Research & Development and Firm Size
The Portuguese Electric/Electronic Industrial Sector: A Survey

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INTRODUCTION

For some decades now, the relationship between innovative activity and firm size has been the object of a fairly extensive research. Motivations underlying such a study include the necessity to assess the contribution of industrial unit size to technical advance, and the related aspect of the search for an optimal industrial structure in terms of innovative efficiency. Insights on the relationship between firm size and innovativeness provided by the empirical research have led, on one hand, to an accumulation of knowledge almost virtually non-existent or non-systematized, and, on the other hand, to the formulation of important policy conclusions and prescriptions as it regards, for instance, anti-trust enforcement or government support of small and medium-sized establishments.

Amidst the debate on this field of study, and the controversy raised by conclusions which have not reached a consensus, is the so called Schumpeter hypothesis, stating that the large scale establishment "...has come to be the most powerful engine of [economic] progress..." (Schumpeter, 1942, p.106), which triggered this research activity.

Here, another contribution to the debate is made, extending the empirical research to a particular country, namely Portugal, and to a particular industrial sector within it, namely the electronic/electrical industrial sector, and testing analytically the validity of the Schumpeter hypothesis on the relationship between size and inventive activity.

Based in the results reported here, obtained through a postal survey addressed to a sample of firms, based on comparative analysis of similar recent research work, and on theories of economics and technical change, it is argued that the understanding of the relationship between firm size and innovativeness will be greatly enhanced if a dynamic perspective on the subject is adopted. There are several indications and evidences leading us to conclude that this relationship is not constant or static but evolves with time, and what causes it to change is strongly related to qualitative advances in science and technology. Furthermore, we support the theory that those changes are part of a broad process of fundamental structural adjustments spreading across the economic systems of the more industrialized countries and they can be related to the business cycles phenomena.

A comprehensive and concise review of the literature on the Schumpeterian hypothesis, and its considerable posterior refinements, is made in Part I.

In Part II, besides the rather descriptive exercise of an exhaustive presentation of the results of the survey, we will also build our case, setting the main arguments and conclusions, based not only on the data presented in this section and on referenced literature, but assuming as well hindsight of Part III.

Formal models will be constructed and extensively analysed in Part III. They will complete the structure of the case.

PART I THE LITERATURE ON FIRM SIZE AND INNOVATION

1. Introduction

A study of the relationship between industrial structure and technical change will inevitably pass through and be grounded on the ideas of Schumpeter (1942), for he was the one who first gave a comprehensive vision, if not a detailed analytic perspective, of the economic role of technical change.

Two broad hypotheses are associated with Schumpeter. The first relates to market structure and technical change, which emphasizes the role a monopolistic structure exerts in terms of technical advance. Schumpeter challenged the common belief about monopoly and competition when he asserted:

> "...perfect competition is not only impossible but inferior, and has no title to being set up as a model of ideal efficiency." (Schumpeter, 1942, p.106)

According to Schumpeter, imperfect competition would stimulate innovative activity. The arguments are that, although perfect competition would optimally allocate resources at a given equilibrium point it would prevent a certain type of behaviour (innovative entrepreneurship) which would optimally allocate resources in a dynamic time framework.

The second hypothesis attributed to Schumpeter relates to firm size and technical change, which asserts that large-scale establishments are more conducive to technical change than small establishments. According to Schumpeter (1942, p.106):

> " Thus it is not sufficient to argue that because perfect competition is impossible under modern industrial conditions - or because it always has been impossible - the large scale establishment or unit of control must be accepted as a necessary evil inseparable from sabotaging by the force inherent in its productive apparatus. What we have got to accept is that it has come to be the most powerful engine of that progress and in particular the long run expansion of total output not only in spite of, but to a considerable extent through, this strategy

> which looks so restrictive when viewed in the individual case and from the individual point of time."

This remarkable declaration synthesizes admirably the Schumpeterian perspectives, both in terms of market structure and innovation and firm size and innovation. The relationship between firm size and technical change was further pushed through and given some ground arguments by Galbraith (1952). He claimed that present technological conditions would require, in order to generate significant inventions and innovations, large financial resources and large firms were, actually, the only ones able to afford them:

> " There is no more pleasant fiction than that technical change is the product of the matchless ingenuity of the small man forced by competition to employ his wits to better his neighbour. Unhappily, it is a fiction. Technical development has long since become the preserve of the scientist and engineer. Most of the simple and cheap invention have, to put it bluntly, been made. Not only is development now sophisticated and costly but it must be on a sufficient scale so that successes and failures will in some measure average out... Because development is costly, it follows that it can be carried on only by a firm that has the resources associated with considerable size" (Galbraith, 1952, p.91-2).

Using the preceding argument, Galbraith presented an hypothesis that can be considered as a restatement or a clarification of the Schumpeterian hypothesis, by virtue of its own conceptual abstraction. The concern of this paper is with this second hypothesis, although, as we shall see in latter sections, an excessive abstraction in terms of firm size as a determinant of innovative activity shall eventually become an obstructive rather than an explanatory path.

We shall make a concise review of the now available vast literature on this topic. We shall first highlight the main arguments that go along with the hypothesis and the motivations underlying the large number of studies on this matter.

2. The arguments

The hypothesis, stated in a more usual and precise manner, asserts that large firms, in a developed capitalist economy, generate a disproportionately large share of society's technological advances. There are several arguments set fourth in support of the hypothesis, besides Galbraith's assertion that modern costs of technological development make innovative activities prohibitive for small firms. First, it is claimed, large firms have advantages in terms of access to capital. This is because capital market imperfections favour large firms in obtaining financial aids to risky and costly projects because large size and consequently large internal funds can provide risk insurance. Moreover, because research and development is risky and with uncertain outcomes, small firms face themselves with an uncomfortable and potentially dangerous situation when all their resources are committed to a single project. Large firms, financially able and willing to diversify their innovative activities over an array of projects, would secure themselves through a failure-success compensating structure.

A second claim is that there are economies of scale in research and development. Restricting us to the size of the research group, there are several ways in which those economies can arise. Examples include the fact that researchers are more productive when they can communicate and interact with more colleagues, the possibility of division of labour, the possibility to better exploit available equipment and the increase in probability that unexpected results will be recognized as important. In addition, there are more opportunities in a large firm to diversify their research and development efforts.

A second source of advantages in a large establishment relates to its complementarities between research and development and other non-manufacturing capabilities. A large firm with an established name or with large marketing facilities can better exploit the output of its research efforts.

Critics to these arguments have been made. Galbraith's assertion that the costs involved in technological innovation are prohibitively large for small firms is contested with the argument that the process of research and development cannot be considered a single-step process. There are singularities between the several phases, usually defined as invention, development and innovation, and each one, by its own nature, requires different resources, thus implying an overall distribution or time function on which costs would depend. Moreover, a notional distribution of technological paths or possibilities would also imply a related cost distribution, which could be compatible with the small size end of the spectrum of firms. In addition, the average size of that part of the spectrum has been rising continuously.

The argument against the fact that large firms are less restricted by risk considerations is grounded on behavioural reasoning. It is reminded that decision-making on risky projects in large organizations is also made by individuals who have also something to lose or gain, with the possible aggravate that the assessment of the viability of the projects may be jeopardized by conflicting interests, practices and philosophies of management. Consequently, quality of innovations could be affected. In that sense, small firms would benefit from a familiar, cohesive and determined team of people commonly sharing the same palpable goal or vision. Organizational features could also result in strategic disadvantageous time delays or act as impediments to creative outputs, either by its own accommodation (bureaucratic paralysis) or by its failure to attract or retain imaginative personnel. On the comparative advantages of small firms as it regards R&D management see Baker *et al.* (1986), Hayes and Jaikumar (1988) and Quinn (1985).

3. The hypothesis testing

To study the question of whether a positive relationship exists between firm size and inventive activity a regression equation may be fitted, and has been commonly used in the literature. The hypothesis is that inventive activity increases more than proportionately with firm size. A measure of R&D activity X is related to a measure of firm size S. The hypothesis is supported if, in a functional form of the type $X= a+bS+u$ (where u is the disturbance term with the usual characteristics), b is greater than one, or if in a functional form of the type $X= aS^bu$, b is greater than zero. Alternatively, a measure of innovation activity may be deflated by a measure of firm size, so in regressions of the form $X/S= aS^bu$ or $X/S= a+bS+u$, the hypothesis is supported if b is greater than zero or, in the language of statistical hypothesis testing, if the null hypothesis that there is no relationship between size and innovative activity can be rejected.

Related logarithmic functional forms have been used to test the relationship between firm size and inventive activity, and over time, a double-log regression model has apparently evolved to be the most reoccurring one. Link *et al.* (1988) have tested the statistical appropriateness of a particular functional form and conclude that the double-log specification is the most appropriate within a class of models.

Empirical testing of the Schumpeterian hypothesis is subjected to a variety of difficulties when confronted with the availability and choices of indicators of either innovative activity or firm size. Quantitative evidences on both variables are not easy to find but several measures have been used. None seems to be completely satisfactory and each one has its own limitations on which we shall briefly elaborate.

The more common proxies for inventive activity include innovation counts, patents counts, estimates of sales associated with new products, expenditures on research and development and number of personnel engaged in R&D activities, where the former three are referred as inventive outputs and the latter two as inventive inputs.

In order to count innovations, one must first identify an innovation. A process innovation may be considered as a change in a production function, which is, in practice, very difficult to identify. Production functions are usually not specified, and increases in productivity may depend on other factors. Identification of a new product is also not a straightforward process. The emergence of radically different or new products dynamically coexists with many incremental improvements on existing ones. The field activity required to collect this kind of information involves analysis of specialized journals, consultation of experts, analysis of patents, interviews, etc., and is costly and time consuming. Databases containing appreciable information on innovations have been laboriously built up during the last decades.

Attempts to discriminate the quality and importance, both in technological and economical terms, of the innovations resulted in some proposed simple taxonomies.

Patents may well circumvent the difficulty in discriminating radical inventions from incremental ones. However, the use of patents as an inventive proxy entails some drawbacks. Patents are issued for minor innovations as well as for major innovations. Many patented processes and products are never commercialised and many innovations are not patented. Pavitt (1987, p.6-7) argues that there will be different sources of bias in representing innovative activities by means of patents:

> "...(1) differences amongst countries in the economic costs and benefits associated with patent protection...(2) differences amongst technologies and sectors in the importance of patents as a protection... compared to other methods of protection, (3) differences amongst firms in the propensity to patent the output of innovative activities".

Basberg (1987) emphasizes the uneven cross sectional patterns of propensity to patent, advancing basically the same arguments. Several authors (Clarck *et al.*, 1981, Soete *et al.*1983) have proposed classification schemes to rank patents according to their significance.

Inventive output measured by the sales volume of new products in the years immediately following introduction has the disadvantage of depending on other factors (market, managerial or others), besides the importance of the innovation. It gauges, nevertheless, the market and economic impact of innovations.

Defining and measuring the inputs to R&D is also a difficult task. A measure of the inputs in the innovation process is total expenditures on R&D. This widely used indicator does not reflect the composition of the inputs, it is treated differently according to firm's accounting practices and does not take into account intangible assets, like accumulated knowledge. However it is argued (Soete, 1979), R&D expenditure is more neutral to firm size than patents counts (due to the shortcomings mentioned earlier) or other input measures such as R&D personnel that may inflate the contribution of small firms.

The number of employees engaged in R&D activities is generally accounted as the number of scientists, engineers and technicians formally assigned to research and development. The total figure may be adjusted by the technical competence or experience of the members and weighed accordingly. This measure, if not modified, may not take into account the personnel not directly involved on R&D but contributing to innovation activities.

A considerable research exists on whether there is a correlation between the various size indicators (size can be measured by number of employees, sales volume or others), a study that is well extended to the measures of research and development. Commanor and Scherer (1969) compared three measures of inventive activity (patents, sales volume of new products, number of R&D personnel) and found a positive and significant correlation. Acs and Audretsch (1988) found a strong correlation between the ratio of patents per innovation and R&D expenditures per innovation. Scherer (1980) says that, in at least two studies, the success rate of R&D projects oscillates between 50% and more than 75%, which is also a rough indicator of the relationship between inputs and outputs of the innovative process.

A direct relationship between innovative inputs and innovative outputs is implicitly accepted and the choice of either inputs or outputs measures or indicators of inventive activity is considered appropriate.

4. Pioneering and consolidating: the pre 80s

The empirical literature on the relationship between structural features (size as well as market structure) and technical change is vast. Scherer (1980), Freeman (1982), Kamien and Schwartz (1975 and 1982) and Baldwin and Scott (1987) provide extensive and comprehensive reviews on the subject. The results reported on those studies are somehow inconclusive, in the sense that, in relation with the Schumpeter-Galbraith hypothesis, it has not emerged a clear and robust picture capable of either confirm or reject the hypothesis, although some strong generalities and conclusions did come out and tended to consolidate, together with a gradual concern on the necessity of further refinements on the theoretical framework.

Baldwin and Scott say that both Schumpeter and Galbraith relied on "...the most casual of data..." when they advanced their hypothesis, the same happening with most of the earlier work on the subject. The first well-designed studies appeared in the late 40s and throughout the 50s. Those earlier studies seem to have found a more strong relationship between market structure and inventive activity than with the size structural variable.

Baldwin and Scott cite a study of Jewkes *et al.* (1958), where invention count was used as an indicator and where they found that a large proportion of inventions had been made by individual inventors, or by small research groups, thus conflicting with the idea that a large proportion of technical change emanated from large establishments, and shedding some gloomy clouds on the correctness of arguments such as those implicit in economies of scale in R&D.

Throughout the late 50s and 60s, many empirical studies, using several indicators gathered in a more systematic fashion, claimed having not found significant correlation between inventive activity and size. However, some other studies did find significant correlation but they were generally weak. Differences in the significance as well as on the coefficients signs amongst industrial sectors was noted as a distinct reoccurrence particularity and the trend was further kept in subsequent research during the 70s.

An important methodological issue, with a concomitant reformulation of the Schumpeter hypothesis, was raised by Fischer and Temin (1973). According to them, empirical estimates of the relationship between innovative inputs and firm size could not be used to infer the relationship between innovative output and firm size because there is no identifiable source of R&D scale economies which would necessarily imply such an inference. Kohn and Scott (1982) elaborated on the Fischer-Temin contribution and proposed two definitions of the extent to which an industry may be "Schumpeterian", depending on the elasticity of R&D (marginal) costs with respect to the output of R&D (as measured by sales volume of new products, for instance), or depending on the elasticity of value added with respect to the size of the firm, and showed that, under certain conditions, an elasticity of R&D inputs with respect to size greater than one implied an elasticity of R&D output with respect to size greater than one. Kohn and Scott analysis leads to a further methodological complication. If firms do not face similar R&D production conditions then data on individual firms cannot be used to test a cross-sectional relationship between size and any measure of R&D activity. It can be shown that cross sectional observed points can yield the appearance of an elasticity of R&D output with respect to size of less than one, in spite of the fact that the actual individual firm's elasticities are greater than one. In line with this approach, Lunn (1982) develops two stochastic models relating R&D inputs to innovative output and argues that "...It is inappropriate to infer a specific relationship between firm size and innovative output from observations on the relationship between size and innovative inputs until more is known about the production of innovation". With his models, he showed that disproportionate inputs might not necessarily imply disproportionate efficiency. Link (1980) suggests that the rate of return earned on R&D expenditures is conceptually more appropriate as a measure of innovative activity, and tests whether the rate of return to R&D is a function of firm size. He found that "...large firm size is a prerequisite for efficient innovative activity only up to a point and then the influence of size remains constant".

This result conforms to other research, whereby non-linear (in the variables) functional forms have been used to test for the relationship between size and inventive activity. Several studies (see Scherer, 1980) claimed to have obtained the best statistical fit with a quadratic functional form and suggest an inverted U relationship, or at best an r-shaped relationship, between firm size and inventive activity, deriving from it important implications as it regards an optimal industrial size distribution in terms of an efficient production of innovations.

Concluding, we may say that two distinct points seem to have consolidated during the late 60's and throughout the 70's: first, the fact that there are inter-industry differences amongst the propensity and the size pattern of innovating firms. A tentative explanation suggested by Nelson (1982a) includes different technological regimes as a causation factor. Second, the notion that an inverted U relationship between size and inventive activity may be the elected one. This pattern of innovative activity was tentatively explained by scale requirements and risk precluding most small firms, and by monopoly power reducing the incentive on large firms.

5. New evidences and new hypothesis: the post 80s

Studies that are more recent tend to confirm the pattern of inter-industry differences while defying other more or less established concepts. Soete (1979) challenges the validity of the conclusions arrived at in the literature, namely the general rejection of the Schumpeterian hypothesis. Using quadratic and cubic regressions and using the same data used by Scherer in a previous study (where Scherer concluded for an inverted U relationship), but making different data assumptions, he found that R&D expenditure as a percentage of sales did increase more than proportionately with size, thus rejecting the inverted U relationship and confirming the Schumpeter-Galbraith ideas with regard to size. However, industry dissimilarities were once again evident. Nelson *et al*. (1967) suggested, in an earlier work, that the existence of an overall relationship between firm size and R&D, but the disappearance of that relationship at a sectorial analytic level, could be explained by a positive bias in the upper end of the size spectrum caused by a group of large high tech firms concentrated in some sectors with institutional or technological exceptional peculiarities (aircraft, electronics).

Cohen *et al.* (1987) found no significant relationship between size and innovative activity. Using data on R&D expenditures and a sample drawn from two thousand of the largest US manufacturing firms, they concluded that the small proportion of variation explained by size was insignificant, whether business or firm size were used as measures of size, whereas industry characteristics explained almost half of the variation:

> "...the relationship between size and innovation may vary across industries with different technologies and market conditions, a possibility largely ignored by the arguments advanced in support of Schumpeter. Interindustry differences in technological opportunities and in the appropriability of returns from R&D investment may, for example, influence the degree to which size confers advantages or disadvantages." (Cohen et al., 1987, p. 545)

They argue that little evidence for the validity of the Schumpeterian hypothesis emerges from other research and emphasize interindustry heterogeneity already mentioned in other works.

The evidence for inter-industry dissimilarity is further reinforced by Pavitt *et al.* (1987), this time in a study of innovations in the UK. The study relies on an impressive data set, a survey of about 4500 innovations compiled over a period of fifteen years and including time periods ranging from 1956 to 1983. Appropriability and technological opportunity, amongst other determinants, are explored in terms of explaining intersectoral differences. The authors test for the significance of those variables and conclude for their importance. Some explanations are advanced, such as the possibility of large firms being coupled with the exploitation of appropriable technological opportunities and the possibility of smaller firms being engaged in providing specialized inputs in conjunction with the large establishments.

But the most striking results reported by Pavitt *et al.* show quite a different pattern and overall relationship between size and innovative activity, compared to previous and generally accepted pictures. Although they did not make formal statistical tests, the data suggests an above average R&D intensity both amongst small and large firms:

> "The latter result is - as far as we know - quite original. Taken together, they suggest that the relationship between firm size and innovative intensity is not r-shapped, but U-shaped, and becoming increasingly so over time" (Pavitt et al., 1987, p.304)

As a matter of fact, Bound *et al.* (1984) reported earlier a similar conclusion, founding, in a study of US manufacturing industry, that R&D intensity first falls and then rises with firm size.

Acs and Audretsch (1988), using also innovation count as a measure of technical change, do seem to substantiate this pattern. In addition, and confirming previous mentioned studies, inter-industry differences were apparent in terms of the share of innovations contributed by small and large firms. In 21 out 35 sectors, large firms accounted for a larger share of innovations while in the remaining sectors small firms accounted for a larger share of innovations. Overall, the ratio large firms innovations/small firms innovations was 1.27 while the ratio large firm employment/small firm employment was 8.44. The efficiency of small firms (defined as those with fewer than 500 employees) was thus larger, being as a whole, 43 percent more innovative than large ones, although, in some industries, the ratio of innovations per employee was 6.64 times greater for small firms. Other variables reflecting industry effects such as measures of appropriability and technological opportunities were tested on measures of size and innovativeness. Although the results are not strictly comparable with those of Cohen *et al.*, since the measures are based on different assumptions, similar conclusions were drawn.

Further evidence on a tentative U model for the relationship between size and inventive activity is provided by Kleinknecht (1989). Arguing that the official survey on research and development on Dutch firms underestimates the contribution from small firms, and using as a proxy for innovative inputs the number of personnel, not only formally but also informally, assigned to R&D, he found that R&D intensity of firms engaged on R&D followed a U pattern, falling first and then rising with size. The inclusion of informal R&D shifted significantly away from the large firms the officially observed R&D concentration.

The importance of informal R&D carried out in small firms is emphasized by Santarelli and Sterlachini (1990) in their study of Italian manufacturing firms. They report a mean R&D intensity (defined as the ratio of R&D man-years to the total number of employees) by size class, even more pronounced than Kleinknecht in favour of the smallest firms and obeying to a U relationship.

Acs and Audretsch (1990) also exhibit such a relationship, using innovation count proxy, and plotting the mean number of innovations per size class on a bar chart.

Whether measured by R&D inputs or by measures of R&D output, a quite different pattern on the relationship between size and inventive activity seems to be emerging in more recent research about the subject, however surprising it may be to those who are acquiescent with the Schumpeter-Galbraith theory and however dissenting it may be with previous studies on the subject.

A possible explanation to the observed discrepancies between earlier and latter findings may rely on the differences on the choice of indicators and on the availability and reliability of data. Most earlier studies used R&D expenditures. It may also depend on data assumptions that can considerably alter the results. The legitimacy of the conclusions on innovative output inferred from innovative inputs is questioned by Fischer and Temin (1973) and several authors criticized the practice and the validity of the conclusions derived from studies where the complete spectrum of firms was not included (Acs and Audretsch, 1988, p.678), although this practice is dictated by limitations on data availability and reliability.

An alternative and more appealing hypothesis is suggested by the observation of the results of Pavitt *et al.* (1987) and implicitly suggested by it. The distribution pattern of the innovation share of the various size classes of firms changes over time. The distribution observed in the first periods, corresponding to the late 50s and 60s, is quite close to the theoretical model on the relationship between size and inventive activity proposed at that time.

However, the pattern does change over the following consecutive periods until the last period, which includes the 80s. It is evident that the innovative share and the innovative intensity of small firms have a clear tendency to rise, just as the intensity of large firms tends to remain high. In contrast, medium-sized firms show a downward trend on their innovative activity, showing poorer relative performance compared either with large or small firms. Kaplinky (1983) acknowledges the validity of earlier works as well as recent ones but, noting that previous research reached their conclusions on a "...highly static framework.” he argues that the relationship between firm size and technical change is a dynamic one. Elaborating on the example of the CAD industry, by analysing its structural changes over periods of time and explaining those changes as being related to appropriability constrains and scale requirements, he argues that relative innovative activity between small and large firms depends not so much on sheer size but rather on dynamic factors. So, the relationship between size and R&D depends on which point of the industry cycle is being considered and measured since the contribution of each size class varies accordingly.

Rothwell (1989) further contributes to this point of view. Relying on the same data set used by Pavitt *et al.*, which shows a dynamic redistribution of research and development relative efforts across small, medium and large firms, over a period of time, emphasizing the innovative relative advantages and the innovative efficiency of small firms, and extending Kaplinsky analysis and arguments, he concludes that "Any study of the roles of small and large firms in industrial innovation and growth should be dynamic. Their relative roles might vary considerably over the industry cycle". Curiously enough, Schumpeter work is revisited in face of the new evidence provided by the latest empirical findings:

> "J.A. Schumpeter (...) suggested initially that it was the exceptional creative drive of independent entrepreneur, undertaking risky innovative developments, that led to the launch of radical new products and new industry sectors which changed existing market structures, and later that was 'endogenous' science and technology, mainly within the R&D departments of large firms, that played a dominant role, increasingly substituting for the mechanism of the

'exogenous' inventor setting up business. This suggests that the relative roles of small and large firms in technological change and industrial production might vary considerably over the industry cycle" (Rothwell, 1989, p.51).

PART II A SURVEY ON INNOVATION ACTIVITIES IN PORTUGUESE ELECTRONICS/ELECTRICAL INDUSTRY

1. The data

The data on R&D on which this study relies upon was collected through a postal survey addressed to 150 firms having 1 or more employees (the largest respondent firm had about 3500 employees, being the largest in the sector, and the smallest respondent firm had 4 employees) in the electric and electronic sector in Portugal. It includes all subdivisions under the heading of ISIC 383. Data from the National Survey on Science and Technology, undertaken by the Junta Nacional de Investigação Científica e Tecnológica (JNICT), shows beyond doubt the important weight this sector has in terms of industrial R&D. According to the latest results of the survey (JNICT, 1989) the electrical/electronic sector alone accounts for as much as 19.6% of total expenditures on industrial R&D and as much as 21.9% of the total work force assigned to R&D activities while accounting for only 11.7% of the total number of innovative firms. The sector is the first both in terms of R&D personnel and R&D expenditures, followed, not so closely, by the chemical sector.

Data on measures of size was collected and compared by three different sources, with respect to the number of employees, and two different sources with respect to turnover. The number of total employees was obtained directly from the questionnaire addressed to the firms, it was obtained from the Dunn & Bradstreet database and also obtained from the Year Book of the Association of the Electric and Electronic Industries (ANIMEE, 1989). The three sources showed a high level of juxtaposition, with only insignificant differences. In any case, the inclusion of each unit in the postulated size classes was similar for the three data sets. Ultimately, the data collected through the questionnaire was the one used in the regression analysis, where division into size classes was not made. The data on sales volume was obtained from Dunn & Bradstreet database and compared with the data from the Year Book of the Association of the Electric and Electronic Industries. This latter source did not give information on each individual firm but classified them according to size classes. Dunn & Bradstreet provided information on each individual firm. A comparison between the two sources revealed perfect compatibility, that is, each individual information provided by Dunn

& Bradstreet fitted exactly within each size class information provided by the Year Book.

The response rate was 46.7%, which represents a fairly good sample of the total population, considering that the total population numbers about 171 firms (according to OECD, 1990). In Appendix 3 is a complete copy of the questionnaire (adapted from Kleinknecht, 1987a) sent to the firms. No significant differences on the response rate, according to size class, were detected. We therefore assume that there is no special propensity to firms with particular characteristics (such as size or innovativeness) to respond, so we derive our conclusions based on the assumption that all non-responding firms have the same behaviour with respect to R&D (or other variables) as the responding firms, i.e., there is no bias problem.

2. The choice of indicators

Information on two R&D indicators was asked for on the questionnaire. The choice of two input indicators - R&D expenditures and R&D man-years - is due to the fact that each indicator has its own limitations. In the absence of a more direct output measure, using two different indicators for each case will ensure a stronger basis to our arguments. In addition, following a growing number of studies where it is suggested that R&D in small and medium sized firms can take place in a rather informal way, outside a formal R&D department (Kamien and Scharwtz, 1982, Oakey, 1984, Kleinknecht, 1989, Santarelli, 1990), and since it is accepted knowledge today that workers specifically assigned to a R&D department are not the only source of innovation (for instance, someone involved in the production process directly is sometimes responsible for the development of a new process or improvement of an existing one), several questions were included in the questionnaire addressing this point (see Part II of the questionnaire, in Appendix 3).

Furthermore, the questionnaire also included a definition of R&D, based on the so-called Frascati Manual (OECD, 1981). A remark on the questionnaire also noted that activities such as design and software were not included under the definition of R&D. This was intended as a precaution against a somewhat wider interpretation of the Frascati definition. Substantial control on whether the respondents interpreted correctly the R&D

definition was not made. However, a random sample, including all size classes, of 10% of the total respondent firms, was extensively inquired and none had misinterpreted the Frascati definition in a manner that could result in an upward bias.

3. Innovation and firm size

3.1 Observations on research and development

The following reported results are based on the returned questionnaires and on the sources mentioned above. The results and data refer to the year 1989. The following is a series of tables where various types of data and data calculations are presented in order to have the most possible global view of what is going on in the sector, and is intended to gauge the situation in the sector. Cases (firms) with missing values in any of the relevant variables were deleted from the analysis. So, the total number of firms under analysis varies from table to table (and from equation to equation, in Part III). Although it may be questionable criteria, it was chosen because the total number of observations is not large and we did not want to sacrifice any usable case.

Analysis of the data seems to reveal a situation comparable to other studies claiming a particular type of research and development and size distribution mentioned in the last section of the review part, namely a U-shaped distribution of innovation effort related to size. It must be noted that some of the respondent firms are not independent firms, but part of a national or international concern. The measure of size is related only to the surveyed national unit, meaning that, actually, what is being measured, in some cases, is the business unit size and not the size of the firm as a whole. It is reasonable to expect that R&D resources allocated by or to such units obey to some form of proportional logic. We assume that the resources devoted to R&D are related to its respective size. This does not obviate problems related to the influences of firm's internal practices, tacit information and behaviour that inevitably any subsidiary of any firm benefits from.

We start with a usual beginning, i.e., by representing the concentration of innovation efforts. Table 1 is ranked by employment and displays concentration of R&D inputs as measured by man-years (total personnel engaged in R&D, including formal, informal and contractual R&D), as well as concentration of R&D as measured by R&D expenditures (total R&D expenditures, including formal, informal and contractual R&D). Table 1, which includes all respondent firms, provides an insight in the industrial structure of the sector in this country. It is highly concentrated, in terms of employment, as well as on R&D inputs, with a few large firms accounting for almost 50% of total employment.

Table 1. R&D concentration. Ranked by employment.
All respondent firms.

		Empl.	R&D per.	R&D exp.
First	4	49.3	68.2	57.6
"	8	67.0	73.7	68.0
"	12	78.8	78.1	72.6
"	16	84.4	78.9	73.4
"	20	88.4	78.9	73.4
"	30	94.2	92.0	97.6
"	40	97.3	95.7	99.0
"	50	99.0	99.1	99.4
all	67	100.0	100.0	100.0

Table 2. R&D concentration. Ranked by employment.
Only R&D performers.

		Empl.	R&D per.	R&D exp.
first	4	56.8	68.2	57.6
"	8	77.1	73.7	68.0
"	12	89.6	78.9	73.4
"	16	93.3	87.4	94.6
"	20	96.0	90.9	99.2
"	30	99.5	98.8	99.2
all	36	100.0	100.0	100.0

The employment concentration structure is confirmed by several studies (DGI, 1987, ANIMEE, 1989). This table gives evidence to a consistently more concentrated R&D inputs, measured either by man-years or expenditures only in the largest firms, decreasing thereafter and increasing again in the smallest firms. This picture is confirmed by table 2, where only R&D performers were included. The pattern is even more pronounced against the very large and the very small. Only the first four firms show a higher concentration of R&D, either measured by man-years or expenditures, when ranked by employment, with concentration rising on the smallest firms. It is curious to note that concentration in the first firms is more evident when measured with man-years whereas concentration on the last firms is more evident when measured with R&D expenditures. This suggests that even when measured by R&D expenditures, as opposed to a more crude measure of R&D personnel, small firms do seem to spend a disproportionately large share of their resources on R&D. Note that either ranked by employment or ranked by sales (see table 3 and table 4, ranked by sales) the same pattern emerges, but less pronounced, i.e., R&D is still more concentrated on the higher ranks but relatively less than when ranked by employment.

However, when only R&D performers are considered, the pattern disappears with respect to the more concentrated R&D on the higher ranks (see table 4; the two firms with missing values, not included in this table but included in table 2, are located, in table 2, at the 21st and at the 34th position; if the calculations for table 2 are made deleting these two cases, the general picture remains the same). In fact, if ranking is by sales, R&D expenditures is consistently less concentrated amongst the largest firms. So, the choice of R&D man-years as an indicator of innovative activity and intensity seems to benefit, in this case, the largest firms.

Commitment to R&D rises steadily with firm size (with the exception of one size class, see table 5). Large firms, i.e., firms with more than 500 employees, are all engaged in R&D activities. Very small firms, that is, firms with fewer than 20 employees, show a somewhat small proportion dedicated to R&D. Such a proportion rises remarkably just in the next size class (firms between 20 and 49 employees) where half of them have R&D activities. Overall 40 out of 71 firms are engaged in R&D, representing a proportion of 56.3% of firms doing some form of R&D, either in a formal R&D department, in another department other than an R&D department or by means of contract. The proportion of firms, according to size class, having a formal R&D department, doing R&D outside an (existing or not) R&D department and contracting out R&D (all respondent firms), is shown in table 5.

Table 3. R&D concentration. Ranked by sales.
All respondent firms.

		Sales	R&D exp.	R&D per.
first	4	50.4	57.3	52.5
"	8	73.3	65.3	73.1
"	12	84.3	69.6	76.0
"	16	90.3	85.6	80.8
"	20	93.9	92.8	85.2
"	30	97.9	98.1	93.4
"	40	99.1	99.0	96.5
"	50	99.7	99.7	97.0
all	61	100.0	100.0	100.0

Table 4. R&D concentration. Ranked by sales.
Only R&D performers.

		Sales	R&D exp.	R&D per.
first	4	63.1	58.2	69.4
"	8	82.3	68.9	75.1
"	12	92.1	85.7	80.8
"	16	96.3	94.3	85.6
"	20	98.2	97.7	91.2
"	30	99.9	99.8	99.0
all	34	100.0	100.0	100.0

Table 5. Firms with formal R&D, firms with informal R&D and firms with contracted R&D. All respondent firms.

Size (empl.)	formal R&D		informal R&D		contracted R&D		Total of firms
	%	n	%	n	%	n	N
1-19	13.3	2	13.3	2	0	0	15
20-49	21.4	3	21.4	3	7.1	1	14
50-99	16.7	2	16.7	2	25.0	3	12
100-199	45.5	5	54.5	6	9.1	1	11
200-499	11.1	1	33.3	3	9.1	2	9
>= 500	60.0	6	40.0	4	20.0	2	10
Total	26.8	19	28.2	20	12.7	9	71

Some of the very small firms, those included in the first size class, do have also a formal R&D department, while not all large firms, those included on last size class, do have a formal R&D department. However, the proportional difference is quite large. As it regards the proportion of firms doing R&D outside an (existing or not) R&D department, the percent figures are remarkably similar with those firms doing formal R&D, with the exception of the firms in the size class 200-499 which show a reasonable increase. Large firms show a slight decrease. Table 5 suggests that the decision to undertake some form of R&D (either formal or informal) seems to be correlated with firm size.

Very small firms (size class 1-19) do not have contracted R&D, while only one fifth of large firms have contracted out R&D activities. If only two classes are considered, those with firms with less than 500 employees and those with firms with more than 500 employees, the proportion of firms doing R&D under contract for the former class is 11.5% while the proportion of firms doing R&D under contract for the latter class is 20%. Intramural R&D seems to be the rule.

Up until now, we have been considering the total population of respondent firms. The previous tables were calculated using both R&D performers and non-performers. Now, we shall restrict our analysis only to R&D performers and will discriminate the size class proportions according to the same indicators.

Table 6 represents the R&D performers firms having an R&D department, firms doing R&D outside an (existing or not) R&D department and firms doing R&D under contract. It should be noted that those proportions could not be summed, since some firms are engaged in at least two types of activity.

Formal R&D is weakly correlated (but not linearly) with firm size, as shown in table 6. It is remarkable to see that even firms in the lowest size classes do have structured R&D activities, and that the percentage differences between the various size classes is not large. However, since the number of observations for each size class is small, a more aggregated procedure would benefit the analysis.

Table 6. Firms with formal R&D, firms with informal R&D and firms with R&D contracted out. Only R&D performers.

size (empl.)	formal R&D		informal R&D		contracted R&D		total of firms
	%	n	%	n	%	n	N
1-19	50.0	2	50.0	2	0	0	4
20-49	42.9	3	42.9	3	14.3	1	7
50-99	28.6	2	28.6	2	42.9	3	7
100-199	62.5	5	75.0	6	12.5	1	8
200-499	25.0	1	75.0	3	40.0	2	4
>= 500	60.0	6	40.0	4	20.0	2	10
Total	47.5	19	50.0	20	22.5	9	40

Considering only two size classes, one with firms under 200 employees and the other with firms above 200 employees, the percentage of firms in the former class having an R&D department is 46.2% while those in the latter class having an R&D department is 60% showing the same weak correlation between size and formal R&D. This is consistent, to a certain extent, with the common sense on this subject as well as the results shown in table 6, providing evidence to a negative correlation between informal R&D and firm size. This correlation is however quite weak and it only becomes a little bit stronger when the proportion of firms with fewer than 500 employees doing informal R&D (53.3%) is compared with the proportion of firms with more than 500 employees doing informal R&D (40%).

However, if a more in-depth analysis of the relationship between formal and informal R&D is made, the picture changes drastically. If, instead of counting the firms doing formal or informal R&D and expressing them as a percentage of the total of firms, the analysis is made counting the number of R&D man-years assigned to formal or informal R&D and expressing it as a percentage of total R&D man-years, or summing the expenditures on formal or informal R&D and expressing them as a percentage of total expenditures on R&D, the relationship between formal and informal R&D and firm size is completely reversed. Tables 7 and 8 show the results of the analysis using such a procedure.

Table 7. Proportion of formal, informal and contractual R&D according to size class.
Only R&D performers. Indicator: man-years.

size (empl)	man-years assigned to formal R&D		man-years assigned to informal R&D		man-years assigned to contracted R&D		total man-years	number of firms
	%	n	%	n	%	n		
1-19	55.6	2.5	44.4	2	0	0	4.5	4
20-49	28.1	5.5	71.9	14.05	0	0	19.55	6
50-99	40.9	9	22.7	5	36.4	8	22	5
100-199	54.9	25	34.1	15.5	11.0	5	15.5	8
200-299	0	0	43.9	12.5	56.1	16	28.5	3
>= 500	37.0	144.2	60.2	235	2.8	11	390.2	10

total	36.5	186.2	55.7	284.05	7.8	40	510.25	36

Either using R&D expenditures or R&D man-years as the indicator, the results provide evidence for a negative relation between formal R&D and firm size, and evidence for a (weaker) positive relation between informal R&D and firm size. The general pictures from tables 7 and 8 do not match perfectly except for the case of the higher size class (>=500) where the percentages for each mode of R&D are almost identical between the two tables. The reasons for the disparities do not lie on the missing cases of table 7. In table 8, the same calculations are made (only) for the respective size classes where those two missing cases fit (the figures are in brackets) and the picture remains essentially the same. Particularly in one size class (20-49) those disparities are quite amazing.

Table 8. Proportion of formal, informal and contractual R&D according to size class.
Only R&D performers. Indicator: expenditures.

size (empl)	expenditures devoted to formal R&D		expenditures devoted to informal R&D		expenditures devoted to contracted R&D		total expenditures	number of firms
	%	10^6 esc.	%	10^6 esc.	%	10^6 esc.	10^6 esc.	
1-19	82.6	10.002	17.4	2.1	0	0	12.102	4
20-49	67.2 (78.3)	9.41 (9.41)	18.5 (21.6)	2.597 (2.597)	14.3 (0)	2 (0)	14.007 (12.007)	7 (6)
50-99	50.5 (53.4)	14 (14)	9.1 (3.8)	2.5 (1)	40.4 (42.8)	11.2 (11.2)	27.7 (26.2)	6 (5)
100-199	55.6	103.37	32.5	60.44	11.9	22	185.81	8
200-299	0	0	11.1	37.5	88.9	300	337.5	3
>= 500	32.3	466.9	65.1	940.5	2.6	37.5	1444.9	10
total	29.9	603.682	51.7	1045.637	18.4	372.7	2022.019	38

(esc=Portuguese escudos)

Table 6 and tables 7 and 8 tell two different but complementary stories. The former shows that a larger proportion of small firms are doing informal R&D compared to the proportion of the large firms. The latter shows that, apparently, those small firms who are doing informal R&D do not give such an activity as much importance as the large firms who are also performing informal R&D give to that same type of activity. These results are somehow inconsistent with some literature on the informal dimension of R&D (Kleinknecht, 1987b, Santarelli, 1990), although the results displayed in table 6 are quite consistent with it. The evidence provided here suggests that great caution should be used when deriving conclusions based on some particular method of analysis and that the details of a particular situation should be explored thoroughly.

Two images are also convened, depending on whether table 6 or table 7 and 8 are considered, with respect to contracted R&D. In table 6, small firms do not seem to be more engaged than larger ones in contractual activities. The proportion of firms under 200 employees doing R&D under contract is 19.2% while the proportion for firms with more than 200 employees is 28.6%. The proportion for firms above 500 employees is 20% against the proportion of 23.3% for firms under 500 employees. No distinct pattern or correlation is visible. However, tables 7 and 8 show that contracted R&D is considerably more important for small firms than to large firms (>=500). Even excluding what can be considered a rather displaced value for the size class 200-499, the percentage of contracted R&D out of the total R&D for small firms is three times larger than the percentage of contracted R&D for large firms. A tentative explanation for the results in tables 7 and 8 may be that there are contractual advantages to small firms, if one takes into consideration the fact that they can access R&D facilities (machinery, know-how) without having to commit large amounts of their own resources (on this, see also section 3.2).

Table 9 presents some additional information on the size distribution of formal and (some) informal R&D. It shows the percentage of firms in each size class doing R&D outside an existing R&D department. This should be distinguished from what we call here informal R&D. The numbers on this table are relative only to firms that have a formal R&D department and also do R&D outside that department. Our definition of informal R&D includes not only these firms but also firms that do not have a formal R&D department but perform R&D (necessarily outside a non-existing R&D department). None of the smallest firms (1-100 employees) seem to do it, which is tentatively explained in terms of optimisation of scarce resources. The proportion of medium sized firms (100-500) having R&D done outside an existing R&D department is larger than the proportion of large firms.

Table 9. R&D done outside an existing R&D department. Only R&D performers.

size (empl.)	R&D done outside existing department		Total of firms
	%	n	N
1-19	0	0	4
20-49	0	0	7
50-99	0	0	7
100-199	37.5	3	8
200-499	25.0	1	4
>= 500	10	1	10
Total	12.5	5	40

Table 10 captures some information about the overall quantitative commitment of resources among firms that report a certain amount of R&D.

Table 10. R&D resource distribution. Only R&D performers.

R&D man-years	% of firms	number of firms	sum of R&D man-years	mean (R&D man-years per firm)
=< 1	16.67	6	4.6	.76
> 1 and =<2	16.67	6	11.0	1.83
> 2 and =<5	27.78	10	41.2	4.12
> 5	38.89	14	453.5	32.4

Total	100.0	36	510.3	14.18

According to the survey, 16.7% of firms reporting some R&D have less than one man-year and 16.7% have between one and two man-years, i.e., more than one third of the firms have 2 or less R&D man-years. Although this percentage of firms doing small-scale R&D seems somewhat high, the significance to the sector as a whole of this small-scale R&D may be considered low if we take into account that approximately 89% of the total of man-years devoted to R&D are in firms reporting 5 or more man-years, suggesting that a large proportion of R&D is made at a reasonable scale and under a structured way. The picture is strengthened by the figures in the right column of the table, showing the ratio of man-years per firm in each qualitative class. The ratio is 32.4 for firms reporting more than 5 man-years. Firms reporting less than 1 man-year have a ratio of .76, suggesting the existence of part-time R&D as argued by some authors (Oakey, 1984, Santarelli, 1990).

However, if we take the measure of R&D man-years as a percentage of total employment, or total expenditures as a percentage of sales, that is, R&D intensity, the picture is somehow different. Table 11 gives the mean R&D intensity by size class of all firms while table 12 gives the mean R&D intensity by size class only to R&D performers.

Even though the percentage of firms with fewer than 500 employees performing R&D is less than the percentage of firms above 500 employees performing R&D, the mean R&D intensity for all firms in the small size classes is greater than the mean R&D intensity for all firms in the large size classes (measured by man-years) as it can be seen in the left column of table 11.

Table 11. Mean R&D intensity by size class. All respondent firms.

size (empl.)	mean R&D intensity (per.)		mean R&D intensity (exp.)	
	(man-years)	number of firms	(expenditures)	number of firms
	(1)	(2)	(3)	(4)
1-19	3.72	15	1.81	11
20-49	4.61	13	.96	13
50-99	3.15	10	.66	11

100-199	3.30	11	1.85	10
200-499	1.31	8	1.28	8
>= 500	1.89	10	1.43	10
Total	3.18	67	1.31	63

A different pattern emerges if the indicator is R&D expenditures as a percentage of total sales, as it can be seen in the third column of table 11, where R&D intensity is relatively large (compared to the average value, 1.31) in both ends of the size spectrum. If only R&D performers are considered (table 12), there is a definite, clear and negative correlation between mean R&D intensity (man-years) and size class, and an inconclusive pattern if R&D intensity is measured with R&D expenditures, except for the fact that firms with more than 500 employees show a lower intensity than the majority (but not all) of the lower size classes.

The differences in the two measures of R&D across the different size classes may reflect differences in resource availability experienced by small and large firms. It is reasonable to expect that small firms may make more use of human resources as a less expensive way of engaging in R&D, and that they do not want or they are not able to internalise other more expensive assets, preferring rather to contract them out. It may also reflect economies of scale in R&D, since a lower R&D intensity in terms of man-years may not necessarily reflect a lower relative innovation output or innovation efficiency (see Part I).

Table 12. Mean R&D intensity by size class. Only R&D performers.

size (empl.)	mean R&D intensity (per.)		mean R&D intensity (exp.)	
	(man-years) (1)	number of firms (2)	(expenditures) (3)	number of firms (4)
1-19	13.94	4	6.65	3
20-49	9.99	6	1.78	7
50-99	6.31	5	1.22	6
100-199	4.54	8	2.65	7
200-499	3.51	3	3.41	3
>= 500	1.89	10	1.43	10

Total	5.92	36	2.30	36

It can also be argued that, although R&D intensity is greater in the small size classes it may not necessarily be conducive to a better quality in terms of innovation output. In fact if, for instance, within the size class of firms with more than 20 and less than 50 employees the mean R&D intensity is 9,99%, it means that they have, on average, between 2 and 5 R&D employees. A similar calculation yields, for firms in the size class of more than 100 and less than 200 employees, an average of 5 and 9 R&D employees. This casts some doubt on whether firms in the smallest class sizes have the possibility to undertake R&D in a systematic way. On the other hand, firms in the largest size classes, and by the same token, show an average number of R&D employees large enough to indicate the presence of structured R&D activities. This suggests that the R&D carried out by small firms may be organized in an occasional and unstructured way and it may be less significant, both in a technological and economic sense, than those carried out by larger firms. However, tables 5 and 6 do not show large dissimilarities with respect to structured and presumably occasional R&D activities and firm size. Acs and Audretsch (1988), based on a four-point taxonomy of the significance of innovations, found a relatively stable distribution of innovation quality amongst large and small firms. Large firms accounted for little less than two thirds of the total innovations ranked in the three more significant levels of quality and a little more than half of the innovations ranked in the last and less significant level of innovation quality. Tests for statistical differences in the frequency of innovation with respect to significance and size showed no great differences in the quality of innovations between large and small firms, suggesting that small firms may create innovations with comparable technological significance as those coming from larger firms, although their market value and impact may not correspond to its technological value.

The figures in table 11 and 12 may also be distorted, particularly with respect to the larger firms, because of reasons related to the industrial environment characteristic of the country. Most firms in the largest categories are not independent firms but subsidiaries of multinational firms (see the right columns of tables 21 and 22), whose R&D activities are generally concentrated on their countries of origin. Thus, the figures on tables 11 and 12 may not reflect the total commitment of those firms with respect to R&D, particularly in regard to basic research, or even to a substantial part of the development phase. R&D activities in the subsidiaries may well be concentrated on a reduced part of the development phase, namely in an activity that is concerned with the problem of adapting elsewhere invented and developed products or processes to particular characteristics of the national market where those subsidiaries have their activities (Rolo *et al.*, 1984, Caves, 1988). Hence, these figures may eventually reflect only one stage of the total R&D pursued by those firms (where now the firm is viewed as a whole, including not only the subsidiaries in Portugal but the whole concern). Since it happens that those subsidiaries are mainly included in the higher size classes, the figures may be downward biased compared with the figures for the lower size classes, thus leading to an underestimation of the R&D intensity of the largest firms.

Having this caveat in mind, we believe, however, that the innovative role of small firms has changed over the last decades. Some authors (Kaplinsky, 1983, Rothwell, 1989) argue that the size distribution of innovative firms, over a national, economical or behavioural environment, is not a constant factor but changes over time, and what causes this shift is mostly, if not essentially, influenced by the underlying science and technology base and its related technological opportunities. It comes in line with the works from Schumpeter and even from Keynes (see Dosi *et al.*, 1988b), related to business cycles and long wave fluctuations across the economic system. Keynes acknowledged the importance and influence of technical change as a determinant of investment behaviour in those periods, while Schumpeter (1942) elected technical change as the phenomena that dominated the whole process of evolution of the capitalist system (the notion of "creative destruction"). Freeman and Perez (1988) argue that science and technology, and the specifics of technology, are indeed the key factors underlying major social and institutional changes whereby the diffusion of particular innovations is accompanied by major structural crisis of adjustment. In an attempt to deal with the complexity of the subject of technology and its relations with historic time series, they developed a four scale taxonomy of innovations and elaborated on its most important dimension, an item which they named techno-economic paradigm, describing a social, technological and economic phase derived from a combination of interrelated product, process, technical, organizational and managerial innovations embodying a definitely advantageous productivity characteristic enabling economy-wide investment moves. According to their classification, the capitalist system is actually experiencing or beginning to pass through such a stage, where the underlying key technology is in the field of electronics and microelectronics.

They argue that phenomena involved in the restructuring of the productive system that accompanies the diffusion of a new techno-economic paradigm throughout the economy may include:

> "...a tendency for new inventor-entrepreneur type small firms also to enter the new rapidly expanding branches of the economy and in some cases to initiate entirely new sectors of production...” and, "...a tendency for large firms to concentrate, whether by growth or diversification, in those branches of the economy where the key factor is produced and most intensively used..." (Freeman and Perez, 1988, p.59).

Kaplinsky supports this argument in his study of the evolution of the CAD sector in the USA and UK, and its relationships with firm size and inventive activity. He argues that the relationship between firm size and inventive activity is not so much a function of each other but rather it depends largely on which time period is being considered, namely on which period of the industry life-cycle the measures are being made:

> "Thus, in the same way that we can expect the relationship between firm size and technical change to vary between the different phases of an industry growth cycle, so we can expect it to vary between different phases of the long wave cycle."(Kaplinsky, 1983, p.58):

Acs and Audretsch (1990) report that a change in the size distribution of firms across the economies of the most industrialized countries is actually occurring and argue that it is linked with a period of "creative destruction", in the Schumpeterian sense, embodying managerial and organizational innovations, in the Freeman sense, and inextricably related to new technologies in the fields of electronics and information technologies.

Piore and Sabel (1984) suggest that the emergence of new technologies places society in a necessity to make a choice between different technological regimes of production, one characterized by inflexibility and tending to favour large scale establishments, and another that relies on flexibility, small scale and customized production. It may seem an excessive dichotomy but it nevertheless supports Freeman's arguments on the birth and dynamics of small innovative firms, largely determined by an increasingly visible societal influence of information-based technologies.

Here we argue that the information provided by this survey is indeed another measurable manifestation of fundamental structural adjustments that are emerging across the economic systems of the more advanced, or at least reasonably industrialized and in a catching-up process, as is the case of Portugal (OECD, 1989a), capitalist societies. We believe other research work conducted in such disparate countries as the USA (Acs and Audretsch, 1988), UK (Pavitt *et al.*, 1987a), The Netherlands (Kleinknecht, 1987a, 1989) and Italy (Santarelli, 1990), all showing similar patterns on the size distribution of innovative firms, is not purely coincidental nor it is a result of methodological inconsistencies. As a matter of fact, the different methodological approaches pursued by each study, on which the choice of indicators varies somehow, is a further robust factor supporting the conclusions derived from the empirical findings. In our case it is surprising to find how much the results conform to the possible effects on industrial structure suggested by Freeman and Perez (see quotation above) as it relates to trends in concentration and the emergence of new small innovative firms in the key technology sector.

The concentration factor is quite evident in Tables 1, 2, 3 and 4, (although they are not time series data) and the emergence of new small innovative firms is also very apparent and it is further confirmed by news reported in specialized journals (Futuro, 1990) noticing the birth and activities of some firms included in our sample. Those new firms are heavily engaged in innovative activities, mainly in the production of new and custom-made products, not readily (or not at all) available from large and mostly mature products producing firms. Examples of products manufactured by small firms (under 150 employees) in our sample include PLCs (programmable logic controls), UPSs (uninterrupted power supplies), microprocessor controlled devices, time control systems and entrances, control units with circuit breakers, telecomand and telemeter devices, microwave ovens, components for electronic automation systems, tantalum capacitors and custom made electronics (source: ANIMEE, 1989). Eventually it reflects a niche strategy pursued by small firms in their efforts to establish themselves. These trends, concentration and emergence of new firms, and its relation to innovative activity and firm size, are also apparent in the mentioned studies on other countries.

Although Portugal is typically seen as a low-tech country, we believe such a fact does not essentially affects our conclusions. Two sides of the problem must be considered. One is the amount of resources devoted to R&D within the country, the other is related with the use of those resources. Compared to other OECD countries, the proportion of GNP allocated to R&D is small (OECD, 1984), hence the technological output from Portugal can be affected not only in quantitative but also in qualitative terms. For instance, projects with certain scale requirements are simply not pursued, either because the research groups are not large enough or because the equipment is too costly. On the other hand, smallness is not necessarily synonymous with oldness. As mentioned in Part I, research has indicated that a substantial proportion of a set of important inventions came out from small research groups. It is adequate to assume that R&D activities are essentially comparable, independently of the environment surrounding them. Moreover, and more important, Portugal is sufficiently developed and updated in science and technology (OECD, 1986, OECD, 1989a, Gonçalves, 1983) to be largely influenced by recent trends.

We also developed a ground statistical basis from which the above arguments are drawn. Part III will deal with the statistical approach and the significance tests on the relationship between firm size and technical advance.

We want to conclude this section with an interesting result related to the relationship between product or process innovation and firm size, which confirms the widely accepted picture with regard to it.

Table 13. Product versus process innovation. Percentage of firms allocating less than 50%, or 50% or more, of their total R&D resources to product innovation.

size (empl.)	< 50%	>=50%

1-19	0	100.0
20-49	28.6	71.4
50-99	28.6	71.4
100-199	50.0	50.0
200-499	66.7	33.3
>= 500	60.0	40.0

We asked firms what proportion of their R&D resources were devoted to product and process innovation. The results displayed in table 13 supports the evidence from the literature that large firms are relatively more engaged in process innovation than in product innovation. There is a visible trend suggesting that, as firm size increases, process innovation becomes more important. The association is statistically significant (correlation coefficient significant at 99% level).

3.2 Cooperation and contracts

Half of the innovative firms declared having some form of cooperation with external organizations. The preferred partner seems to be foreign firms. 27.5% of the R&D performing firms cooperated with other firms abroad while pursuing their innovative activities, against only 12.5% cooperating with national firms (see table 14). Cooperation with other firms seems to be more important than cooperation with R&D organizations.

Table 14. Cooperation. Percentage of firms cooperating with firms
(in Portugal or abroad) and with R&D organizations (in Portugal or abroad).

	Firms		R&D Organizations	
size (empl.)	Portugal	Abroad	Portugal	Abroad
1-19	25.0	25.0	50.0	0
20-49	14.3	0	14.3	0
50-99	0	28.6	0	0
100-199	12,5	25.0	0	0
200-499	25.0	50.0	25.0	25.0

>= 500	10.0	40.0	30.0	20.0
Total	12.5	27.5	17.5	7.5
Grand total	40.0		25.0	

An explanation for this behaviour may find its basis in recent works trying to analyse this increasingly important trend of cooperation. In one way or another, there has always been some form of cooperation among firms, but at present, it seems to be gaining a considerable momentum.

Teece (1987) advances some arguments on if, why and how, should an innovative entity such as a firm, engage in agreements with other firms. It relies heavily on specifics of technology and mainly on its regime of appropriability. Hagedoorn (1989) gives a comprehensive review in the subject of inter-firms modes of cooperation and suggests an analysis based on transaction costs economics, arguing that it has some advantages in clarifying some particular modes of inter-firm cooperation.

Basically argues that, due to technological uncertainties derived from a changing technological environment (the emergence of a new techno-economic paradigm), and pressed by a competitive market, firms may benefit by pursuing strategic partnerships, engaging in contractual moves which secure their own appropriable technological core while searching for fundamental complementarities. The argument is eventually more suitable to large firms than to smaller ones, since it is doubtful whether there are a large number of small firms performing breakthrough innovative activities, which could conflict with the market position of larger firms. Rather we must expect small firms, excluded from this preferential path to alternatively resort to other organizations, like national research institutes or universities, potentially capable of providing high quality, state of the art, technical work. R&D public organizations, however, lack somehow entrepreneurial spirit and market orientation (qualities that can be decisive in terms of determinants of success; see project Sapho, in Freeman, 1982). Large firms have also great interest in maintaining contacts with R&D organizations, but a market orientation relative disadvantage characteristic of those organizations, coupled with problems of appropriability, may shift the preferences of large firms towards other firms. It may also be that the two kinds of organizations are searched for because of different and complementary reasons. Agreements with other firms exist due to technological complementarities, financial incapability and information on the activity of the competitors, while agreements with R&D organizations may be due to a search for possible exploitation of new technologies, on a medium or long-term perspective.

Figures in table 14 are quite consistent with this analysis. Large firms are preferentially involved in cooperation with other firms, while having a substantial amount of cooperation with R&D organizations. Small firms are more involved with R&D organizations than with other firms.

The fact that small firms are more involved in agreements with R&D organizations than with other firms and the fact that large firms are somewhat less involved in cooperation with R&D organizations than smaller firms may provide the basis for inferences in terms of the quality of the innovation embodied in each mode of cooperation and in each size class.

It is reasonable to expect that, since R&D organizations are preferentially involved in state of the art technology, the reason why small firms search for this kind of expertise is that they intend to develop state of the art products. So, we are inclined to expect from this cooperation, at least technologically significant outputs, if not successful in terms of market impact. This argument does not imply, of course, disqualification of the importance of the innovations in large firms, since these firms, are not only significantly involved in cooperation with R&D organizations, but also have their own structured basic and applied research facilities, which somehow substitute for R&D organizations, enabling firms to build their own tacitly appropriable technology. It may be a reason that could explain the less intensive pattern of cooperation with R&D organizations from the part of large firms.

However, the scope of internal basic and applied research may be more restricted than that which is carried out in public R&D organizations, with considerable consequences in terms of cross applications of new developments in areas not necessarily close to a more conventional or tacit approach. That, as we have argued, may be a reason why large firms cooperate with R&D organizations, and it may be an argument in favour of the creativity of small firms.

It is necessary, at this point, to emphasize an important conceptual distinction between invention and innovation. Invention is an idea to develop a new product or process. It may be a written idea or it may be embodied in a sketchy piece of laboratorial equipment, or both. An invention can be patented or not and it can be commercialised or not. It must be distinguished from innovation, whereby an economic dimension determines the term. An invention becomes an innovation if, after an appropriate development phase, it enters the economic circuit, being the object of a transaction. The reason why this distinction is important, in order to understand the role of small and large firms in the process of technical change, is because the necessary development phase mediating the invention stage and the innovation stage, may imply strong contingencies in terms of financial commitments. The development phase can be considerably lengthy and costly, compared to the invention stage, attributes that can preclude small and resourceless economic agents from continuing a certain process, thereby conferring to larger establishments a comparative advantage, relative to small ones, in the development phase of inventions ultimately leading to innovations.

Taking in consideration that small firms are cooperating fairly strongly with research organisations, which we assume are providing them state of the art know-how, and providing them access and the opportunity to use expensive and advanced machinery (so that small firms do not have to buy prohibitively expensive equipment) or even supporting some of the development costs, taking in consideration that this cooperation may be a way to develop new approaches to scientific and technological problems or to develop new products suitable to specific purposes, and taking in consideration that the inception of important inventions and their first commercial transactions may take place at new small firms (created to exploit those inventions), we advance the argument that technological importance of the innovations developed by small firms cannot be a-priori disqualified based solely on arguments of sheer size, like Galbraith has done it (see quotation above). Furthermore, our results suggest that there are no significant differences in the quality of output across the various size classes (see table 18 and related comments on section 4.1). Similar results on the relationship between quality of output and firm size are also reported by Acs and Audretsch (1988).

These arguments also apply, to a certain extent, to the results concerning the size proportion of firms reporting R&D activities made externally via contract. Only nine firms out of the R&D performing firms reported having made it by means of contract, representing a proportion of 22% (see table 15).

The sum of the percentages does not equal 100% because two of the firms had contractual arrangements with more than one entity. One of the firms in the size class of more than 500 employees had contractual arrangements with all three entities and the firm in the size class 100-199 had arrangements with research organizations and with universities. It must be noted that this item differs from that of cooperation in the sense that it is restricted to a particular mode of contractual arrangement. It is however more difficult to discern a pattern from this results, presumably due to the small number of observations.

Table 15. Number of contractual arrangements with research Organizations, with universities and with other firms.

size (empl.)	research organizations	universities	firms	number of firms
1-19	0	0	0	0
20-49	1	0	0	1
50-99	0	0	3	3
100-199	1	1	0	1
200-499	0	1	1	2
>= 500	1	1	2	2
Total	3 (33.3%)	3 (33.3%)	6 (66.7%)	9

One conclusion can nevertheless be drawn, namely that firms in our sample prefer intramural R&D to external arrangements. The pattern of inter-sectoral (government sector, higher education sector, industry sector) R&D financial flows reported by OECD (1989a) at national level conforms with this picture. Each sector finances virtually exclusively intramural R&D activities.

4. Observations on R&D related aspects

4.1 Barriers to innovation, patents and licenses

We wish to conclude the presentation of the survey results showing more relationships between firm size and other related aspects to the innovation process.

Our questionnaire asked firms whether they had experienced obstacles in pursuing their innovative activities. A set of possible obstacles to innovation was proposed in the questionnaire. Table 16 presents the results, according to size class and type of obstacles.

There are problems in analysing and deriving conclusions from these figures. There is no way of making an objective statistical-type measurement of barriers to innovations. The survey can give no more than a subjective perception of the barrier by the person questioned. The procedure is essentially static, since that perception depends on which phase of the innovation process the measurement is being made. The sense of the barrier may not reflect necessarily its importance or its decisiveness to the successful completion of the innovation project. It may rather reflect an upsetting coincidental preoccupation occurring at that precise period of time when the survey is being responded, which can latter on and ultimately be surmounted. Having this caveat in mind, it can be seen from table 16 that lack of capital seems to be largely responsible for difficulties in inventive activities for firms with less than 200 employees, while for firms above that size it becomes less important. It may be a consequence of financial market imperfections.

Table 16. Barriers to innovation. Percentages of firms declaring an obstacle important.

size (empl.) ->	1-19	20-49	50-99	100-199	200-499	>= 500
Lack of capital	50.0 (60.0)	66.7 (71.4)	60.0 (58.3)	62.5 (54.5)	33.3 (11.1)	10.0 (10.0)
Project costs	50.0 (26.7)	16.7 (35.7)	20.0 (25.0)	50.0 (36.4)	33.3 (22.2)	10.0 (10.0)
Qualified personnel	75.0 (46.7)	33.3 (21.4)	20.0 (25.0)	12.5 (36.4)	0 (22.2)	60.0 (60.0)
Access to information	0 (6.7)	0 (0)	20.0 (8.3)	12.5 (9.1)	0 (0)	10.0 (10.0)

Demand forecast	0 (6.7)	16.7 (21.4)	20.0 (8.3)	12.5 (18.2)	0 (11.1)	0 (0)
Government regulation	25.0 (6.7)	16.7 (7.1)	20.0 (8.3)	0 (0)	0 (0)	0 (0)

(R&D performers without brackets. All firms in brackets.)

The strength of the positive association between firm size and lack of capital as a barrier to innovation (when all firms are considered) suggests that lack of capital may be an important barrier to entry in innovation activities for small firms.

Although table 16 suggests that problems of lack of capital affected more the small firms, table 17, contradictory or not, projects a more aggressive attitude towards innovation from the part of the smaller firms, as it respects future intentions of action in regard to innovative activities. It shows that firms with less than 500 employees are more willing to increase their R&D inputs than their larger counterparts. A chi-square test on the significance of the association between firm size (all classes considered) and future intentions (only for R&D man-years) turned out to be significant at 90% level (however, the proportion of cells with expected frequency less than 5 is 75%, which is far too large to be considered acceptable).

The expected cost of an innovation project seems to matter less, in general terms, than the lack of capital or the difficulty in access to it. The explanation may be found in behavioural terms. A mood of confidence on successful output and optimistic perspectives of future gains, independently of the development costs could be the reason why the expected cost do not act as a substantial (compared with lack of capital) deterrent to innovation.

Table 17. Future intentions. Percentage of firms declaring a certain type of future intention as it regards R&D. Only R&D performers.

	size -> (empl.)	< 500	>=500
man-years-> (R&D)	increases a lot	40.0	22.2
	increases little	28.0	55.6
	remains same	32.0	-
	diminishes little	-	22.2

expenditures->	increases a lot	56.0	44.3
(R&D)	increases little	40.0	33.3
	remains same	4.0	-
	diminishes little	-	22.2

Both very small as well as large firms report more difficulties in finding qualified personnel than other size classes, and this seems to be quite an acute problem for large firms. This pattern may lean again in favour of the hypothesis of a size spectrum of firms whose extremes are relatively more intensively innovative, and whose technological output deserve equal consideration in terms of quality. It may also reflect a competitive pattern between those two extremes, as the opportunities to launch new firms may affect the supply of specialized labour to large firms (it is widely acknowledged the phenomena of creative scientists and engineers who quit their jobs in large organizations in order to pursue their own entrepreneurial and inventive visions). It may also be the consequence of particularities in the environment in respect to the efficient supply of scientists and engineers from the national system of education. In the particular case of Portugal, specialized labour supply seems to be insufficient, at least quantitatively, and stifled by weaknesses and deficiencies of the system (OECD, 1986). It may also be due to particularities of the underlying technological base. This sector relies heavily, not only on hardware requirements but increasingly more on software requirements. Development of software is highly sequential and implies a heavy reliance on tacit information. If personnel turnover becomes significant it may have considerable impact on research and development activities. Kaplinsky (1983) acknowledges this barrier as a very important one in the CAD sector. In any case, qualified personnel seem to have quite a significant impact in terms of barriers to innovation.

Firms seem to have no particular problems regarding obtaining information, forecasting demand to new products and dealing with government regulations (see table 16). No variation pattern between size classes is discernible, except in terms of government regulations, where the smaller firms report some degree, although low, of difficulty, as opposed to larger firms that report none at all.

A related aspect usually linked to the subject of barriers to innovation is that of patents. In our survey, none declared having applied for patenting, and only one large firm licensed another. This result raises some possibilities and speculations. First, it may be the case that we are facing an industrial research environment that is mainly devoted to the development of incremental innovations, and indeed adapting mostly a passive attitude towards indigenous research and development. Portuguese industry, in general, is characterized by a high degree of dependence on the outside world in respect to the purchase of patents, licences, knowledge and technology as shown by several indicators. Patent statistics show that for the period 1975-1985 only a minute percentage of patent applications concerned Portuguese nationals, and the technological balance of payments (patents, licences, know-how, trademarks, etc) has been persistently negative throughout the period 1970-1985 (OECD, 1989b). The national survey on science and technology (JNICT, 1989) reports a total absence of basic research in this sector and an almost total neglect for applied research.

Second, it may reflect differences in propensity to patenting among the various industrial sectors. Most of the economic agents in the industry, which is composed of a large proportion of small firms, may find it too costly and expensive to resort to patenting. It may also be that the patenting system may not match coherently with the technology itself. Mansfield (1984) argues that "...the value and cost of individual patents vary enormously within and across industries and sectors...Many inventions are not patented. And in some industries, like electronics, there is considerable speculation that the patent system is being bypassed to a greater extent than in the past. Some types of technologies are more likely to be patented than others."

In an effort to gauge the quality of the output of R&D activities carried out by the firms, we asked the firms to classify their inventive output according to a four point scale. Table 18 shows the results.

Table 18. Innovation quality. Percentage of firms assessing their inventive output according to a four point scale.

size (empl.)	new to the firm	new to the sector	new to the country	new to the world
1-19	25.0	-	75.0	-
20-49	40.0	-	60.0	-

50-99	60.0	-	40.0	-
100-199	37.5	12.5	37.5	12.5
200-499	50.0	-	50.0	-
>= 500	37.5	-	50.0	12.5
Total	40.6	3.1	50.0	6.3

As it relates to size class, there is no discernible pattern in terms of quality of innovations (market impact not considered). It confirms also our previous arguments about the innovative mood in this country, at least in this sector. However, during telephone interviews we had with some firms, we noticed a considerable precaution on the part of the respondent firms in answering this question, trying not to give an upward assessment of their own work. Some of the respondents who have declared country level quality of output, declared not knowing if their product had similar counterparts in other parts of the world, but were unambiguously assured of the non-existence of such a product at the national level.

Another possible reason why the output of patents is so small is linked with problems of appropriability. A strategy of secrecy may turn out to be more effective in securing core technological assets, as opposed to patenting, if, for instance, short life-cycles of the product and rapid obsolescence of the innovation is such that the time necessary to have a patent accepted and the costs incurring in doing so are by no means justifiable and, in practice, wholly unnecessary. The patent may find itself useless by the time it is granted. Secrecy may also be, in some cases, a better way to prevent rapid imitation of the invention. Also, due to short product life cycles, secrecy may be preferred to patenting as a mean of technological appropriability.

4.2 Incentives

Ten firms declared having received financial incentives for innovation, representing a proportion of 25% out of the total R&D performers. However, only 40% of those incentives were really directed at indigenous research and development activities. The other incentives came exclusively from EEC structural funds and were aimed at the modernization, through purchase of the production process equipment. The net proportion of firms performing R&D receiving incentives to research and development is thus only 10%. It is in agreement with data on gross R&D expenditures in Portugal (OECD, 1984) showing an insignificant amount of funds coming from other sources than the industry itself, as we have mentioned earlier. Resources coming from the government sector, higher education sector or non-profit organizations are negligible compared to resources coming from the industry itself.

4.2 Non-R&D innovation and software

Tables 19 and 20 show the results from the survey answers on the extent of adoption and introduction of innovations in other dimensions of the firm, other than research and development. It refers to the purchase of equipment to the automation of the office or to the automation of the production process, connection to external computer networks, recruitment of qualified personnel, licence acquisition, design and internal and external software.

Table 19. Non-R&D innovation. Percentage of firms having introduced other innovation related aspects.

size (empl.) ->	1-19	20-49	50-99	100-199	200-499	>= 500
office automation	33.3	35.7	33.3	54.5	33.3	30.0
process automation	26.7	42.9	16.7	36.4	66.7	70.0
computer network	0	0	0	0	22.2	40.0
recruitment of qualified personnel	20.0	28.6	41.7	45.5	33.3	60.0
licence acquisition	0	0	0	18.2	0	10.0
Design	13.3	14.3	16.7	27.3	11.1	10.0

The purchase of equipment for office automation is quite constant across the size classes but mostly skewed in favour of the larger firms with respect to the purchase of equipment for automation of the production process. Scale requirements and cost strategies are not unexpectedly behind the explanation for this behaviour, namely the fact that large firms are more concerned with improvements at the production stage.

Both licence acquisition and network connections are excluded from the smaller firms, presumably due to financial reasons or lack of necessity or failure of perception of that necessity. Design seems to be more important in the lower size classes, a situation not estranged from the technological flexibility propositions and the customized regime of management asserted in above arguments. However, the pattern is very weak.

Both purchase of external software and internal writing of software show a relation with firm size (see table 20). As a matter of fact, internal software writing did indeed show up, in regression analysis, as a significant explanatory variable of R&D intensity (see Part III).

Table 20. Software. Percentage of firms having reported external or internal software. All respondent firms.

size -> (empl.)	1-19	20-49	50-99	100-199	200-499	>=500
External software	46.7	50.0	66.7	81.8	77.8	100.0
Internal software	20.0	42.9	25	36.4	88.9	90.0

4.4 International orientation

We asked whether the firm had subsidiaries abroad or had some form of participation in foreign firms. Table 21 and table 22 show the situation as it regards international orientation of the surveyed firms.

International orientation is markedly related to firm size, even when only national firms are considered. We made the distinction because, as shown in the right columns of both tables, the share of national firms decreases with firm size. In the largest size class, less than half are Portuguese firms, the other being subsidiaries of multinational firms.

Table 21. International orientation. All respondent firms.

size (empl.)	only national firms		all firms		total of firms		
	%	n	%	n	national	all	proportion of national firms
1-19	14.3	2	13.3	2	14	15	93.3
20-49	7.7	1	14.3	2	13	14	93.0
50-99	18.2	2	25.0	3	11	12	91.7
100-199	33.3	3	45.5	5	9	11	81.8
200-499	40.0	2	66.7	6	5	9	55.6
>= 500	75.0	3	90.0	9	4	10	40.0
Total	23.2	13	38.0	27	56	71	78.9

Table 22. International orientation. Only R&D performers.

size (empl.)	only national R&D performers		all R&D performers		total of firms		
	%	n	%	n	national	all	proportion of national firms
1-19	25.0	1	25.0	1	4	4	100
20-49	14.3	1	14.3	1	7	7	100
50-99	16.7	1	28.6	2	6	7	85.7

100-199	28.6	2	37.5	3	7	8	87.5
200-499	50.0	1	50.0	2	2	4	50.0
>= 500	75.0	3	90.0	9	4	10	40.0
Total	30.0	9	45.0	18	30	40	75.0

National firms seem to be reasonably engaged in pursuing strategies on internationalisation, not only R&D performers but also all firms (the distribution is very similar in both cases), at least those firms above a certain size (above 100 employees).

The explanation lies presumably on diversification reasons, necessity of expanding their network in order to have access to other markets, and the perspective of a fast approaching European common market.

PART III INNOVATION AND FIRM SIZE: A CLOSER LOOK

1. Introduction

In the following, we will use the data gathered from the survey to specify formal models which will provide a stronger basis to our previous conclusions on the impact of size and other determinants on research and development. Our expectations as it regards other determinants of R&D, based on the available literature on the subject, would lead us to expect that exports shares on total sales and turnover development could be positively related to R&D intensity and that firm status (foreign ownership of capital) and regional location (R&D resource allocation in Portugal is quite uneven; see OECD, 1989a) can be related to R&D intensity. It turned out, however, that only turnover development was significantly correlated with R&D intensity but with an opposite sign to the one expected. We therefore tried multiple possibilities of determinants significance, based on our survey data, with no a-priori expectations, and retained only those which proven to be statistically significant at a certain level. Deviations from the normality assumptions where also excluded (even if coefficient estimation was statistically significant).

A methodological issue must first be clarified. Most authors, when estimating statistical models on the determinants of R&D, include only firms which perform research and development activities and exclude those which do not perform R&D activities, without giving any explanation for such a procedure (of the literature referred to here, only Soete, 1979, and, in more detail, Cohen *et al.*, 1987, mentioned that aspect; see below). In principle, there is no theoretical reason why R&D non-performers should not be included. After all, they have a measurable reflection of their R&D activities, and such a measure is expressed by the number zero (a difficulty may arise if estimates are on a logarithmic functional form, since the logarithm of zero is not specified). We therefore must consider a notional decision model describing the engagement of firms in R&D activities. It may be argued that there is no qualitative difference in the fact that firms engage or do not engage in those activities. Both are relevant and conceptually indistinguishable activities, equally deserving the same analytic weight. In this sense, the decision to undertake R&D activities is configured as a one-stage decision model, whereby the fact that there are no R&D activities is simply reflected in the presence of the zero digit in a continuous measurement scale. On the other hand, the process can be configured as a two-stage decision model where two micro-level routines, in the Nelson and Winter sense (Nelson and Winter, 1982a), can be differentiated. In a first stage, the decision to undertake R&D activities is expressed in a discrete fashion, i.e., it can have only two possible outcomes, yes or no, with its inherent two digit discrete representation, one or zero. The other stage would then be dependent on the outcome of the first, only if a certain choice was made. The object of analysis would then be restricted to only one set of identical outcomes, those which decided yes, and would be a stage describing, in a continuous fashion, differences in the activity weight. Any continuous outcome, within certain limits, can be possible, and each continuous value greater than zero and lower or equal than the limits imposed by particular micro-characteristics, such as size or capital, is conceivable. The measurement of such a stage would reflect the relative importance attributed by firms to its R&D routine. Implicitly, the two-stage model is followed when estimates are based only on R&D performers.

Cohen *et al.* (1987) tackle the problem using a procedure that gives a statistical basis and interpretation to a one-stage decision model, where all observations, including those reporting zero R&D, are included. Using the Tobit model, the statistical coefficients in such a model can be interpreted as a weighted average of two effects:

> "1) The effect of an increase in an independent variable on the possibility that the dependent variable exceeds the limit (in our case, that R&D is greater than zero) and 2) the effect on the expected value of the dependent variable, given that it is above the limit" (Cohen *et al.*, 1987, p.551).

Thus, the probability that a firm engages in R&D, given its size, can be estimated, as well as the estimation of the effects on R&D due to variations in size. Nevertheless, for purposes of comparability with other research, we follow the prevailing practice, and estimate an OLS model including only R&D performers.

2. Indicator: R&D Personnel

The functional specification of our (final, linear in the variables) model is as follows:

Equation (1):

$$RDI_m = \alpha_1 + \alpha_2 \ln SIZE_m + \alpha_3 \, SOFTI + \alpha_4 \, SALE + \alpha_5 \, BAPER + \alpha_6 \, INC + \upsilon$$

where the variables are defined as follows:

RDI_m = R&D intensity (measured in man-years assigned to R&D deflated by size of firm)

RDI_{mf} = R&D intensity (measured in man-years assigned to R&D deflated by size of firm, only formal R&D);(this variable will be used in a posterior model; see below)

RDI_{im} = R&D intensity (measured in man-years assigned to R&D deflated by size of firm, only formal and informal R&D, excludes contracted R&D); (this variable will be used in a posterior model; see below)

$SIZE_m$ = firm size (measured in numbers of employees)

SOFTI = internal software intensity (measured in man-years devoted to internal writing of software deflated by firm size)

SALE = a dummy variable for firms whose turnover development increased in 1989 (compared to 1988)

BAPER = a dummy variable for firms reporting as a barrier to innovation the difficulty in finding qualified personnel

INC = a dummy variable for firms reporting having received a governmental incentive

and υ is the disturbance term.

The following equation (equation 2) shows the estimate of the influence of the different variables on the R&D intensity of firms. The R&D intensity of firms is defined as the sum of all their R&D man-years, i.e., man-years devoted to formal R&D (within a formal R&D department), plus man-years devoted to informal R&D (outside an existing or non-existing R&D department), plus man-years devoted to external R&D (contracts), expressed as a percentage of the firm's total employees. The equation has a semi-log (linear-log) functional form with respect to the size variable (linear in the dependent variable and logarithmic in the independent variable) and a linear functional form with respect to the internal software intensity variable:

Equation (2):

$$RDI_m = \underset{(5.74)^{***}}{16.78} - \underset{(-3.94)^{***}}{2.22} \ln SIZE_m + \underset{(4.46)^{***}}{3.10}\, SOFTI - \underset{(-2.86)^{***}}{5.80}\, SALE + \underset{(1.85)^{*}}{3.37}\, BAPER + \underset{(2.07)^{**}}{4.03}\, INC$$

adj. R^2 = .622 F value = 11.51 *** n=33

significant at 90% level *

significant at 95% level * *

significant at 99% level * * *

(t values in brackets)

As it can be seen, the combined effects of included variables, explain almost two thirds of the variation of the dependent variable with a joint statistical significance at the 99% level, whereby the variables for size, internal software intensity, and turnover development show coefficients significant at the 99% level and the variables for qualified personnel as a barrier to innovation and incentives show coefficients significant at the 95% level and 90% level, respectively.

The most interesting result in the equation is the negative sign on the size coefficient. In contrast to a more or less established notion that R&D intensity increases with firm size, at least until a certain point, the results suggest that small firms are more R&D intensive than large firms. This result is, however, consistent with more recent research and supports our previous observations and conclusions on the subject.

To test for the significance of size alone on R&D intensity, a regression of R&D intensity on size gave the following result:

Equation (3):

$RDI_m = 17.25 - 2.297 \ln SIZE_m$

(5.28) *** (-3.66) ***

adj R^2= .261 F value=13.4 *** n=36

significant at 99% level * * *

(t values in brackets)

which not only confirms but increases the statistical significance of the size coefficient. However, size alone explains only a quarter of the variation of the dependent variable. Other factors are significant determinants of R&D intensity, in agreement with previous research on the subject.

In order to establish how the inclusion of informal R&D affects the outcome, an estimation of the above equations were made using only formal R&D in the calculation of R&D intensities, i.e., we confined our analysis only to firms performing R&D in a formal R&D department. This has the additional advantage of enhancing the comparability of our study with other similar research, since official data on which most of the research depends capture only formal R&D. Equation 4 shows the influence of size alone on formal R&D intensity (RDI_{mf}). Comparing this equation with equation 3 we see that not only the sign of the coefficient didn't change, persisting in showing a negative correlation between size and R&D intensity, but the proportion of variation of the dependent variable explained by the independent variable increased significantly. This is in agreement with table 11 that shows a high R&D intensity in the smallest size classes.

Equation (4):

$$RDI_{mf} = 18.84 - 2.568 \ln SIZE_{m}$$

(5.25) *** (-3.816) ***

adj. R^2= .444 F value=14.56 *** n=18

significant at 99% level * * *

(t values in brackets)

Some caution should be used in interpreting these results. First, it relates only to R&D performers, as we have said before. The proportion of firms performing R&D in the smallest size classes is lower than those performing R&D in the highest size classes (see table 5). Second, R&D resources in absolute terms, in very small firms, are quite low, even though in relative terms may sound considerably high. For instance, a firm with 5 employees and with two R&D employees shows an R&D intensity of 40%. Nevertheless, it seems that those small firms which perform R&D are high tech firms deeply involved in research activities, as suggested by our previous observations and in line with our previous arguments about dynamic consequences on a shift of a technological paradigm and the parallel aspects of technological opportunities.

The complete model including all statistical significant variables on a model restricted to formal R&D is represented in equation 5. Comparing with equation 2 we see that most variables lost their significance. Only BAPER retained its significance with the sign remaining positive (note that the coefficient on BAPER is now larger than the coefficient for BAPER in equation 2).

Equation (5):

$$RDI_{mf} = 17.32 - 2.62 \ln SIZE_m + 6.43\ BAPER$$

(5.78) *** (-4.73) *** (2.94) **

adj. R^2= .624 F value=15.10 *** n=18

significant at 95% level * *

significant at 99% level * * *

(t values in brackets)

In addition to our previous arguments on this subject, some specific ones may be suitable to this particular situation. It is reasonable to expect that management of structured R&D is more severe when assessing personnel qualifications. If formal R&D does, in some way, imply superior research quality, then admission and continuity of personnel cannot be decided leniently.

Going back now to our model expressed by equation 2, which includes all significant determinants on total R&D intensity, we see that the significant coefficient for internal software shows a positive influence on R&D intensity. The problem of causation is always a dilemma in interpreting the relationships emerging from statistical models like the one we use. In any case, quite a strong relationship exists, suggesting a definite connection between software and research and development intensity (not surprisingly, though, in view of the proximity of the two scientific and technological fields in question, namely electronics and software). This relationship supports the very important role information technologies have in respect to the scope of the transformations they are inducing, at several levels, on the contemporary economic system and more particularly, in sectors with a strong science base, as it is the case. As suggested by several authors (Freeman and Perez, 1988, Dosi et *al.*, 1988b) the contemporary economic system, in capitalist societies, is experiencing a pattern of technical change which is not only quantitatively but qualitatively different, involving a somehow discontinuous shift towards new radical approaches on the process of scientific and technological discoveries and the exploitation of those discoveries. The situation is best described by using the concept of scientific paradigm (Kuhn, 1962) and the close concept of technological paradigm. For our purposes, we are interested in the concept of technological paradigm as a "...pattern of solution of selected techno-economic problems based on highly selected principles derived from the natural sciences, jointly with specific rules to acquire new knowledge..."(Dosi, 1988a, p.1127). The manner in which scientists and engineers choose the way to proceed in the resolution of their problems, the way they handle them and the way they choose what kind of knowledge to search for the resolution of those problems are highly conditioned, specified and tending to proceed in particular directions.

The relationship between the emergence of such an information intensive based paradigm and firm size has been suggested earlier, and it is connected to the rise of small research intensive firms, a situation made possible either by opportunities embodied in the new technology or by a new set of heuristics, or both. In spite of the fact that the numbers on software intensity do not fall under R&D (the respondents were explicitly warned against that) it may nevertheless be interpreted as a routine spreading throughout the entire firm. In that sense, the tacit information embodied in such a routine could have a significant influence on R&D. Further, a considerable large proportion of the variation of the independent variable is significantly explained by the inclusion of SOFTI in equation 3, as shown by the increase in adj.R^2 (compare with equation 3):

Equation (6):

$$RDI_m = 14.40 - 2.166 \ln SIZE_m + 2.81\ SOFTI$$

(4.42) *** (-3.32) *** (3.75) ***

adj. R^2= .474 F value=15.4 *** n=33

significant at 99% level * * *

(t values in brackets)

The coefficient on the SALE dummy variable is somehow surprising, contradicting the common sense in the literature as it respects the demand influence on R&D intensity. A positive influence on innovative activities is generally associated with growing industries. If sales growth is used as a proxy for demand growth, then our results do not conform with the so-called "demand-pull" hypothesis, attributed to Schmookler (see Kleinknecht, 1990). Maybe it can be the case that an inverse relationship may take place, that is, a decrease in sales may boost the innovative efforts of the firms, as they can see such an action as an elected way to face competition. This dummy looses its significance, but retains the sign, if included in different equations (for instance, if only $SIZE_m$ and SALE are used as independent variables; see Appendix 1).

Both BAPER and INC, dummy variables related to qualified personnel and governmental incentives, respectively, show positive and significant influence on R&D intensity. BAPER shows a somewhat more robust behaviour than INC, a variable that is statistically significant only in a reduced set of combinations of independent variables (see Appendix 1). It was surprising to find out that the inclusion of a dummy variable for firms having recruited qualified personnel did not turn out to be statistically significant. The differences in significance of these two variables are somehow surprising, since it is reasonable to expect that R&D intensity would be positively related to recruitment of personnel and negatively related to problems in finding qualified personnel since the presence of a problem would probably lead to a decrease in R&D intensity. Thus, a negative sign on BAPER was to be expected. Presumably, this is caused by the fact that only firms who are heavily engaged in R&D face this particular problem. Hence, the coefficient would indicate reverse causation. The positive influence of INC seems to show that those incentives do have some reflections on R&D intensity, in spite of the fact that they are mainly directed towards the modernisation of the production process. It may nevertheless have an indirect or a feedback influence in terms of R&D.

If contracted R&D is omitted from the calculus of R&D intensity, then we can see the influence of size (and other factors) on virtually exclusively intra-mural R&D. Equation 7 shows the estimates of the $SIZE_m$ variable on R&D intensity excluding contracts (RDI_{im}). There are essentially no changes in the values of the coefficients or on their statistical significance.

Equation (7):

RDI_{im} = 17.40 - 2.33 ln $SIZE_m$

(4.92) *** (-3.43) ***

adj. R^2= .258 F value=11.77 *** n=32

significant at 99% level * * *

(t values in brackets)

Only INC looses its statistical significance if a model including the same variables present in equation 2 is constructed using R&D intensity without contracts. No other available variable, different from those included in equation 2, acquired significance (equation 8).

Equation (8):

RDI_{im} = 16.48 - 1.95 ln $SIZE_m$ + 2.91 SOFTI - 6.71 SALE + 5.3 BAPER

(5.19) (-3.33) (4.04) (-3.03) (2.73)

*** *** *** *** ***

adj. R^2= .638 F value=13.32 *** n=29

significant at 99% level * * *

(t values in brackets)

There are no essential changes in the value of the coefficients and on their statistical significance, excepting the case of the variable BAPER whose coefficient increased its statistical significance (compared to equation 2), probably due to the fact that, since now the R&D under consideration is intra-mural, the problem is perceived more directly.

3. Indicator: R&D Expenditures

Similar estimations of the influence of size and other factors on R&D intensity were made using R&D expenditures as an indicator of innovative activity. R&D intensity is defined here as the sum of total expenditures on R&D (formal, informal plus contracts) expressed as a percentage of total sales. Correlation between R&D intensity using expenditures as the indicator and R&D intensity using man-years as the indicator is not perfect (R=.615, significant at the 99% level) suggesting that what determines R&D expenditures is not quite similar to what determines inputs to R&D personnel. Actually, none of the variables present in the previous model (see equations 1 and 2), or any other available one, retained or acquired significance on our second model (note that the definition of size is now different; see below), when total R&D expenditures (formal, informal and contractual) was used. However, the $SIZE_e$ coefficient remained negative. Only when restricting the analysis to formal R&D (estimating a model using only firms reporting formal R&D) did the size coefficient become significant. We tried multiple possibilities with other variables and only one turned out to be significant (always restricted to formal R&D), but, surprisingly, when it was included in the model the size variable lost its statistical significance. The definition of the variables is as follows:

RDI_e = R&D intensity (measured in R&D expenditures deflated by size of firm)

RDI_{ef} = R&D intensity (measured in R&D expenditures deflated by size of firm; only formal R&D)

$SIZE_e$ = firm size (measured in total sales)

If total R&D expenditures (formal, informal, contractual) are used the coefficient on the $SIZE_e$ variable retains its negative sign but it is less negative than in equation 2, suggesting a weaker correlation as compared to equation 2. But, as a matter of fact, if size alone is regressed on R&D intensity, the statistical significance is lost. Equation 9 shows the estimates of the $SIZE_e$ variable on R&D intensity. The equation has a double log functional form.

We also tested in which way the inclusion of informal R&D affected our results. Thus, an estimate of the above equation was made, confining ourselves only to R&D performed in a formal R&D department.

Equation (9):

$$\ln RDI_e = 1.38 - .204 \ln SIZE_e$$

(1.54) º (-1.58) º

adj. R^2= .0411 F value=2.5 º n=36

insignificant º

(t values in brackets)

As we have said before, only in this case does the $SIZE_e$ variable become significant (see equation 10) but the negative sign on the coefficient of the size variable persists:

Equation (10):

$$\ln RDI_{ef} = 2.95 - .399 \ln SIZE_e$$

(2.03) * (-2.01) *

adj. R^2= .169 F value=4.05 * n=16

significant at 90% level *

(t values in brackets)

What lies behind the differences in the estimates using the two R&D indicators? We should expect that R&D expenditures would be in some form dependent on the wages of R&D personnel. Possibly, dissimilarities in the mean value of wages practiced at the various size classes is determinant for the explanation of such a disparity. But, if it is not the case, i.e., if the mean value of wages are equivalent at any given size class, then we may conclude that the pattern of expenditures on other R&D assets is different between small and large firms. In any case, it makes a strong case for the necessity of finding more direct measures of inventive activity, such as, for instance, innovation counts.

4. Quadratic Regression

Since our negative signs on the size coefficients, evident on all previous regressions, are obviously caused by the influence of a set of highly research intensive small firms, we wished to determine if the exclusion of the small firms from the analysis could significantly influence the results. For that purpose, we sequentially excluded small firms from the analysis until the size coefficient turned positive. That happened when only firms with more than 200 employees were included. However it was not statistically significant. Only when firms with fewer than 500 employees were excluded from the regression analysis did the size coefficient become statistically significant at 90% level (equation 11), but then the number of observations was quite low:

Equation (11); (only firms above 500 employees):

$$RDI_m = -14.25 + 2.27 \ln SIZE_m$$

(-1.64) o   (1.865) *

adj. R^2= .216   F value=3.48 *   n=10

insignificant   o

significant at 90% level   *

(t values in brackets)

The statistical significance of the size coefficient did not show up, however, when R&D expenditure was used as an indicator and, as a matter of fact, it remained negative (equation 12).

In face of these results, particularly those respecting the equation using R&D personnel as an indicator of inventive activity, we were led to the conclusion that the relationship between size and R&D intensity might take a nonlinear (in the variables) functional form. Accordingly, we specified a quadratic model in the size variable and tested for its significance. When R&D expenditure was used as the indicator, the results were not significant, but when R&D personnel was used as an indicator, the model turned out to be significant.

Equation (12); (only firms above 500 employees):

$$\ln RDI_e = -.141 - .0263 \ln SIZE_e$$

(-.034) º (-.057) º

adj. R^2= 0 F value= .00324 º n=10

º insignificant

(t values in brackets)

So, using our data we estimated a second-degree polynomial model on the influence of size on R&D intensity, in order to establish if a threshold pattern could be discerned. The specification and the estimate of the model, based solely on size, are shown in equation 13, where S_m is the size variable measured in total employees (the same as $SIZE_m$).

The joint significance is at the 90% level (actually very close to the 95% level), suggesting a U relationship between size and R&D intensity.

This is in broad agreement with our arguments (in fact, they are based on these results) and supports and it is supported by several studies showing a similar pattern in respect to this particular sector (Cohen, 1987, Acs, 1988, Freeman, 1982) or to manufacturing industry in general. The proportion of explained variation is rather small but it is significantly enhanced if other variables are included in the equation (equation 14).

Equation (13):

$$RDI_m = 8.60 - .01176\ S_m + 3.4x10^{-6}\ S^2_m$$

(5.57) (-2.392) (2.026)

* * *   * *   *

adj. R^2= .115   F value=3.27 *   n=36

significant at 90% level *

significant at 95% level * *

significant at 99% level * * *

(t values in brackets)

Equation (14):

$$RDI_m = 9.36 - .0152\ S_m + 5x10^{-6}\ S^2_m + 2.95\ SOFTI - 6.6\ SALE + 4.97\ BAPER + 4.03\ INC$$

(5.12) (-3.47) (2.79) (3.99) (-3.13) (2.47) (1.91)

* * *   * * *   * * *   * * *   * * *   * *   *

adj. R^2= .585   F value=8.51 * * *   n=33

significant at 90% level *

significant at 95% level * *

significant at 99% level * * *

(t values in brackets)

All the variables used in our previous model (see equation 2) proved to be significant if included in the quadratic model. The specification of each variable is the same (except for $SIZE_m$ or S_m, now not being specified in a logarithmic form).

Although both the linear and the quadratic model fulfil the necessary requisites to describe the data, there are reasons to pick up the linear model as the best fit. From equation 13, the coordinates of the extreme value can be calculated as being equal to (1729, -1.6). Since the value for the y coordinate (corresponding to the value of RDI_m) not only lies outside the sample range but takes, in fact, an unrealistic negative value, the adequacy of the quadratic model is somewhat reduced. Moreover, the scatter plot of $SIZE_m$ with RDI_m shows that a reduced set of outliers has an influence on the regression (if the regression is run without the three largest firms, the coefficient for S^2_m looses its statistical significance), particularly in the upward sloping portion of the curve (see Appendix 2).

SUMMARY AND CONCLUSIONS

The present survey analyses the relationships which exist, at several levels, between firm size and inventive activity in the electronic/electric industrial sector in Portugal.

It displays a series of tables providing information on several innovation related aspects and their relationships with firm size. Those innovation related aspects include an assessment on the part of the respondents of the importance of a possible set of obstacles to innovation. Problems with finding qualified personnel, lack of capital and difficulties with ongoing project costs were the problems perceived as most acute, but with different degrees according to size class. Small firms felt problems related to lack of capital and project costs more strongly, while small as well as large firms found considerable problems in finding qualified personnel. The survey also collected information on the introduction of innovations related to several activities of the firm. Purchase of equipment for office automation was spread evenly over small and large firms, while purchase of equipment for the automation of the production process was mostly done by large firms. Procurement of software as well as internal writing of new software turned out to be positively correlated to firm size.

The most important result coming out of this research is related to the relationship between firm size and research and development. The results show that R&D intensity is generally higher in the smaller size classes, whether measured by personnel engaged in R&D activities or by expenditures on R&D.

The coefficients of the size variable in regression equations, in which the indicator of inventive activity was expressed in man-years assigned to R&D, turned out to be negative and statistically significant. Even if informal or contracted R&D was not included in the computation of R&D intensity, the negative sign on the coefficient of the size variable as well as its statistical significance did not change essentially when omitting that information from the measure of R&D intensity. In regression equations where the indicator of inventive activity was expenditures on R&D the sign on the coefficient of the size variable was also negative, but it was not statistically significant. It should be noted that those regressions were run in firms which have R&D activities. Firms which did not report R&D activities were deleted from the regression analysis. The percentage of firms which perform R&D is positively related to firm size. All firms in the highest size class reported R&D activities against, only 26.7% of firms reporting R&D in the lowest size class.

The results from this survey are strikingly similar to those reported by recent research work on the same subject. Studies conducted in several Western European countries and in the US (including all industrial sectors) show a common pattern with respect to a general relationship between size and inventive activity, reporting, specifically, that R&D intensity first falls and then rises with firm size. Moreover, some studies suggest that the relationship between firm size and inventive activity has changed and has evolved with time, casting doubts on the adequacy of restricting the analysis to the size explanatory variable.

We interpret the above mentioned similarities as not being coincidental but as being measurable signs of fundamental structural adjustments pervading the capitalist system, caused by radical changes in science and technology and in the way the process of scientific and technical knowledge and discovery is being conducted. We advance no definite answers as it relates to the acceptance or rejection of the Schumpeterian hypothesis. Rather, we support the notion that the subject should be viewed in a dynamic perspective and, concomitantly, include other explanatory factors, notably those related to changes in the science and technology base underlying innovative activities.

The results of this study suggest that small firms have an important role to play in the innovation process and some important policy conclusions may be derived from it, namely with respect to the attitude of governments towards anti-trust policies, mergers and take-overs or towards government support of innovative activities. In the particular case of Portugal, where the opportunities of national industry for competing with giants of mature technologies established elsewhere are not large, one may wonder if support of the innovative potential of small or medium-sized firms would not be a realistic way of enhancing its technological capabilities.

Finally, a last methodological question is due on the use of R&D indicators, concerning the disparities revealed by the use of two input R&D indicators. Those disparities may cast some doubts on the adequacy of at least two procedures: inferring conclusions on R&D outputs based on R&D inputs, and, inferring conclusions based solely on one type of indicator. The use of a more direct measure of innovation, however difficult it may be to gather, is consequently recommended.

APPENDIX 1: REGRESSIONS

I - LINEAR REGRESSION ESTIMATES

Dependent variable: RDI_m
Cases: R&D performers

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Variables						N	Adj.R^2
	const.	ln $SIZE_m$	SOFTI	SALE	BAPER	INC		
Estimated equation								
1	16.78 (5.74) * * *	-2.22 (-3.94) * * *	3.10 (4.46) * * *	-5.80 (-2.86) * * *	3.37 (1.85) *	4.03 (2.07) * *	33	.622 (11.5) * * *
2	16.05 (5.23) * * *	-1.97 (-3.38) * * *	2.86 (3.95) * * *	-5.22 (-2.46) * *	4.30 (2.30) * *		33	.577 (11.9) * * *
3	16.29 (4.96) * * *	-1.90 (-3.05) * * *	3.24 (4.30) * * *	-4.21 (-1.89) *			33	.515 (12.3) * * *
4	14.40 (4.42) * * *	-2.17 (-3.32) * * *	2.81 (3.75) * * *				33	.474 (15.4) * * *
5	17.25 (5.28) * * *	-2.30 (-3.66) * * *					36	.261 (13.4) * * *
6	17.85 (4.93) * * *	-2.27 (-3.54) * * *		-.983 (-.404) o			36	.242 (6.6) * * *
7	15.77 (5.04) * * *	-2.35 (-3.88) * * *			4.78 (2.37) * *		36	.349 (10.4) * * *

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Variables						N	Adj.R^2
	const.	ln $SIZE_m$	SOFTI	SALE	BAPER	INC		
Estimated equation								
8	17.48 (5.39) * * *	-2.52 (-3.90) * * *				3.04 (1.28) o	36	.275 (7.63) * * *
9	17.25 (5.16) * * *	-2.27 (-3.86) * * *		-2.83 (-1.21) o	5.54 (2.63) * *		36	.358 (7.5) * * *
10	13.87 (4.36) * * *	-2.21 (-3.55) * * *	2.43 (3.19) * * *		3.34 (1.69) o		33	.504 (11.8) * * *
11	14.72 (4.70) * * *	-2.34 (-3.83) * * *	2.88 (4.01) * * *			4.00 (1.90) *	33	.516 (12.36) * * *
12	18.50 (5.13) * * *	-2.49 (-3.82) * * *		-1.64 (-.668) o		3.35 (1.38) o	36	.262 (5.15) * * *
13	4.16 (3.43) * * *		3.27 (3.87) * * *				33	.304 (15.0) * * *

From col.(2) to col.(7): t values in brackets.
In col.(9): F values in brackets.

insignificant	o
significant at 90% level	*
significant at 95% level	* *
significant at 99% level	* * *

Notes: The equation numbers in col.(1) do not correspond with those in the main text. Refer to pages 62 and 63 for the definition of the variables.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Variables						N	Adj.R^2
	const.	ln $SIZE_m$	SOFTI	SALE	BAPER	INC		
Estimated equation								
14	7.96 (3.85) * * *		3.77 (4.55) * * *	-5.46 (-2.21) * *			33	.381 (10.85) * * *
15	3.36 (2.43) * *		2.97 (3.93) * * *		2.73 (1.17) o		33	.312 (8.25) * * *
16	3.59 (2.53) * *		3.34 (3.90) * * *			1.92 (.782) o	33	.295 (7.69) * * *

From col.(2) to col.(7): t values in brackets.
In col.(9): F values in brackets.

insignificant o
significant at 90% level *
significant at 95% level * *
significant at 99% level * * *

Notes: The equation numbers in col.(1) do not correspond with those in the main text. Refer to pages 62 and 63 for the definition of the variables.

II - QUADRATIC REGRESSION ESTIMATES

Dependent variable: RDI_m
Cases: R&D performers

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Variables							N	Adj.R^2
	const.	S_m	S^2_m	SOFTI	SALE	BAPER	INC		
Estimated equation									
1	8.60 (5.57) * * *	-.012 (-2.39) * *	$3.4x10^{-6}$ (2.03) *					36	.115 (3.27) *
2	6.56 (4.27) * * *	-.013 (-2.46) * * *	$5.0x10^{-6}$ (2.24) * *	2.87 (3.53) * * *				33	.384 (7.64) * * *
3	9.92 (3.95) * * *	-.012 (-2.39) * *	3.5x10-6 (2.06) * *		-1.79 (-.67) o			36	.10 (2.29) *
4	6.94 (4.48) * * *	-.013 (-2.87) * * *	$3.5x10^{-6}$ (2.28) * *			5.97 (2.67) * *		36	.253 (4.95) * * *
5	8.17 (5.10) * * *	-.013 (-2.55) * *	3.6x10-6 (2.11) * *				2.78 (1.03) o	36	.116 (2.54) *
6	5.86 (3.38) * * *	-.015 (-2.91) * * *	$5.2x10^{-6}$ (2.43) * *	2.29 (2.76) * *		4.46 (1.96) *		33	.438 (7.25) * * *
7	9.54 (4.99) * * *	-.014 (-3.06) * * *	5.1x10-6 (2.62) * *	2.77 (3.61) * * *	-5.97 (-2.74) * *	5.44 (2.61) * *		33	.544 (8.64) * * *
8	9.36 (5.12) * * *	-.015 (-3.47) * * *	5.1x10-6 (2.79) * * *	2.95 (3.99) * * *	-6.60 (-3.13) * * *	4.97 (2.47) * *	4.03 (1.91) *	33	.585 (8.51) * * *

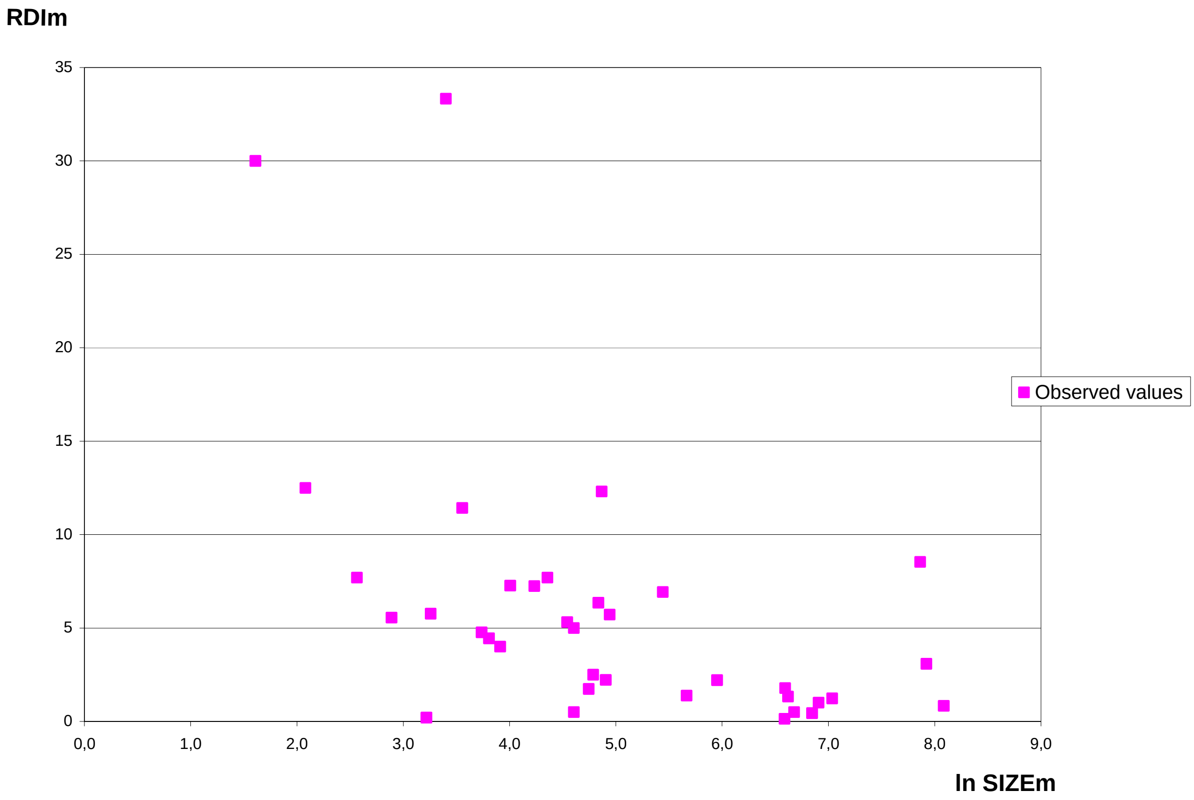
From col.(2) to col.(8): t values in brackets.
In col.(10): F values in brackets.

insignificant	o
significant at 90% level	*
significant at 95% level	* *
significant at 99% level	* * *

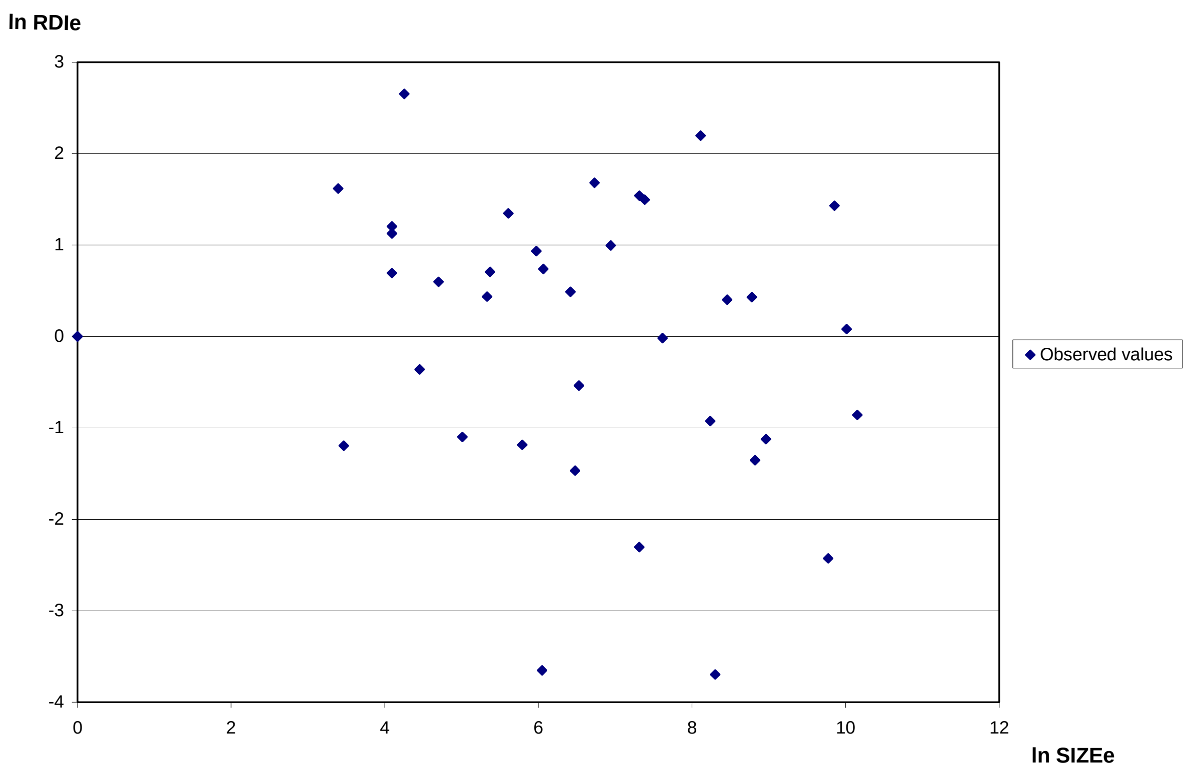
Notes: The equation numbers in col.(1) do not correspond with those in the main text. Refer to pages 62, 63 and 75 for the definition of the variables.

APPENDIX 2: PLOTS

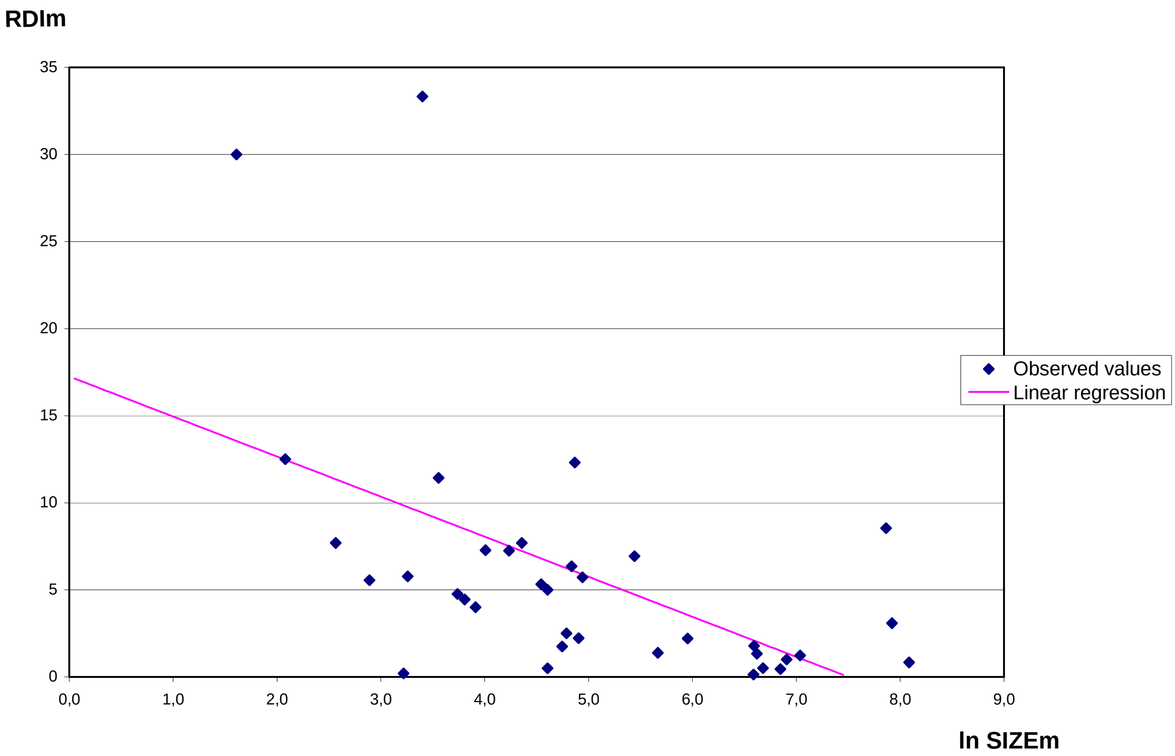
1.1 Plot of RDI_m with ln $SIZE_m$



1.2 Plot of ln RDI_e with ln $SIZE_e$

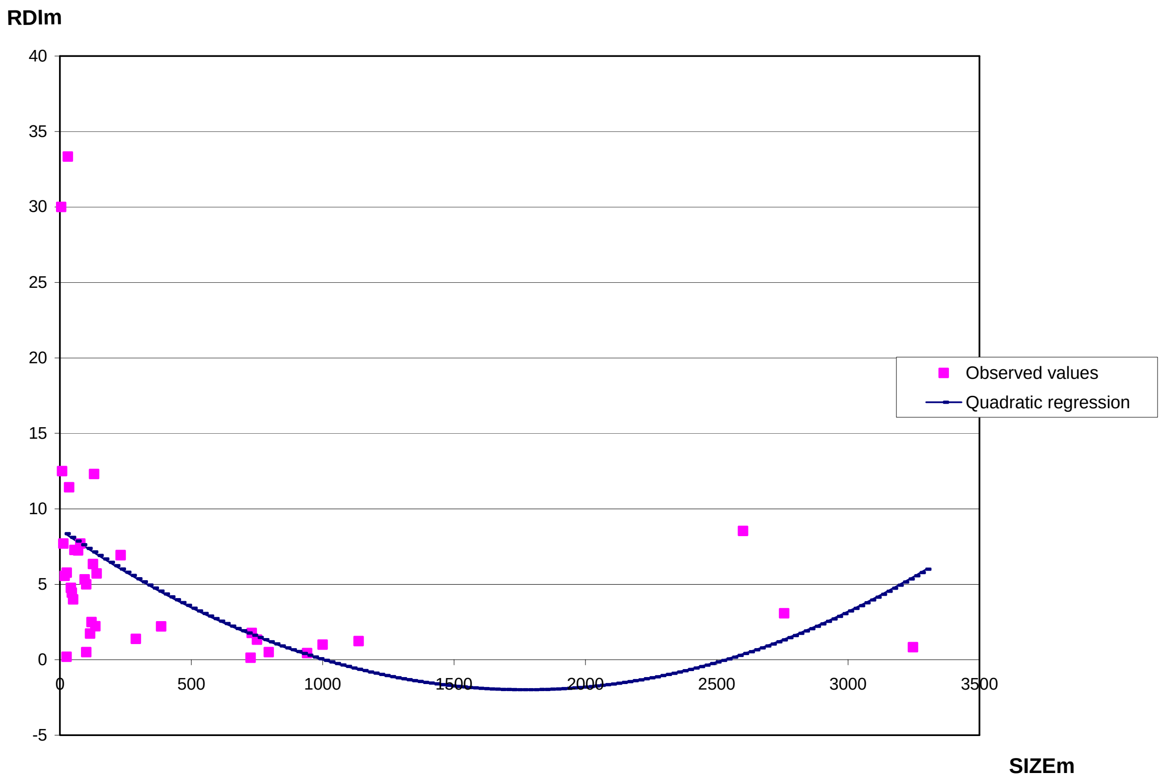


2.1 Plot of RDI_m with ln $SIZE_m$ plus the estimated linear curve



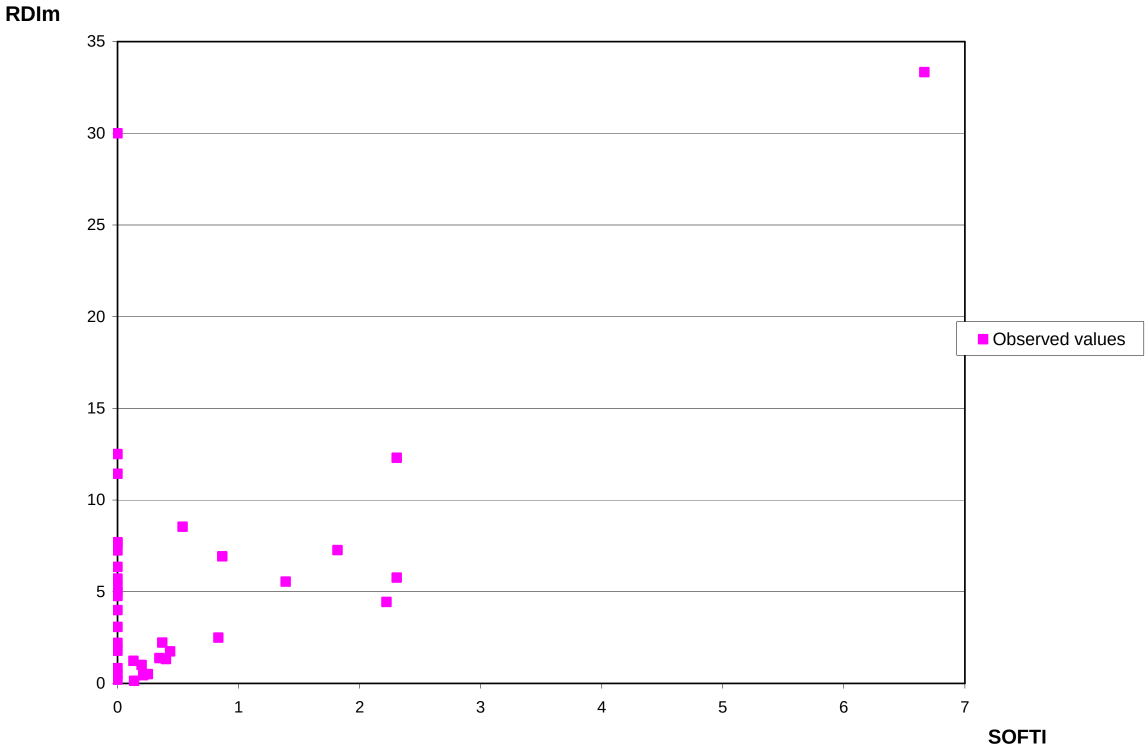
$$RDI_m = 17.25 - 2.30 \ln SIZE_m$$

2.2 Plot of RDI_m with $SIZE_m$ plus the estimated quadratic curve



$$RDI_m = 8.60 - 0.012 S_m + 3.4 \times 10^{-6} S_m^2$$

3. Plot of RDI_m with SOFTI



APPENDIX 3: THE QUESTIONNAIRE

SURVEY ON TECHNOLOGICAL INNOVATION
IN THE PORTUGUESE INDUSTRY

Executed by F. Romero (adapted from A. H. Kleinknecht)

Maastricht Economic Research Institute on Innovation and Technology
Limburg University
Maastricht
The Netherlands

Dear Sir

The present inquiry intends to capture the level of innovative activity in the Portuguese industry. The anonymity of the participants of this survey will be guaranteed. The final report will only be presented with summarizing statistics and general conclusions. These statistics do not hold information on data concerning separate companies.

In order to take up as little of your time as possible, we have endeavoured to keep this questionnaire simple. In most of the cases you will only have to put a cross against the pre-printed answers.

You are kindly requested to return this questionnaire before 30th September 1990.

You can use the enclosed return envelop. No stamps required. If any questions arise during the completion of this questionnaire you can phone to: 01-575395 (Mr. Romero)

I GENERAL DATA

1. Are you an independent company or part of a concern?

1☐ an independent company

☐ part of a concern with main office:

2☐ in Portugal

3☐ abroad

If your company is part of a concern, for which division of the concern are you completing this questionnaire?______________

2. How many people were employed by your company on 31st December 1989?

Number of employees: _____(convert part-timers into full-timers)

3. Exports: which percentage of your turnover (in escudos) can be attributed to exports?

1☐ no exports

2☐ exports constitutes less than 10% of turnover

3☐ export between 10% and 25% of turnover

4☐ export between 25% and 50% of turnover

5☐ export between 50% and 75% of turnover

6☐ export more than 75% of turnover

4. **Turnover development** in 1989: if you compare your turnover (in escudos) of 1989 to the turnover you had in 1988, your turnover in 1989 was:

1☐ higher 2☐ virtually the same 3☐ lower

If higher:

4☐ up to 10% higher
5☐ 10 to 20% higher
6☐ more than 20% higher

if lower:

7☐ up to 10% lower
8☐ 10 t0 20% lower
9☐ more than 20% lower

II RESEARCH AND DEVELOPMENT (R&D)

You can find a definition of R&D on the green supplementary sheet. The questions 5 up to 13 are concerned with R&D in scientific subjects (mathematics, physics, chemistry, technical, etc.)
Please note that activities with regard to software and design do not fall under R&D.

Note: it could occur that you can only cross out "no" or "not applicable" with regard to questions 5 up to 12. However, it is important for our survey that you do answer the questions.

5. Does your company dispose of a separate department for Research and Development (R&D)?

1☐ **Yes**

2☐ **No** (continue with question 7)

6a. If your company disposes of a separate R&D department: in 1989, how many man-years were spent on R&D within this department?

Number of R&D man-years in 1989:______________________

6b. If your company disposes of a separate R&D department: in 1989, how many thousands of escudos were spent on R&D within this department?

Thousands of escudos spent on R&D in 1989:______________

7. R&D activities could be taken up by different departments in your company. Examples: the sales department that develops a new product, or the production department that develops a process improvement.

In 1989, have there been any R&D activities in your company executed by other departments than a separate R&D department?

2☐ **No** (continue with question 8)

1☐ **Yes**; could you estimate the number of man-years and escudos that were spent on those activities in 1989? (If necessary a rough estimation.)

Number of man-years for R&D in 1989:____________

Thousands of escudos for R&D in 1989:______________

8. R&D activities contracted out: in 1989, did you appealed to any external R&D facility in Portugal or abroad, besides or in stead of the internal R&D activities?

2☐ **No** (continue with question 10)

1☐ **Yes**; could you estimate the extent (in man-years and costs) of the R&D activities contracted out?

Extent of R&D activities contracted out in 1989:

Man-years:______________________

Thousands of escudos:________________________

9. To which R&D institutions have you appealed to execute the R&D activities contracted out mentioned in the last question?

1☐ LNETI

2☐ Universities

3☐ Other firms

4☐ Private R&D institutions

5☐ Others, namely:_____________________________________

10. With regard to your R&D activities (internal or external) is there any form of cooperation with other companies or R&D organizations?

0☐ **Not applicable:** you do not have R&D
(continue with question 14)

2☐ **No** (continue with question 11)

1☐ **Yes**, namely with (you can cross more than one possibility):

☐ firms

a☐ in Portugal

b☐ abroad

☐ R&D organizations

c☐ in Portugal

d☐ abroad

11. R&D can refer to innovation of products as well as to the innovation of the production process within your company. If you equate your total R&D with 100%, how would you divide your R&D over these two types of innovation in 1989 (give, if necessary, a rough estimation)?

innovation of **products** ....%

innovation of **processes** ....%

unable to divide ....%

Total of R&D activities 100 %

12. What are your expectations with regard to the number of man-years and escudos that will be spent on R&D within your company in 1990 and 1991?

Compared to 1989, the number of man-years for R&D in 1990 and 1991 will:

1☐ strongly increase
2☐ slightly increase
3☐ remain virtually the same
4☐ slightly decrease
5☐ strongly decrease

Compared with 1989, spending (in escudos) for R&D in 1990 and 1991 will:

6☐ strongly increase
7☐ slightly increase
8☐ remain virtually the same
9☐ slightly decrease
0☐ strongly decrease

13. During 1989 your company was eventually engaged in some innovation project. That innovation can incorporate a new product or a considerably improved product, or a new or considerably improved process. How would you classify that innovation in terms of its degree of newness?

1☐ New to the firm
2☐ New to the sector
3☐ New to the country
4☐ New to the world

III OTHER INNOVATION RELATED ACTIVITIES

Note: the following questions are related with aspects of the innovation process that are not necessarily related to R&D, even though they might be closely linked to R&D.

14. During 1989, did you apply to one or more patents at the European Patents Bureau and/or in the United States of America?

2☐ **No**
1☐ **Yes**; can you indicate the number?

Number of **European** patents applied for:________________
Number of **American** patents applied for:________________

15. You might have been engaged in R&D for the innovation of products or processes. However, you may also have developed innovation in another way, besides or instead of R&D. Which of the following possibilities played an important role in the innovations in 1989?

☐ Procurement of advanced machinery:

a☐ for the office computerisation
b☐ for the production computerisation
c☐ for other purposes, namely:___________

d☐ Connection to an external computer network
e☐ Recruitment of better qualified personnel
f☐ Procurement of licence
g☐ Design
h☐ other, namely:_____________________________________
i☐ not applicable (there were no innovation related activities)

16a. In 1989, did your company spent any money on the procurement of software, or on the writing or rewriting of software by a third party?

2☐ **No** (continue with question 16b)
1☐ **Yes**; can you give an estimation of the expenditures that were involved?

Expenditures on software assignments to third parties in 1989:_______________________________

16b. In 1989, were there any working hours spent on writing new software or on the rewriting of existing software?

2☐ **No**

1☐ **Yes**; can you give an estimation (if necessary, a rough estimation) of the number of man-years that were spent on writing software?

Number of man-years spent on software within the company in 1989:___________________________________

17. What are the main bottlenecks you encounter in your innovation activities?

1☐ lack of capital

2☐ costs of the projects too high

3☐ lack of qualified personnel

4☐ problems with access to information

5☐ problems in estimating market demand

6☐ problems with government regulations

7☐ others, namely:________________________________

8☐ not applicable (there were no innovation activities)

18. **Training courses**: in 1989, which percentage of your personnel participated in an internal or external training course, of which the costs were (partly) borne by your company?

1☐ 0% (no training courses)
2☐ up to 10% of your personnel
3☐ 10 to 25% of your personnel
4☐ 25 to 40% of your personnel
5☐ more than 40% of your personnel
6☐ impossible to state

19. Did you make use of any governmental incentive during your R&D or innovation efforts?

0☐ **not applicable** (there were no R&D or other innovation efforts)

2☐ **No**

1☐ **Yes**; please mention which ones:
(you can mention a maximum of five incentives, in bold letters)

1:____
2:____
3:____
4:____
5:____

20. **International Orientation.**

Does your company have one or more offices abroad or some form of participation in foreign companies?

1☐ Yes
2☐ No

During the **last two years**, did your company provide one or more licences to foreign companies?

1☐ Yes
2☐ No

21. This questionnaire was filled by:

Mr/Mrs:______________________ Job title:_______________________

In case of any indistinctness, you can be contacted on phone number:_____________________ regional code:____________________

THANK YOU VERY MUCH FOR YOUR COOPERATION!

You can use the enclosed envelope to return this questionnaire (no stamp required). If you no long possess this envelope, you can return the questionnaire free of charge, by using the following address:

TECHNOLOGICAL INNOVATION INQUIRY
Freepost Number 22025
1141 LISBON Codex

EXPLANATION TO THE QUESTIONNAIRE ON TECHNOLOGICAL INNOVATION IN THE PORTUGUESE INDUSTRY SECTOR

Definition of Research and Development (**R&D**):

Research:

Creative, systematic activities aimed at increasing scientific knowledge and scientific understanding. Research can be divided into:

a) Fundamental research that is not first or foremost aimed at finding a solution to a practical problem.

b) Applied research that is specifically aimed at finding a solution to a specific practical problem.

Development:

Creative, systematic activities aimed at using the results of research in order to develop new or strongly improved materials and/or products, as well as to install new processes or systems or considerably improve processes or systems already at use.

These definitions are based on the so-called Frascati Manual, a manual for the statistical measuring of research and development, published by the Organisation for Economical Cooperation and Development (OECD).

It is not easy to draw a distinct line between activities that are regarded as Research and Development and related activities which do not fall under R&D. The presence of a distinct element of originality or innovation is characteristic for Research and Development. This is in contrast with related activities that can not be considered as Research and Development, such as:

- the routinely gathering of data which are of importance to science, but which are in the first instance gathered for a different purpose, such as the composition of statistics , daily meteorological measurements, other routine measurements, tests or analysis, etc.(Unless new methods are developed.)

- documentation activities and translations which are not directly aimed at a specific scientific research, e.g., library documentation.

- distribution of scientific publications.

- the use of scientific knowledge for educational purposes consultancy purposes.

- scientific courses and training.

- research into the feasibility of certain house building, electrical installations, or other utility projects.

- market research (unless new methods are developed).

- activities related with computer programming not directly related with scientific research (unless new methods are developed).

The following activities, more closely related with industrial production, do not fall under the definition of Research and Development:

- industrial design (unless it is related with a systematic search for ergonomic adaptation of appliances).

- routine analysis of products (quality control).

- experimental production and tooling up, except for feedback research and development.

- troubleshooting, except for feedback research and development.

- technical service rendering.

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