech	1350	93.60	67.46	50.59
Wilcoxon test of homogeneity		$\chi^2 = 4.45$	p value = 0.0349	
Product				
Low-tech	711	90.43	61.01	45.37
High-tech	1502	93.87	68.50	50.00
Wilcoxon test of homogeneity		$\chi^2 = 7.67$	p value = 0.0056	
Stage and product				
Low-tech stage/low-tech product	225	89.76	59.03	38.51
High-tech stage/low-tech product	486	90.74	61.88	47.61
Low-tech stage/high-tech product	638	92.79	65.52	46.48
High-tech stage/high-tech product	864	94.67	70.63	52.32
Wilcoxon test of homogeneity		$\chi^2 = 13.78$	p value = 0.003	

Source: Data compiled from Thomas Register of American Manufacturers.

TABLE II
Kernel estimated hazard rates for stage and for product

	Stage		Product	
	Low-tech	High-tech	Low-tech	High-tech
		Kernel fit statistics		
c value	0.177	0.250	0.186	0.1734
R^2	0.68	0.74	0.90	0.69
MSE (GCV)	0.0004	0.00007	0.0002	0.0001
Age		*Estimated hazard rates*		
1	9.11	7.82	10.99	6.95
2	10.05	8.04	11.26	7.73
3	10.28	8.07	10.44	8.28
4	8.62	7.79	8.93	7.89
5	6.76	7.23	7.24	7.03
6	6.44	6.56	6.21	6.60
7	7.26	5.97	6.23	6.39
8	7.53	5.58	6.19	5.97
9	7.44	5.60	5.90	6.03
10	7.74	6.00	5.71	6.84
11	7.96	6.37	5.18	7.65
12	7.16	6.41	4.23	7.72
13	6.48	6.30	3.84	7.11
14	7.11	6.46	3.92	7.52
15	7.01	6.88	4.21	8.13

Source: Data compiled from Thomas Register of American Manufacturers.

cohorts are categorized based on stage of entry, and whether the product market was technical or non-technical.

5.1. *Small firm survival rates and technological activity*

Small firm survival rates is first examined separately across technological stages and across high-tech and low-tech products, and then within the interaction of stage and product. Table I reports the one-, five-, and ten-year survival rates for high and low technological stages, and high and low-tech products.

Small firms clearly have higher survival rates in a high-tech environment, and the tests of homogeneity show the differences to be significant across technological stages, products and for stage and product interaction. Across technological stages, while small firms in high-tech stages show only a one percent advantage over small firms in low-tech stages in the initial year, the differences increase over time. After ten years, the survival rate of small firms operating in a high tech stage shows a 14 percentage change relative to small firms in low-tech stages Similar results are seen for differences in technological level across products. The one year survival rate of small firms entering in high-tech products is three percent higher than small firms entering in low-tech products, and the five year survival rate shows a 12 percentage change of survival rates for small firms operating in high-tech products over counterparts in low-tech products.

The differences in survival rates as a function of technological activity is particularly obvious

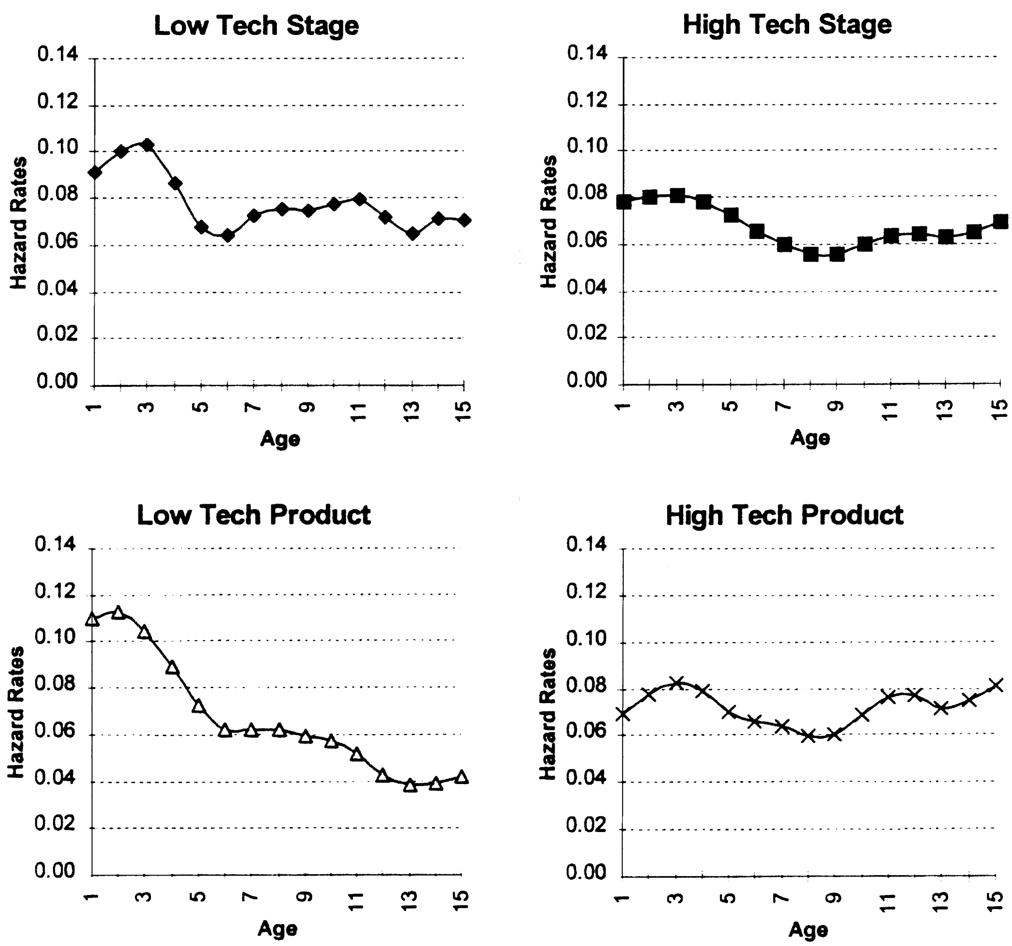

Figure 1. Kernel estimated hazard rates for stage and for product.

when the interaction of stage and product are considered. Small firms operating in a low-tech environment both in terms of stages and products are significantly worse off than their counterparts in a high-tech environment either in terms of stage or product. The one year survival rate is seen to steadily increase across more high-tech environments, and the ten-year survival rates also reflect adversities of the low technological activity. In particular, while a little more than a third of small firms survive ten years after entry in a low tech environment (stage and product), close to fifty percent of the firms that enter in some type of high-tech environment survive the same time span. This confirms the results obtained by Audretsch (1991). In an entrepreneurial regime, small firms show a higher success rate in terms of years of survival. Technological activity seems to favor small firms, and the negative impact of higher uncertainty in a high-tech environment seems to be overshadowed by the positive effects of informational advantages.

5.2. Small firm hazard rates and technological activity

This section explores the relation between small firm survival, age and technological activity by considering the hazard rates across stages and products differing in technological activity.

Table II and Figure 1 give the kernel estimated hazard rate functions of small firms first for high and low tech stages, and then for high and low tech products. The Jovanovic effect – increase in hazard rate in the first two years of a firm's life due to the time it takes to learn about its own efficiency level – is observed for all the hazard functions. Small firms show higher levels of failure rates in stages of low technological activity, consistent with the result on survival rates above. More importantly though, the shape of the hazard function for both low and high technological stages show a non-monotonic relation with age. Hazard rates decline in both types of technological stage immediately after the Jovanovic effect, but the decline is more rapid and ends at an earlier age (age six for small firms operating in the low

TABLE III
Kernel estimated hazard rates for stage/product interaction

	Low-tech stage Low-tech prod.	High-tech stage Low-tech prod.	Low-tech stage High-tech prod.	High-tech stage High-tech prod.
		Kernel fit statistics		
c value	0.205	0.332	0.183	0.204
R^2	0.58	0.74	0.60	0.63
MSE (GCV)	0.0024	0.0003	0.0004	0.0002
Age		*Estimated hazard rates*		
1	12.02	10.32	8.23	6.20
2	12.68	10.00	9.16	6.77
3	12.01	9.39	9.60	7.30
4	9.42	8.50	8.39	7.47
5	7.22	7.48	6.77	7.20
6	7.17	6.60	6.31	6.74
7	7.61	5.98	7.12	5.98
8	7.95	5.55	7.49	5.33
9	9.37	5.17	6.92	5.67
10	9.29	4.82	7.31	5.68
11	7.49	4.49	8.00	7.39
12	5.35	4.20	7.54	7.64
13	4.29	4.02	7.02	7.33
14	5.05	4.14	7.45	7.62
15	5.85	4.64	7.26	8.30

Source: Data compiled from Thomas Register of American Manufacturers.

tech stage. For firms operating in the high-tech stage, the decline in hazard rates is gradual and ends around age nine. While firms operating in the low tech stage seem to have a roughly constant hazard rate beyond age six, the hazard rates of small firms in the high-tech stage are seen to steadily increase in their later life span.

Turning to small firms operating in different types of products, one clearly sees the steady decline from a high level of hazard rate for low-tech products. In the high-tech product environment, while the levels of hazard rates are much lower for small firms, the firms are seen to experience an increase in hazard rates around age ten. Thus, the technological environment affects the shape of the hazard rate function. Plausible reasons for this phenomena stem from the complex relationship between technological activity and survival. While firms in a higher technological environment enjoy lower levels of hazard rates due to potential advantages gained by innovation, the obsolescence of knowledge causes their hazard rates to increase at later ages.

Table III and Figure 2 report the kernel estimated hazard rates for the interaction effects between stage and product. Infant mortality is the highest in the low tech environment in terms of both stage and product, and the lowest for high tech stage and product. Firms entering in the high tech stage of high tech products have an infant mortality rate of six percent, half of their counterparts entering in the low tech stage of low tech product who show a 12 percent infant mortality rate. The shape of the hazard function is also

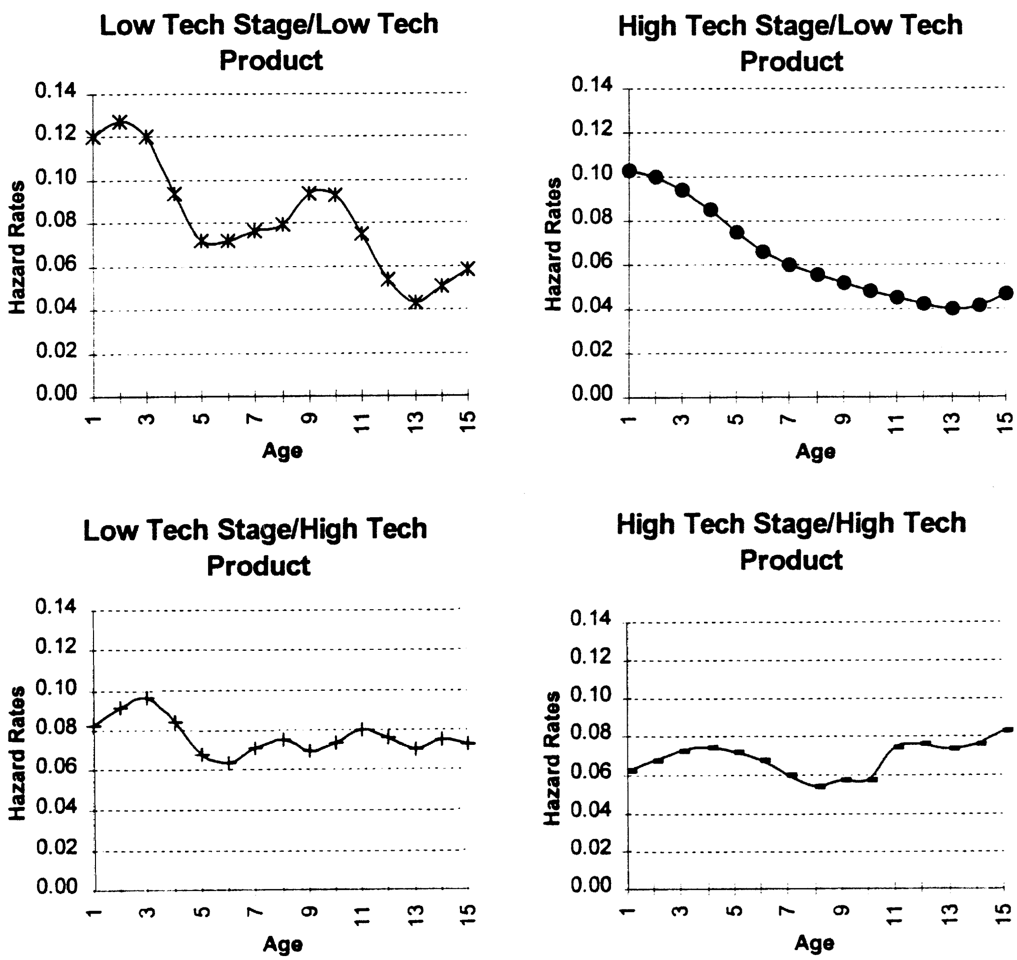

Figure 2. Kernel estimated hazard rates for stage/product interaction.

affected by the technological environment. The behavior of the hazard function is the most erratic in low tech product and stage, though the general pattern is seen to decline. Small firms operating in low tech products during the high tech period of the life-cycle show a smooth initial decline till age 11, after which obsolescence effects predominate. For small firms in low tech period of the life-cycle of high tech product markets, the hazard rate declines between ages 3 and 5, and is roughly constant thereafter. While firms in the high tech environment for both stages and product have the lowest infant mortality, their hazard rate increases steadily after age 7. One sees a complete reversal in hazard rate levels across technological environment for older firms. While infant mortality was lowest for firms entering in the high tech stage of high tech products, the mortality rate for older firms is the highest. Fifteen year old firms exhibit less than six percent mortality rate in the low tech environment, while counterparts in high tech stage and product experience more than eight percent mortality rates.

Existing theoretical models indicate a monotonic (either positive or negative) relationship between survival and technological activity, and a positive relation between survival and age of firm. The results above suggest a more complex relationship between age, survival and technological activity.

6. Conclusions

The paper investigates the post-entry performance of small firms under different technological regimes. Differences in technological activity is measured in two ways – the product market in which the firms operate, and the stage of the product life cycle. Small firm survival rate is affected by both the technological environment and the age of the firm. Higher levels of technological activity decrease the survival rate, particularly for new entrants.

More importantly, the data and the use of nonparametric techniques show that the shape of the hazard rate function is also affected by technological activity. While infant mortality is reduced when small firms compete in a high tech environment, the firms also face a higher rate of obsolescence of knowledge, which is reflected by an increase in hazard rates for old firms in particularly those stages and products where there is a high level of technological activity. By not imposing any structure as predicted by existing theories, the study shows that the relation between technological activity, age and small firm is not monotonic, and more complex than previously modeled. There is a need for further theoretical analysis that recognizes that technological environments can affect survival in a non-monotonic manner, i.e. that high-tech activity can both help and hinder survival.

Notes

[1] See Nelson and Winter (1978), Gort and Klepper (1982), Jovanovic (1982), Acs and Audretsch (1990), Audretsch (1991), Mahmood (1992), Audretsch and Mahmood (1995), Jovanovic and MacDonald (1994a, b), Malerba and Orsenigo (1995), Agarwal and Gort (1996), Agarwal (1996, 1997a).

[2] The stages are determined using discriminant analysis. For a detailed discussion on the decomposition of the stages, see Gort and Klepper (1982) and Agarwal and Gort (1996).

[3] The *Thomas Register* is a widely used source of information by purchasing agents of all companies and public agencies. Its completeness is a consequence of strong incentives on the part of the manufacturers to be included in the listing, since inclusion broadens the market for their products at no additional cost to them. The *Thomas Register* for a year is published in the early months (usually January/February) so that prospective clients can identify manufacturers of a product for the same year. Firms operating in a particular year are listed by product categories, and the constructed database contains information on every year that each firm was in operation in a particular product market.

[4] 15 of the 46 products could not be used for the new data development for various reasons. Some products, like Nylon, Telemeters, Computers and Solar Batteries had breaks in consistency either because the listing was missing in the *Thomas Register*, or due to substantial changes in the definition of the product over the years. Products like DDT and Cryogenic Tanks were omitted since these were discontinued over the years for which the analysis was extended (from 1973 to 1991). Other categories like Streptomycin and Penicillin were discarded in favor of a broader product group Antibiotics. Finally, a few products were not included in the analysis due to time limitations on the development of data.

[5] The *Thomas Register* lists the asset size of firms in categories ranging from less than 100,000 to greater than 250 million. Since the data spans a period of more than eighty years, the asset size boundaries for small firms are adjusted over time to account for inflation, and are available from the author on request.

[6] The decision is based on the classification of the products in 3 digit SIC industries for 1987 and therefore reflects difference in technology across products in the later stages. However, the distinction is believed to be largely applicable

to the entire life-cycle, since the differences in technology within a product life cycle are already captured by the stages in the life-cycle.

[7] Since small firms are identified at time of entry, we consider firm survival only in its first fifteen years. The Wilcoxon test is the most appropriate test for differences in survival and hazard rates that occur in the early years of a firm's history. (See Lee (1992)).

Appendix

Products in study, year of introduction, corresponding SIC code and technological index

Product name	Year of commercial introduction[a]	SIC code[b]	Technological index[c]
Antibiotics	1948	28331	1
Artificial Christmas Trees	1938	3999813	0
Ball-point Pens	1948	39511	0
Betaray Gauges	1956	n.a.	1
Cathode Ray Tubes	1935	36712	1
Combination Locks	1912	n.a.	0
Contact Lenses	1936	38516	0
Electric Blankets	1916	3634583	0
Electric Shavers	1937	36342	0
Electrocardiographs	1942	3845101	1
Freezers	1946	36322	0
Freon Compressors	1935	35854	0
Gas Turbines	9443	5112	1
Guided Missiles	1951	37611	1
Gyroscopes	1915	381112	1
Heat Pumps	1954	35851	0
Jet Engines	1948	372402	1
Microfilm Readers	1940	38614	1
Nuclear Reactors	1955	34436	1
Outboard Motors	1913	35195	1
Oxygen Tents	1932	3841176	0
Paints	1934	28513	1
Phonograph Records	1908	36520	1
Photocopying Machines	1940	38612	1
Piezoelectric Crystals	1940	36797	1
Polariscopes	1928	n.a.	0
Radar Antenna Assemblies	1952	3662021	1
Radiant Heating Baseboards	1947	3634820	0
Radiation Meters	1949	3829240	1
Recording Tapes	1952	36522	1
Rocket Engines	1958	3724220	1
Styrene	1938	2821361	1
Video Cassette Recorders	1974	36516	1

n.a.: not available

[a] Based on the Thomas Register of American Manufacturers.

[b] SIC Codes obtained from the Alphabetical list of SIC codes, Census of Manufactures 1987 Manual and from Predicasts.

[c] Technological index based on Hadlock, Hecker and Gannon (1991) classification of 3-digit SIC industries as technological by ratio of R&D personnel to sales.

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