R&D Entry, Persistence and Deepening: Evidence from Spanish corporate R&D

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ABSTRACT:
We analyse the growth of corporate R&D in the Spanish manufacturing sector through its decomposition into extensive and intensive margins. These margins are decomposed into three distinct components: starting new R&D activities; R&D activities that survive or persist; and deepening of existing R&D efforts. The data used is a panel of Spanish manufacturing firms drawn from the *Encuesta sobre Estrategias Empresariales*, for the period 1990-2006. We show that despite having experienced a substantial increase in R&D, the relative importance of each component differs for small and large firms, and for industry technological classification. We use numerical simulation to compare the increase in deepening, persistence an entry components that would be needed to achieve a given increase in corporate R&D growth.

KEYWORDS: R&D; Extensive margins; Intensive margin; Survival; Simulation
JEL Classification: O30, C15

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1 Introduction

The importance of investment in research and development (R&D) for a country's long-term rate of economic growth has received increasing attention both from researchers and policy-makers. Indeed, increasing R&D intensity is an issue of major concern for long-term European policy strategy. In 2000 the European Union launched the Lisbon Agenda, an ambitious strategy which aimed at making Europe the most dynamic knowledge economy by 2010. Two years later, in the spirit of the Lisbon strategy, the EU members set the "Barcelona target", a compromise to increase Europe's expenditure on R&D to 3% of GDP by 2010, two thirds of which should come from the private sector. Despite the very limited progress towards this target, it was ratified by the European Council in 2001 as one of the headline objectives of the Europe 2020 strategy. For instance, the EU27 on average spent on R&D just 1.83% of GDP in 2006, with Spain lagging significantly behind with only 1.2%. Regardless of the low R&D investment rates, Spain has experienced a substantial increase in R&D expenditure since the mid-1990s. This study aims to analyse the main components of these changes in corporate R&D expenditures for the Spanish industry and to inform innovation policy on possible channels to attain, or at least to converge, to the "3% target".

The recent availability of disaggregated data at firm level has increased the interest in a more careful accounting of changes in patterns of corporate R&D investment. In particular, the aim of this study is to analyse the growth of private R&D investment in the Spanish manufacturing sector through the decomposition into extensive and intensive R&D margins. The extensive margin refers to the evolution of R&D expenditure capturing the number of firms that start performing R&D (i.e. new firms with positive R&D expenditure). Whereas the intensive margin can be decomposed into two distinct parts: (i) established R&D activities that survive or persist; and, (ii) deepening existing R&D activities (intensifying the R&D investment effort by existing R&D performers). Starting new R&D activities (i.e. extensive margin) is the motivation behind many R&D promotion policies. However, such policies might in many occasions be of limited value as, in general, it is the intensification of R&D activities (i.e. the intensive margin) what reports the highest pay-offs in terms of inventions, patents or other output measures of innovation.

Previous literature analysing the distinction between intensive and extensive margins has focused mainly on volumes of trade (Besedes and Prusa, 2007) or on the adoption of new technology (Comin *et al.*, 2006), neglecting the decomposition for R&D investment. Moreover, the analysis of the survival and deepening components of the intensive margin are seldom distinguished in the literature. Existing research has focused only on changes in R&D investment and the number of firms undertaking R&D activities over time and implicitly considering only R&D deepening without taking into account the issue of survival of R&D performers. In this paper, we investigate that not accounting for this component may have consequences in the analysis of R&D expenditure and in its policy implications. This assertion is based on our following hypothesis:

Hypothesis 1: We expect R&D expenditures to be relatively low the first years for a new R&D spell and increase with the duration of the spell. We define an R&D spell as the number of years for which a firm continuously performs R&D activities (i.e., it has a positive R&D expenditure).

Hypothesis 2: The probability of failure of R&D spells decreases with the length of the spell (Mañez *et al. 2009b*)

These two hypotheses imply that increases in the intensive margin are only possible for those firms with high survival rates; otherwise we would not observe deepening of the R&D expenditures. In other words, we are assuming that deepening is conditional on survival. Further, higher survival rates would result in higher R&D expenditure growth even in the absence of deepening. And, the R&D activities embodied in failures dampen a country's overall R&D expenditure growth. Finally, the assumption of a constant failure rate across years and different technological industries is generally rejected by the data. By focusing just on the total number of firms engaged in R&D activities might overlook the role of R&D activity survival.

The aim of this research is to study the growth of R&D expenditure for Spanish manufacturing, applying the extensive and intensive margin decomposition approach to gain insight in the role played by these different components. To conduct our research we use a representative sample of Spanish manufacturing firms drawn from the *Encuesta sobre Estrategias Empresariales* (ESEE) for the period 1990-2006. Given the size of our database, we will analyse intensive and extensive margins by groups of industries, using as grouping criterion the technological intensity (high, medium and low tech industries). This study represents the first attempt, using a panel dataset of Spanish firms, to analyse the relative importance of the extensive and intensive margins in explaining corporate R&D growth.

The rest of the paper is organized as follows. Section 2 provides a review of previous literature on the intensive and intensive margins. Section 3 describes the data and comments on the representativeness of the sample. Section 4 provides some preliminary evidence of the intensive and extensive margins. The methodology used to decompose R&D growth is outlined in Section 5. Section 6 presents the main results relating to the intensive and extensive margins and their relative importance. Section 7 offers some concluding comments.

2. Related Literature

The relative importance of the extensive versus the intensive margin has been an issue of considerable debate in the international trade literature (Besedes and Prusa, 2007). Though there are studies that emphasize the importance of extensive margins in explaining the growth of trade volumes (Hummels and Klenow, 2005), numerous recent studies highlight the important role played by the intensive margin (Bernard *et al.*, 2009; Besedes and Prusa, 2007; Brenton and Newfarmer, 2007; and Helpman *et al.*, 2008). That is, the growth of trade comes primarily from existing trade flows rather than from new trade flows.

The distinction between the intensive and extensive margin has also received attention in the literature of adoption and diffusion of new technology (Comin *et al.*, 2006, and Battisti *et al.*, 2009). In this literature, the extensive margin relates to the spread of first use of a new technology across countries, industries or firms. On the other hand, the intensive margin relates to the extent to which the technology is used within countries, industries or firms. These studies also stress the importance of the intensive margin in explaining the growth of technological usage. In particular, Battisti *et al.* (2009) conclude that to achieve further usage of e-business, firms should concentrate upon greater depth (intensive margin) rather than greater breath (further spreading of basic usage).

Despite the number of studies looking at the distinction between intensive and extensive margin, the survival and deepening components of the intensive margins have been seldom analysed. In particular, existing research has focused mainly on the deepening component of the intensive margin without considering the issue of survival. Besedes and Prusa (2007) claim that this omission is not without consequence given that survival is a necessary condition for deepening and that longer survival would result in higher growth even in the absence of deepening.

Regarding the study of R&D growth, existing research has focused on changes in R&D investment driven by the number of firms undertaking R&D activities over time and implicitly considering only R&D deepening without taking into account the issue of survival of R&D performers in an integrated approach. Though economic theory emphasises that innovation is inherently a dynamic process between heterogeneous firms (Blundell *et al.*, 1995), firm level empirical evidence on the persistence in R&D activities is rather scarce[2]. Particularly, persistence in innovation have been studied from the output side of the innovation process[3], however few studies have paid attention to the input side, i.e. to the persistence in R&D activities (the exceptions being Máñez *et al.*, 2009a, 2009b; and

[2] There are several theoretical reasons that may explain persistence in innovation: learning effects (Rosemberg 1976); a success-breeds-success process (Mansfield 1968) or the existence of R&D costs (Sutton 1991). For a more detailed explanation see Mañez et al. (2009a, 2009b).
[3] The results on the output side are inconclusive. While studies using patents found low levels of persistence (Cefis 2003; Geroski et al. 1997), those using innovation counts obtain mixed findings: on one hand Duguet and Monjon (2004) and Rogers (2004) find high persistence, but on the other hand Geroski et al. (1997) and Raymond et al. (2006) could not ascertain innovation persistence for UK and Dutch manufacturing firms.

Peters, 2009). These studies found that R&D behaviour is persistent at the firm level to a very large extent and that innovation persistence is technology specific. Using survival techniques, Mañez et al. (2009b) focus exclusively on the determinants of the survival of R&D performers. They find that R&D capital is an important driver of R&D persistence and that firm's R&D spells exhibit negative duration dependence, indicating that the probability that a firms stops doing R&D decreases as the performance of R&D continues.

Among the other things highlighted this review makes clear that there is no prior study that tries to integrate the different aspects of the extensive and intensive margin in order to explain corporate R&D growth. Therefore, this will be our aim in this study.

3. Data

The data used in this paper are drawn from the *Encuesta Sobre Estrategias Empresariales* survey (ESEE), for the period 1990-2006. This survey, sponsored by the Ministry of Industry, is conducted yearly since 1990 (for more details on the survey, see, for example, Fariñas and Jaumandreu, 1999). The ESEE is representative of Spanish manufacturing firms classified by industrial sectors and size categories and provides exhaustive information at the firm level, including R&D expenditures. The sampling scheme is as follows. Manufacturing firms with less than 10 employees are excluded from the survey. Firms with 10 to 200 employees are randomly sampled by industry (at two-digit NACE level) and size, holding around a 5% of the population in 1990. All firms with more than 200 employees are requested to participate, obtaining a participation rate around 70%. The ESEE survey is an unbalanced panel given that some firms exit the market, shift to non-manufacturing activities or leave the survey.
Important efforts have been made to minimise attrition and to annually incorporate new firms with the same sampling criteria as in the base year, so that the sample remains representative over time.[4]

[4] See http://www.funep.es/esee/ing/i_esee.asp for further details.

3.1 Representativeness

In Table 1 we summarize the sample used, the percentage of employment, sales and R&D expenditure, for large and small firms in the 1990 complete sample and in the continuing sample.[5] Comparing these two samples we see that small firms are overrepresented in our sample (with respect to the complete sample in 1990) in terms of proportion of firms, employment sales and R&D expenditure. However, if we focus on the sample of firms (both large and small) performing R&D, see Table 2, and compare them with the sample of firms that do not perform R&D, we get that for small firms both the complete and the continuing samples provide very similar results in terms of percentage of firms, size, R&D expenditures over sales, sales and employment. For large firms we see that both the proportion of firms and the R&D expenditure over sales are quite similar for both samples but the figures differ in terms of size, sales and employment.

Table 1. Sample representativeness: large *versus* small firms, 1990.

	1990 complete sample		*Continuing sample 1990*	
Averages	Small firms	Large firms	Small firms	Large firms
Number of firms	1478	710	301	103
% of total sample	67.55%	32.45%	74.50%	25.50%
% of total employment	9.42%	90.58%	16.11%	83.88%
% of total sales	6.95%	93.05%	11.80%	88.20%
% of total R&D expenditure	3.90%	96.10%	13.36%	86.64%

Table 2. Sample representativeness: R&D firms *versus* non-R&D firms, 1990.

	1990 complete sample		*Continuing sample 1990*	
Averages	Non-R&D Firms	R&D firms	Non-R&D Firms	R&D firms
1. Small firms				
Number of firms	1215	249	256	45
% of total sample	82.99%	17.01%	85.05%	14.95%
Average size (employees)	32.64	66.65	29.56	63
R&D expenditure/Sales (average)	0%	4.42%	0%	2.93%
% of total sales	67.55%	32.45%	67.69%	32.31%
% of total employment	70.50%	29.50%	73.01%	26.99%
2. Large firms				
Number of firms	225	472	39	64
% of total sample	31.78%	68.22%	37.86%	62.14%
Average size (employees)	506.30	900.95	653.89	456.32
R&D expenditure/Sales (average)	0%	1.96%	0%	1.32%
% of total sales	19.31%	80.68%	58.27%	41.72%
% of total employment	21.13%	78.87%	46.61%	53.38%

[5] We will use the sample of continuing firms, which means firms that are in operation and do not suffer any process of merger, acquisition or other from 1990 to 2006.

Finally, in Table 3 we report the proportion of firms in low, med and high tech industries, both for small and large firms, for the complete sample in 1990 and the continuing sample.[6] For small firms we obtain very similar proportions while for large firms only the percentage of firms in low-tech industries is similar across samples, being the firms operating in med-tech industries overrepresented in our sample and the firms operating in high-tech underrepresented.

Therefore, we consider that the sample we use to carry out our analysis is comparable to the complete sample for small firms in most of the aspects we analyse and has some differences for large firms, although we get comparable figures for the variables of interest (size and R&D expenditure over sales)

Table 3. Sample representativeness by size and technological sector, 1990.

	Low-tech		*Med-tech*		*High-tech*	
	1990 complete sample	Continuing sample 1990	*1990 complete sample*	Continuing sample 1990	*1990 complete sample*	Continuing sample 1990
Small firms						
	885	180	368	82	225	39
	59.80%	59.80%	24.90%	27.24%	15.22%	12.96%
Large firms						
	285	45	223	39	202	19
	40.14%	43.69%	31.41%	37.86%	28.45%	18.45%

A key step in our analysis involves converting the annual data into spells of R&D activity. We define an R&D spell as the number of years for which a firm continuously performs R&D activities (i.e., it has a positive R&D expenditure).

[6] See the Appendix for the classification of industries in the three technological groups.

4 Extensive and Intensive Margins

4.1 Extensive Margin

We define the extensive margin as the number of new firms doing R&D in each technological sector. An industry can experience a change in its extensive margin if a firm that had not previously done R&D, starts performing R&D activities. We begin by providing summary statistics about the growth in corporate R&D, for small and large firms operating in low, med and high-tech industries. The first column in Table 4 shows the growth of aggregate R&D (in real terms) or each type of industry (high, medium and low-tech). The second column shows the growth in number of new firms doing R&D. We can see that the growth of R&D expenditure (which is related to the intensive margin) is always higher than the growth of R&D firms (more related to the extensive margin). Firms operating in the low-tech sector experience the largest gains in the growth of R&D firms. As regards to size, small firms experience larger gains in the growth of firms performing R&D,[7] however large firms have a higher growth in R&D expenditure on average.[8]

Another interesting descriptive statistic is the realized potential number of firms performing R&D. The maximum potential number is 100%. In columns 3 and 4 of Table 4 we report the maximum potential number of firms that can perform R&D activities both in 1990 (starting period of our sample) and in 2005 (final period). The figures in columns 3 and 4 reveal that, on average, only 14.95% of small firms perform R&D activities in 1990 and this figure rises to 19.93% in 2005. For large firms we observe that 63.11% of firms performed R&D activities in 1990 and 67.96% in 2005. Inspecting these figures by technological sector we find that the proportion of small firms performing R&D activities, both in 1990 and in 2005, increases significantly from low to high-tech sectors. For large firms this is not completely so as in 2005 the proportion of large firms performing R&D activities was larger in the med-tech sector than in the high-tech sector. For each technological sector and size group (except for large firms

[7] This conclusion is true for low, med and high-tech industrial sectors.

[8] Large firms operating in med-tech industries mainly drive this result, as the growth of R&D expenditure for small firms operating in low and high-tech industries is larger that the corresponding figures for large firms.

operating in high-tech sectors) we observe an increase in the potential number of R&D performers although there is still scope for gain, specially for small firms for which only 20% of them perform R&D activities (this proportion for large firms is around 68%). In summary, although firms have made an effort from 1990 to 2005 to undertake R&D activities, there are still many firms (especially among small firms) that do not perform these activities.

In the last two columns we investigate further the extensive margin. Thus, in column 5 we report the average number of firms that are in their initial year performing R&D, over the total number of firms performing R&D. We detect that the extensive margin is always greater for small firms (20.51% and 6.86% on average for small and large firms, respectively). The difference between small and large firms is especially relevant in low and me-tech industries where the small firms' extensive margin is around 25%. This suggests that the extensive margin may play an important role explaining R&D growth for small firms but does not seem to be so relevant for large firms.

Table 4. R&D and extensive margin growth rates, 1990-2005.

	Growth of R&D expenditure (Real terms) (1)	Growth of R&D firms (2)	Realized potential in 1990 (3)	Realized potential in 2005 (4)	Extensive margin (average) (5)	Value-weighted extensive margin (average) (6)
Total						
Small firms	4.83%	1.80%	14.95%	19.93%	20.51%	8.00%
Large firms	11.71%	0.46%	63.11%	67.96%	6.86%	1.13%
Small firms						
Low-tech firms	8.77%	3.37%	7.78%	13.33%	25.27%	10.66%
Med-tech firms	0.39%	0.83%	17.07%	19.51%	25.47%	10.67%
High-tech firms	6.29%	1.02%	43.59%	51.28%	7.97%	2.36%
Large firms						
Low-tech firms	3.86%	2.20%	42.22%	60.00%	10.64%	5.73%
Med-tech firms	18.52%	0.00%	76.92%	76.92%	4.63%	0.35%
High-tech firms	1.89%	-1.30%	84.21%	68.42%	4.17%	1.52%

Note: 1993 represents 99.51% of total R&D by new entrants and in 1998 represents a 97.53%.

In column 6 we present a weighted measure of the size of the extensive margin, where we use R&D expenditure to weight the extensive margin. The general pattern we observe is comparable to that observed in column 5, however these two columns differ in that R&D expenditures for new firms performing R&D are considerably smaller than those for firms that perform R&D on continuous basis. Thus we get, as one would expect, that new R&D performers invest less in R&D than established R&D performers. This evidence reinforces the idea that new R&D firms can only have a significant impact on the aggregate R&D growth of a country if they survive and deepen, as in their initial years the R&D expenditure is too small to have a significant effect on the overall R&D expenditure growth.

4.2. Intensive Margin

We define the intensive margin of R&D performance in terms of survival and deepening.

Survival

In a given calendar period, we find different lengths for the R&D spells: some firms perform R&D for a long period in a continuous basis, while others do so for a short period. Thus in the same period different firms are active in R&D for different number of years, and the distribution of duration reflects the longevity of active relationships. The duration in performing R&D is most appropriately summarised using survival analysis. We estimate the Kaplan-Meier survival function both for large and small firms and for low, med and high-tech sectors. We plot these graphs in Figures 1, 2 and 3.

In figure 1 we plot the survival distribution for large and small firms. From the inspection of figure 1 we can conclude that the survival function for small and large firms is very different.[9] Further, duration of R&D spells is remarkably short for small firms as compared with large firms. The median survival time is 2 years for small firms, while it is 11 years for large firms. That is, within small firms 50 percent of R&D spells fail in the first two years. Further, 50% of the R&D spells for large firms are still in function after 12 years whereas only 20% of the R&D spells for small firms are still in operation after 12 years. After 16 years, 45% of R&D spells for large firms are still alive but only 15% of the R&D spells survive within small firms. Therefore, large firms perform better than small firms in terms of survival or

[9] We test (using log-rank test) for equality of survivor functions. We reject the null hypothesis of equality with a $\chi^2 = 32.79$ and a *p*-value=0.000).

R&D spells. This high failure rate for small firms points out that when analysing the R&D growth rate we should be cautious to attributing gains along the extensive margin. This survival analysis reveals that increases in the extensive margin for small firms in a given year will disappear within few years. The above conclusion does not hold for large firms, as the R&D spell survival is much longer.

In figure 2 we plot the survivor functions for small firms disaggregated by technological sector (either low, med or high-tech sectors). We observe two different patterns in terms of survival: on the one hand, we observe that small firms operating in med and low-tech industries have a short R&D spell duration, the median survival time is 2 years for these firms, and on the other hand we have firms operating in high-tech industries which have a much longer R&D spell duration, with the median duration time being 11 years. Further, more than 45% of the R&D spells for firms operating in high-tech industries are still alive after 16 years, while this figure is around 10% for firms operating in low and med-tech industries. We test for equality of survivor functions and reject the null hypothesis of equality of the three functions.[10]

Finally, in figure 3 we plot the corresponding survivor functions for large firms across the three technological sectors. As shown, the R&D spell patterns for large firms are different to the ones obtained for small firms. The three survivor functions are very similar and we cannot reject the null hypothesis of equality.[11] However, the median duration time of spells changes across technological sectors: it is 5, 10 and 16 years for firms in low, high and med-tech industries, respectively. It is interesting to observe that large firms operating in med-tech industries enjoy the highest median survival rates. In any case, the results confirm that innovation persistence is a characteristic of large firms and, irrespectively of size, of high-tech sectors.

Deepening

[10] We reject the null hypothesis of equality with a $\chi^2 = 16.00$ and a *p*-value=0.000.

[11] We cannot reject the null hypothesis of equality with a $\chi^2 = 3.35$ and a *p*-value=0.187.

The examination of the survival component indicates that many small firms do not have an opportunity to deepen their R&D efforts given their early failure. To analyse the deepening component we are going to focus, particularly, on the long term relationships, by which we mean those R&D spells that continue for the entire period since 1990 to 2005.

Columns 1 to 3 of Table 5 characterize the long term deepening component of R&D. As discussed previously, small firms –particularly in low and med tech industries- are unable to continue doing R&D in the long term. This fact is also reflected in column 1, which reports the fraction of R&D spells in 2005 which were active in 1990. While 66% of large firms that did R&D in 1990 still continue persistently doing R&D in 2005; only 29% of small firms remain active. If we look at sectoral level, the differences between large and small firms are still more notorious with the exception of high tech industries, where the differences are less pronounced. For instance, in the case of low tech sectors we find that 63% of large firms continue persistently doing R&D for the whole period while only 7% of small firms do so. Looking at column 2 we observe that long term relationships embody the majority of R&D value. Large firms, especially those in med tech and high tech sectors have more than 90% of their 2005 R&D value embodied in the long term relationship. Small firms in the med-tech sector have the lowest percentage of their 2005 R&D value in long term relationship at 36%, followed by small firms in low-tech sectors. High failure rates and low fractions of R&D value embodied in long term spells suggest an important role of survival for R&D growth in small firms, with the only exception of small firms in high tech sectors. The results imply that small firms have a larger share of their R&D embodied in short term R&D activities which are more likely to fail, given that few of them persist doing R&D over the long term.

Column 3 examines average annual deepening of long term relationships. Independently of size, we observe that R&D long term performers in med tech industries deepen at a faster rate than those in other sectors, particularly in low tech sectors. Overall, small firms deepen at lower rates than large firms, with a larger difference in the high tech industries in which the deepening rates are 5.7% for large and 2.55 % for small firms.

Columns 4 and 5 provide a different perspective of the deepening component. We obtain deepening rates for spells of 5 and 10 years respectively. In other words, these figures represent the annual average growth rate of R&D value for firms doing continuously R&D over at least 5 and 10 years respectively. Comparing with the results for the long terms spells we observe that the deepening rate increases with the number of periods doing R&D. Overall, the deepening rate is 3.34% (-1.01%) for large (small) firms doing R&D for at least 5 years, 5.06% (4.24%) for firms doing R&D for at least 10 years, and 5.69% (4.34%) for the long term R&D performers. Interestingly, the value of R&D for spells of at least 5 years decreases in the case of small firms, due to the decrease in med tech small firms. For longer spells, we always observe positive deepening rates. Additionally, we observe similar patterns than in the analysis of long term spells, i.e. independently of the technological sector, small firms deepen at lower rates than large firms.

Table 5. Deepening in performance of R&D, 1990-2005.

	Long term spells			R&D value (average growth)	
	Fraction of 2005 R&D spells (1)	Fraction of 2005 R&D value (2)	Average growth of R&D value (intensive)[(1)] (3)	For spells of at least 5 years of duration (4)	For spells of at least 10 years of duration (5)
Total					
Small firms	28.88%	56.33%	4.34%	-1.01%	4.24%
Large firms	66.15%	95.50%	5.69%	3.34%	5.06%
Small firms					
Low-tech firms	7.14%	54.82%	2.22%	2.20%	4.68%
Med-tech firms	21.43%	36.00%	6.23%	-6.05%	0.90%
High-tech firms	52.94%	70.53%	2.55%	0.99%	5.21%
Large firms					
Low-tech firms	63.16%	72.93%	2.96%	0.64%	2.27%
Med-tech firms	66.67%	97.67%	7.30%	4.97%	6.67%
High-tech firms	68.75%	91.80%	5.70%	5.25%	5.36%

Notes:

(1) Average cumulative annual rate.

5. Decomposing R&D growth

5.1 Methodology

To examine how the intensive and extensive margins explain the evolution of R&D expenditure growth we first need to decompose R&D expenditure to capture the two dimensions we are interested in. Thus, for any year t we can write the total value of corporate R&D expenditure for technological intensity group $z \in Z$ (where Z is either high, medium and low tech groups) and for size group $j \in J$ (where J is small and large)[12] as:

$$V_{zj,t} = n_{zj,t} v_{zj,t}$$

where $V_{zj,t}$ is the value of total corporate R&D expenditure in year t for size group j and technological group z, $n_{zj,t}$ is the number of R&D spells, and $v_{zj,t}$ is the average value of R&D expenditure for each R&D spell in year t. R&D spells consist of those that survive from $t-1$ to t, denoted $s_{zj,t}$, and new spells, denoted $e_{zj,t}$, so that we can write $n_{zj,t} = s_{zj,t} + e_{zj,t}$.

Using the above notation, the increase in total R&D expenditure for size group j and technological intensity group z, from period t to $t+1$, can be written as:

$$\begin{aligned} V_{zj,t+1} - V_{zj,t} &= n_{zj,t+1} v_{zj,t+1} - n_{zj,t} v_{zj,t} = (s_{zj,t+1} + e_{zj,t+1}) v_{zj,t+1} - (s_{zj,t} + e_{zj,t}) v_{zj,t} = \\ &= s_{zj,t+1} v_{zj,t+1} + e_{zj,t+1} v_{zj,t+1} - s_{zj,t+1} v_{zj,t} - d_{zj,t} v_t = s_{zj,t+1}(v_{zj,t+1} - v_{zj,t}) - d_{zj,t} v_{zj,t} + e_{zj,t+1} v_{zj,t+1} \end{aligned} \tag{1}$$

where $s_{zj,t+1}$ is the number of surviving spells from t to t+1, $(v_{zj,t+1} - v_{zj,t})$ is the growth of R&D expenditure for each surviving spell, $d_{zj,t}$ is the number of R&D spells that fail in t, being $d_{zj,t} v_{zj,t}$ their total value in terms of R&D expenditure, and $e_{zj,t+1}$ is the number of new R&D spells, being $e_{zj,t+1} v_{zj,t+1}$ its total value in terms of R&D expenditure.

[12] Due to the sampling scheme of the ESEE (see data section) we carry our analysis for two size groups of firms: small firms (those with 10 to 200 employees) and large firms (those with more than 200 employees).

We aim to refine our decomposition for R&D growth in each technological intensity group z, considering that the probability of failure for an R&D spell in t may depend on the age of the spell (more specifically, we expect the probability of failure to be negatively related with the duration of the spell; i.e. negative duration dependence). To do so, we need to incorporate the age of the R&D spell into the decomposition. And second, we may estimate survival and hazard functions at the technological intensity group level. If we take into account these two refinements, we can define:

$$
\begin{aligned}
s_{zj,t} &\equiv \left\{ s^0_{zj,t}, s^1_{zj,t}, s^2_{zj,t}, \ldots, s^i_{zj,t}, \ldots, s^I_{zj,t} \right\} \\
d_{zj,t} &\equiv \left\{ d^0_{zj,t}, d^1_{zj,t}, d^2_{zj,t}, \ldots, d^i_{zj,t}, \ldots, d^I_{zj,t} \right\} \\
v_{zj,t} &\equiv \left\{ v^0_{zj,t}, v^1_{zj,t}, v^2_{zj,t}, \ldots, v^i_{zj,t}, \ldots, v^I_{zj,t} \right\} \\
h_{zj,t} &\equiv \left\{ h^0_{zj,t}, h^1_{zj,t}, h^2_{zj,t}, \ldots, h^i_{zj,t}, \ldots, h^I_{zj,t} \right\}
\end{aligned}
$$

where superscript i denotes the age of the spell (survival year), and $h_{zj,t}$ denotes the hazard rate for an R&D spell in size group j and technological intensity group z, ending between t-1 and t. As we have interval group data we assume that the minimum duration of the R&D spell is one year, $s^0_{zj,t} \equiv 1$ (by extension $d^0_{zj,t} \equiv 1$ and $h^0_{zj,t} \equiv 1$). The expression $s^i_{zj,t}$ denotes the number of R&D spells between t-1 and t that survive through the i^{th} year of uninterrupted performance of R&D.

Now, we can rewrite equation (1) as follows:

$$
V_{zj,t+1} - V_{zj,t} = \underbrace{\sum_{i=1}^{I} \underbrace{\left[\left(1 - h^i_{zj,t+1}\right) n^i_{zj,t} \right]}_{survival-stayers} \underbrace{\left[v^i_{zj,t+1} - v^i_{zj,t} \right]}_{deepening} - \sum_{i=1}^{I} \underbrace{\left[\left(h^i_{zj,t+1} n^i_{zj,t} \right) v^i_{zj,t} \right]}_{failures}}_{\text{Intensive margin}} + \underbrace{\underbrace{e_{zj,t+1} v^0_{zj,t+1}}_{entrants}}_{\text{Extensive margin}} \qquad (2)
$$

where I denotes the maximum potential length of an R&D spell; $(1 - h^i_{zj,t+1})$ gives the percentage of surviving R&D spells between t and t+1; and, $(1 - h^i_{zj,t+1}) n^i_{zj,t}$ gives the total number of surviving R&D

spells between t and t+1 that correspond to firms performing R&D uninterruptedly for i years. Expression $\left[v^{i}_{zj,t+1} - v^{i}_{zj,t}\right]$ represents the deepening or growth in R&D expenditures for surviving R&D spells; $(h^{i}_{zj,t+1} n^{i}_{zj,t})$ gives the number of R&D spells that end in year t+1; $(h^{i}_{zj,t+1} n^{i}_{zj,t}) v^{i}_{zj,t}$ gives their total value; and, $e_{zj,t+1} v^{0}_{zj,t+1}$ gives the value of new R&D performers in year t+1.

If we sum equation (2) across the three technological intensity groups, we can decompose the variation in total manufacturing R&D expenditure for size group j in intensive and extensive margins:

$$V_{j,t+1} - V_{j,t} = \sum_{z \in Z} \left\{ V_{zj,t+1} - V_{zj,t+1} \right\} = \sum_{z \in Z} \left\{ \sum_{i=1}^{I} \left[(1 - h^{i}_{zj,t+1}) n^{i}_{zj,t} \right] \left[v^{i}_{zj,t+1} - v^{i}_{zj,t} \right] - \sum_{i=1}^{I} \left[(h^{i}_{zj,t+1} n^{i}_{zj,t}) v^{i}_{zj,t} \right] + e_{zj,t+1} v^{0}_{zj,t+1} \right\} \tag{3}$$

This equation is the decomposition of the growth of total R&D expenditures into extensive and intensive margins that we propose. The intensive margin is comprised of deepening and survival. Higher survival (lower hazard) results in more R&D spells (more continuing R&D spells and fewer failures). The final term captures the extensive margin. We would like to emphasize that it is crucial to account for the age of the R&D spell as we expect the probability of failure of an R&D spell to be higher at earlier stages (negative duration dependence).

A further step to evaluate the importance of survival, deepening and entry to explain the growth of R&D expenditures, for each of the different technological intensity groups is to undertake counterfactual exercises.

5.2 Counterfactuals exercises

To assess the contribution of each of the R&D expenditure growth components we will carry out a series of counterfactual exercises. These will be performed by substituting each of the R&D growth components in equation (3) by a hypothetical firm or group of firms. In doing so we will be able to answer the question of what would have been the R&D growth performance of small (large) firms had they had other (hypothetical) experience in each of the components (either survival, deepening or entry). These exercises will allow us to assess the importance of each component on R&D growth. To analyse how the R&D growth of each group of firms would change with counterfactual survival we would change the survival component in equation (3) by the counterfactual values,

$$V_{j,t+1} - V_{j,t} = \sum_{z \in Z} \left\{ \sum_{i=1}^{I} \left[(1 - h_{zj,t+1}^{CF,i}) n_{zj,t}^{i} \right] \left[v_{zj,t+1}^{i} - v_{zj,t}^{i} \right] - \sum_{i=1}^{I} \left[(h_{zj,t+1}^{CF,i} n_{zj,t}^{i}) v_{zj,t}^{i} \right] + e_{zj,t+1} v_{zj,t+1}^{0} \right\} \tag{4}$$

where the superscript *CF* denotes the counterfactual values. Analogously, we can calculate the counterfactual deepening and entry effects, respectively, as follows:

$$V_{j,t+1} - V_{j,t} = \sum_{z \in Z} \left\{ \sum_{i=1}^{I} \left[(1 - h_{zj,t+1}^{i}) n_{zj,t}^{i} \right] \left[v_{zj,t+1}^{CF,i} - v_{zj,t}^{CF,i} \right] - \sum_{i=1}^{I} \left[(h_{zj,t+1}^{i} n_{zj,t}^{i}) v_{zj,t}^{i} \right] + e_{zj,t+1} v_{zj,t+1}^{0} \right\} \tag{5}$$

$$V_{j,t+1} - V_{j,t} = \sum_{z \in Z} \left\{ \sum_{i=1}^{I} \left[(1 - h_{zj,t+1}^{i}) n_{zj,t}^{i} \right] \left[v_{zj,t+1}^{i} - v_{zj,t}^{i} \right] - \sum_{i=1}^{I} \left[(h_{zj,t+1}^{i} n_{zj,t}^{i}) v_{zj,t}^{i} \right] + e_{zj,t+1}^{CF} v_{zj,t+1}^{0} \right\} \tag{6}$$

The decomposition of growth in each of the components allows us to evaluate how different the R&D of each group of firms would have been if it had had the chosen (hypothetical) counterfactual survival, deepening and entry performance.

6. Results

In this section we present the decomposition of R&D growth, for small and large firms, in each of the components and the counterfactual results.

6.1. Decomposition of R&D growth

We start by analysing the decomposition of R&D growth by size group. In table 6 we report the percentage contribution of both the intensive and extensive margin to R&D growth. We also divide the intensive margin into its two components: the contribution of survivors (survivors times deepening) and the contribution of the firms that fail to continue performing R&D.

For small firms we find that, as expected (see table 4), the extensive margin is the main driver of R&D growth (167.61%). And we find that the intensive has a negative contribution (-67.61%). If we analyse in detail the intensive margin we find that although the contribution of surviving small firms is important and positive (179.67%), the negative impact of the failures (-247.28%) more than compensates this contribution resulting in a negative contribution of the intensive margin. On the other hand, we find the opposite situation for large firms. In this case the main driver of R&D growth is the intensive margin (89.02%). This is consistent with the results obtained in table 4. Looking at the components of the intensive margin for large firms, we find a significant contribution of surviving firms (122.27%) that it is only reduced by a 33.24% due to firms that fail in performing R&D activities, resulting in a positive and significant contribution of the intensive margin (89.61%). Finally, the intensive margin only contributes with a 10.98%.

Table 6. Decomposition of R&D growth components, 1990-2005.

	Intensive margin (%) components			
	(Survival)x(deepening) contribution (%)	Failures contribution (%)	Total intensive margin (%)	Total extensive margin (%)
Small firms	179.67%	-247.28%	-67.61%	167.61%
Large firms	122.27%	-33.24%	89.02%	10.98%

Notes:

In sum, the R&D behaviour of small firms is characterised by high rates of turnover and low persistence. Growth rates of R&D are explained mainly by the R&D spent by new performers; while the increase in R&D done by companies that continue doing R&D is more than compensated by the loss of those that fail. On the contrary, the R&D behaviour of large firms in the Spanish manufacturing sector is characterized by high persistence. The overall growth rate of large firms is explained mainly by the growth of R&D of continuous performers.

6.2. Counterfactual exercises

In this section we describe the counterfactual results obtained for each size group and technological sector. Before presenting the results we explain the hypothetical exercise we carry out in this research. We calculate the counterfactual results for each size group of firms (and for each technological sector) by increasing in a 5% either the survival, deepening or entry components (we also provide results increasing these components by a 10 and a 15%)[13]. The aim behind these exercises is to assess the importance of each component (for each group of firms) should we intended to increase the R&D growth rate. These results will help us in providing policy prescriptions to increase the R&D growth among Spanish manufacturing.

In table 7 we present the results from the 3 counterfactual exercises we have performed. For these three exercises we consider a specification where we allow each technological sector and size group hazard rate to vary by the spell length and starting year. In particular, we estimate a separate hazard function for each size and technological intensity group spell starting in every observed calendar year (e.g., a hazard function for each technological industry and size group for spells starting in 1990, 1991, etc.).[14] As mentioned above, we provide three exercises changing the percentage of increase for the three components to check if our results are robust. As we get almost lineal changes when changing the proportion of increase, we comment the results for the exercise where we increase the components by a 5%.

[13] It is important to clarify that a 5% increase in the survival component is not equivalent to a 5% increase in the deepening or entry component. Therefore, it is meaningless to compare percentage increases across columns of table 7.

[14] By allowing the hazard rates to vary along these dimensions we can control for the fact that a size group and/or technological sector experiences changes in its hazard over calendar time.

In the first column, we present the actual average annual growth of R&D expenditure (in real terms) for each size group and technological sector, for the period 1990-2005. The following three columns report the average change in the R&D expenditure growth we would observe if each of the three components (survival, deepening and entry) of R&D growth experienced a hypothetical increase of 5%. In order to interpret the changes for each counterfactual we compare the percentage change in the R&D growth within each column. In particular and for the survival component, we find that a hypothetical increase in 5% in the survival rate would have a much larger impact on R&D growth for small than for large firms. The increase in R&D growth that small firms would experience is 0.41 percentage points (from 4.83% to 5.24%) whereas the increase for large firms would be 0.09 percentage points (from 11.71% to 11.80%).

Table 7. Counterfactual exercises and R&D growth components.

		Increase of 5%			Increase of 10%			Increase of 15%		
	Actual R&D growth	Survival	Deepening	Entry	Survival	Deepening	Entry	Survival	Deepening	Entry
Total										
Small firms	4.83%	0.41	0.87	0.27	0.78	1.63	0.54	1.25	2.32	0.79
Large firms	11.71%	0.09	1.03	0.03	0.17	1.92	0.06	0.26	2.70	0.09
Small firms										
Low-tech	8.77%	0.44	1.25	0.32	0.82	2.29	0.62	1.21	3.18	0.92
Med-tech	0.39%	0.79	1.63	0.56	1.51	2.93	1.07	2.14	4.00	1.54
High-tech	6.29%	0.12	0.50	0.05	0.24	0.96	0.09	0.35	1.39	0.14
Large firms										
Low-tech	3.86%	0.17	0.47	0.20	0.33	0.90	0.39	0.48	1.3	0.58
Med-tech	18.52%	0.09	1.16	0.01	0.18	2.14	0.02	0.26	2.99	0.03
High-tech	1.89%	0.10	0.60	0.08	0.19	1.15	0.15	0.28	1.65	0.22

However, the increase in R&D growth is not homogeneous across technological sectors. Thus, the increase in R&D growth for small firms operating in med-tech industries is the largest (0.79 percentage points) and almost double what small firms operating in low-tech firms would experience (0.44 percentage points). Further, the increase in R&D growth for small firms operating in high-tech sectors is the lowest (0.12 percentage points). We also find heterogeneous results across technological sectors within large firms although the differences are smaller.[15] We see that increasing the survival rate by a 5% (or equivalently by reducing the hazard rate by 5%) would have the largest impact on R&D growth (0.17 percentage points) for large firms operating in low-tech industries as compared to large firms operating in med and high-tech industries (0.09 and 0.10 percentage points, respectively). These results help to clarify the relative impact of this component on R&D growth. From the above evidence we can conclude that survival is a much more important factor (about 4 times larger) for small firms R&D growth than for large firms, and this is especially important for small firms operating in med-tech (and in low-tech) industries. The above results are consistent with the descriptive evidence we presented in section 4: survival for small firms' R&D spells is lower than the corresponding for large firms, being especially low the survival for small firms operating in low and med-tech industries.

As regards the deepening component we observe that the increase in R&D growth, if there was a hypothetical increase in the deepening component of 5%, would be larger for large firms than for small firms, 1.03 and 0.87 percentage points, respectively. However, these aggregate figures hide a heterogeneous pattern across technological sectors. As regards to small firms, we observe that the increase in the deepening component would increase the R&D growth by 1.63 percentage points for firms operating in med-tech industries, by 1.25 percentage points for firms in the low-tech industries and by only 0.50 percentage points for firms operating in high-tech industries.

Thus, our results seem to suggest that deepening is an important factor for small firms whose activities are in med-tech (and also, to a lesser extent, for low-tech industries), but not for firms in high-tech industries. If we turn to large firms, we obtain a similar conclusion. The increase in R&D growth, if there was a 5% increase in the deepening component, would be 1.16, 0.60 and 0.47 percentage points for firms operating in med, high and low-tech industries, respectively. Therefore, as previously, deepening turns out to be the most important component for firms operating in med-tech industries, regardless of their size, in order to increase the R&D growth.

---

[15] We find (see section 4.2) that the survivor functions for large firms are not distinguishable across technological sectors as we cannot reject the H_0 of equality of the three survivor functions.

Finally, regarding the entry component, we observe that a hypothetical increase in the entry rate by 5% would increase the growth rate of R&D by 0.27 percentage points in small firms, while the average increase is nearly non significant in the case of large firms (0.03 percentage points). Again, the impact of an increase in the entry rate is not uniform across technological sectors. Within small firms, those in the med-tech industry experience the largest change with an increase of 0.56 percentage points; followed by firms in the low-tech industry (0.32) and those in the high-tech are the ones experiencing the lowest impact (0.05). Regarding the impact in large firms, an increase in the entry rate by 5% would only have a significant impact in low-tech firms, which would see an increase in the R&D growth rate of 0.20 percentage points. Therefore, and supporting the evidence found in the descriptive analysis, entry appears to be particularly important in small firms, or independently of size in med-tech industries.

Additionally, in order to assess the relative importance of each component for R&D growth we carry out a numerical simulation exercise. In this exercise we would simulate how much should any component vary in order to achieve an increase in the average R&D growth of a one-percentage point. By performing these simulations we will be able to assess the relative importance of each component for each group of firms and also across groups of firms. These results are reported in table 8.

We start by comparing large and small firms. For both groups of firms, the most effective target to reach an increase of a one-percentage point is the deepening component, being the required variations quite similar for both groups of firms. In other words, to increase the average R&D growth rate of small and large firms we would need to increase the amount of R&D spent by R&D performers (i.e. the deepening component) in 5.62% and 4.82% for small and large firms, respectively. However, we find remarkably differences in the other two components. Thus, whereas for small firms we would need either to increase the entry component by an 18.65%, or to reduce (increase) the hazard rate (survival) by 11.64%, these figures would be 186.88% and 51.52% for entry and survival, respectively, for large firms. This evidence points out that deepening is an important component, as compared to the other two components, for small firms but it reveals to be, by far, the most important component for large firms. This adds evidence to our descriptive analysis and indicates that survival for large firms is already high and in order to achieve a significant increase in R&D growth through this component a big effort would be needed. As regards to entry, we presented in our descriptive statistics that entry is very low for large firms (see table 4) and thus the increase in the number of large firms doing R&D should also be significant in order to make a contribution of one percentage point to R&D growth.

The results presented above are not uniform across technological sectors. Thus, for small firms, although deepening is the most important component to reach a one percentage increase in R&D growth in the three technological sectors, we find important differences in the other two components between small firms operating in low and med-tech sectors as compared to firms operating in high-tech sectors. In particular, the increase in entry and in survival should be much larger for small firms in high-tech sectors as compared to firms in low and med-tech sectors. Therefore, this points to the fact that deepening is comparatively the most important component for small firms operating in high-tech sectors. This is consistent with the descriptive evidence we presented in table 5 and indicates that high-tech small firms have a profile similar to large firms.

Table 8. Numerical simulation exercises and R&D growth components.

	Actual R&D growth	1 percentage point increase in R&D growth	Survival	Deepening	Entry
Total					
Small firms	4.80%	5.80%	11.64%	5.62%	18.65%
Large firms	11.71%	12.71%	51.52%	4.82%	186.88%
Small firms					
Low-tech	8.77%	9.77%	12.26%	3.92%	16.47%
Med-tech	0.39%	1.39%	6.47%	2.91%	9.35%
High-tech	6.29%	7.29%	36.75%	10.40%	107.99%
Large firms					
Low-tech	3.86%	4.86%	26.07%	11.24%	26.87%
Med-tech	18.52%	19.52%	56.01%	4.25%	519.61%(1)
High-tech	1.89%	2.89%	53.21%	8.61%	74.04%

Notes:
(1) The result we obtain for large firms in med-tech industries is not very reliable, as we do not have much entry in this sector along the period of analysis.

As regards to large firms, we find that the three components are quite similar for large firms in med and high-tech industries (except for the entry component for firms in med-tech sectors)[16]: for both groups of firms deepening is by large the most important component, being especially important for med-tech industries. It is important in the sense that we would only require a modest increment in the deepening rate to attain the desired target. For large firms operating in low-tech industries we also find that deepening is the most important component but this does not differ significantly from the importance of the other two components: survival and entry. Therefore we can conclude that deepening is the most important component to achieve an increase of a one-percentage point in R&D growth for large firms regardless of the sector in which they operate.

7. Conclusions

The objective of this paper was to study the differences in the growth of corporate R&D expenditure in the Spanish manufacturing sector based on their performance at the extensive and intensive margin. To do so, we use firm level data on R&D expenditures for manufacturing firms over the period 1990-2005 drawn form the Encuesta sobre Estrategias Empresariales. We find firms differ in their R&D performance along each margin according to their size and technological group. Our results show the R&D behaviour of small firms is characterised by high rates of turnover and low persistence. Growth rates of R&D are explained mainly by the R&D spent by new performers; while the increase in R&D by log term performers is more than compensated by the loss of those that fail. On the contrary, the R&D behaviour of large firms in the Spanish manufacturing sector is characterized by high persistence. The overall growth rate of large firms is explained mainly by the growth of R&D of continuous performers.

Te counterfactual exercises reveal that small firms would have had significant higher R&D growth were they able to improve their performance with respect to the survival channel of the intensive

[16] This result is not highly reliable, as we do not have much entry in this sector along the period of analysis.

margin as well as the performance of the extensive margin. However, the high failure rate in R&D activities for small firms reveals that increases in the extensive margin in a given year will not contribute to the long run R&D growth, as these gains will disappear within few years. The results also show that large firms would be able to attain higher rates in the long term if they could deepen their actual R&D efforts, particularly in med tech industries.

R&D activities are high on the policy agenda of governments at national, European and regional level. R&D expenditures in Spain have been clearly lower than the OECD and European average, and clearly the country is falling behind with regards to the Lisbon Agenda's 2010 objective to assign 3 percent of GDP to R&D efforts, with at least two-thirds coming from private investments. The results of the counterfactual and numerical simulation exercises allow us to draw some policy prescriptions in order to boost these activities. Firstly, our results confirm the need to designed oriented policy initiatives according to firm size and technological field. Secondly, we find that policy initiatives designed to improve the deepening component of R&D growth appear to be the most effective, as it is only required a modest increment in the deepening rate to attain the desired target. However, these will only have a short run effect in small firms. Unless small firms have the right incentive to persist investing in R&D, any gain at the deepening or at the extensive component will vanish within few years.

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Figure 1. R&D spells survivor functions by size, 1990-2005.

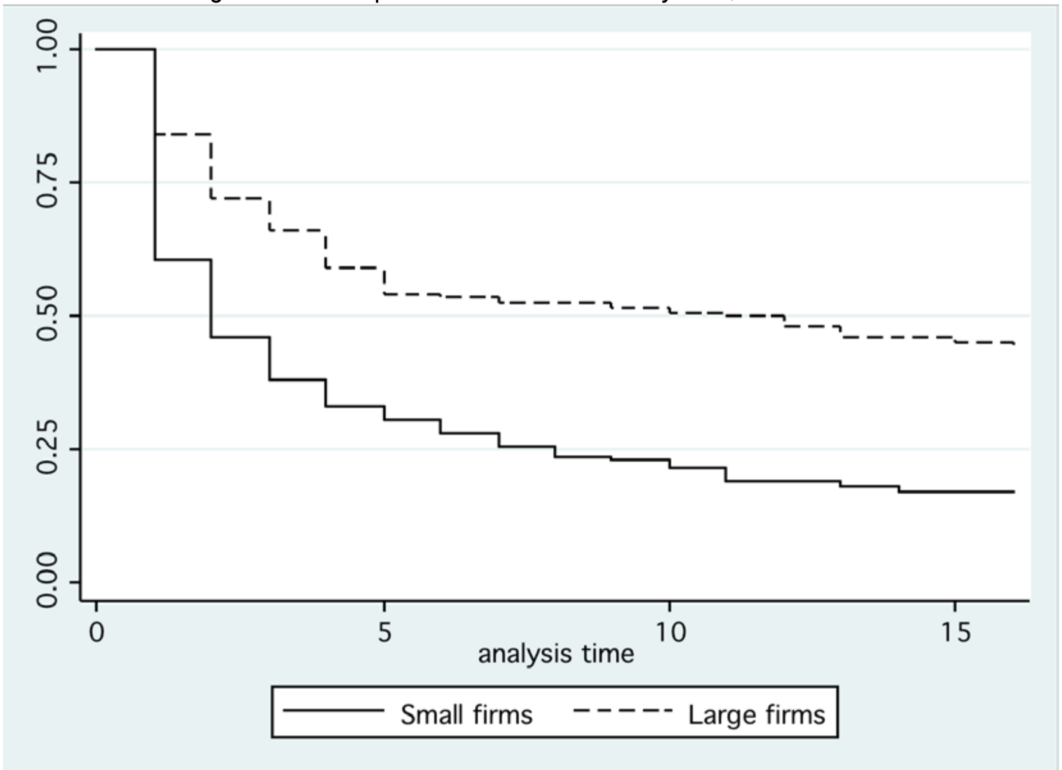


Figure 2. R&D spell survivor functions for small firms by technological sector, 1990-2005.

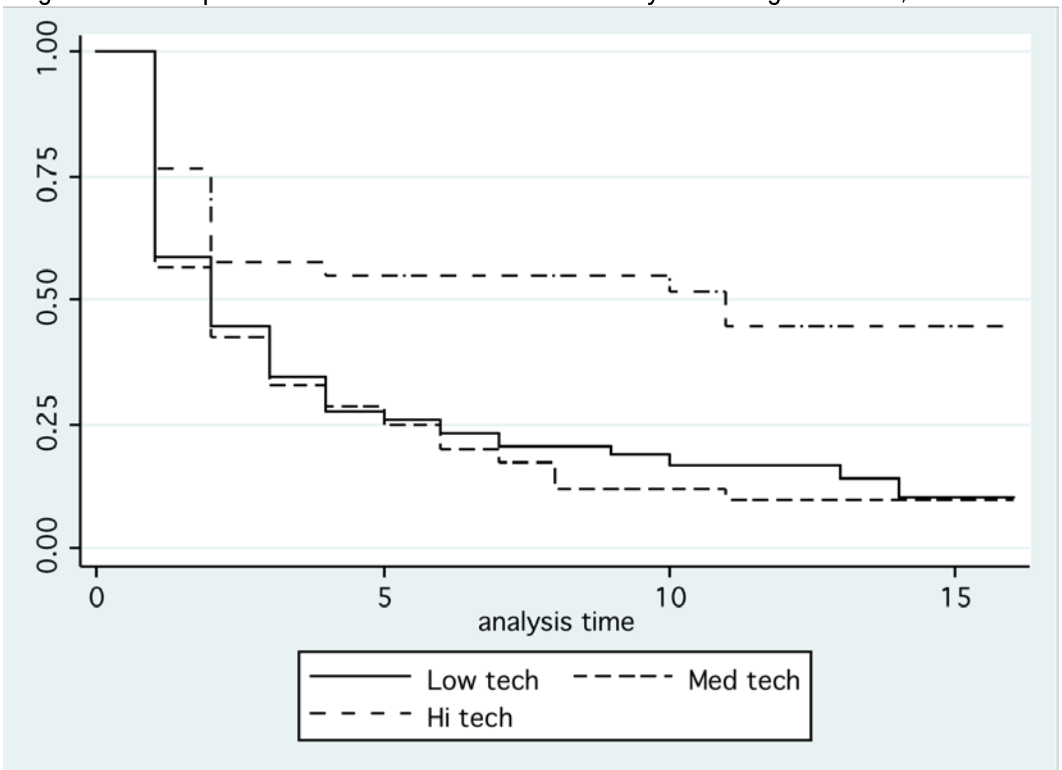
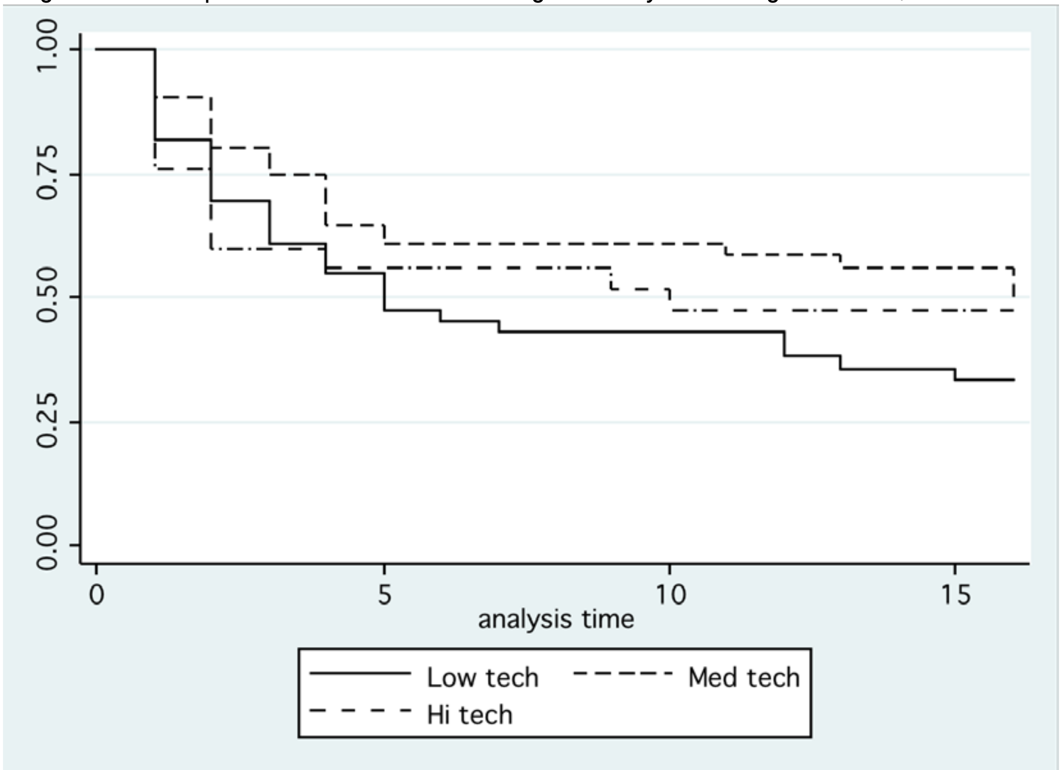


Figure 3. R&D spell survivor functions for large firms by technological sector, 1990-2005.



Appendix

Table A1. Industrial technological intensity (NACE-93 two digits industrial classification).

Industry	Industrial technological intensity
Beverages	Low
Textiles and clothing	Low
Leather and shoes	Low
Timber	Low
Paper industry	Low
Printing and printing products	Low
Non metallic mineral products	Low
Metallic products	Low
Furniture	Low
Other manufacturing goods	Low
Food and tobacco	Medium
Rubber and plastic	Medium
Metallurgy	Medium
Machinery and mechanical equipment	Medium
Motros and cars	Medium
Chemical products	High
Office machines	High
Electric and electronic machinery and material	High
Other transport equipment	High