



Product Innovation, Process Innovation, and Size

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Abstract. We test the hypothesis that large firms devote a higher proportion of their research and development (R&D) expenditure on process innovation than smaller firms. According to the estimates, process- and product R&D expenditure rise less than in proportion to size. The size effect is somewhat stronger for process R&D but the difference to product R&D is in no way dramatic. This difference with regard to size elasticity of process- and product R&D is somewhat more pronounced when accounting for possible interrelationships between expenditure on process- and product R&D but remains statistically non-significant.

Key words: Enterprise size, process innovation, product innovation, R&D expenditure.

JEL Classifications: D21, O31.

I. Introduction

The relationship between innovation activity and firm size has been subject to theoretical speculation and particularly to empirical investigation for a number of decades (see Cohen, 1995, for an overview). This research was mainly motivated by the implications that the findings have for the development of market structure and the long-term stability of a market economy. Recently, Cohen and Klepper (1996a, b) have developed a model for the relationship between R&D activities and business size. One important element of their approach is the hypothesis that the return of an innovation is positively related with the size of the respective business unit and that this relationship is stronger for process innovation than for product innovation. As a consequence, large firms may be expected to devote a higher proportion of their R&D expenditure towards process innovation than smaller firms.

In this paper, we test this hypothesis by investigating the relationship between size and the amount of resources spent on product- and on process innovation using data for German enterprises.¹ First, we outline the argument raised by Cohen and

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¹ The term 'enterprise' here refers to a productive unit at a specific location that may be part of a firm with several units at different locations. This kind of unit of observation is sometimes also referred to as 'establishment'.

Klepper (1996a, b) in some detail (Section II). Section III gives information on our data set and the average amount of R&D expenditure in the sample. In Section IV, we specify our approach to estimate the relationship between different kind of R&D expenditure and size. The results (Section V) indicate some confirmation of the Cohen–Klepper hypothesis with regard to the variation of product- and process innovation effort with size. This effect, however, is not very pronounced.

II. Product and Process Innovation by Firm Size

1. THEORY

Cohen and Klepper (1996a, b) have introduced a model for the relationship between firm size and R&D effort devoted to product and process innovation.² In this model the effect of an innovation is expressed by a certain increase of the price-cost margin (pc). In the case of a process innovation this increase of a firm's price-cost margin results from lower production costs. The firm will benefit from the higher price-cost margin as long as its competitors have not imitated the innovation. In the case of a product innovation the price-cost margin increases because buyers are willing to pay more for new product features and the firm yields monopoly rents until these new features are imitated. It is assumed that innovations are not licensed or sold to other firms in disembodied form. The rationale for this may be seen in the problems involved in a transfer of information on markets (Arrow, 1962; Geroski, 1995). This assumption implies that returns from a firm's innovation can exclusively result from spreading the benefits of that innovation over its own output. Cohen and Klepper assume that an innovation requires R&D effort (r) and that there exists a positive relationship between the amount of R&D and the respective increase of the price-cost margin (pc). As marginal returns from R&D effort are positive but decreasing, we can write for the price-cost margin

$$pc(0) = 0; pc'(r) > 0; pc''(r) < 0. \quad (1)$$

In explaining the relationship between innovation and size as specified by Cohen and Klepper (1996a, b) in some more detail, let us start with the case of process innovation. If the innovation can not be sold in disembodied form, the return of a process innovation due to an improvement of the price-cost margin is positively related to the number of internal applications which depends on the firm's output level (q). Therefore, the return from a process innovation (e) is given by

$$e = pc_{\text{process}}(r_{\text{process}})q. \quad (2)$$

The higher the volume of production the higher the total gross benefit of an innovation. Larger firms are, therefore, able to derive a higher return from a certain

² Basic ideas of this model have been applied by Klepper (1996) for an explanation of market evolution over the product life cycle.

innovation than smaller firms simply because the larger firms can spread this benefit over a greater volume.

Cohen and Klepper (1996a, b) make two important qualifications with regard to the specification of the size measure. First, they state that size should be measured at the level of business units and not at the firm level. The reason is that in case of multi-product firms when the innovation can only be applied to a part of the product program, total sales volume at the firm level does not represent the relevant number or volume of applications. Second, Cohen and Klepper (1996a, b) assume that firms do not expect to grow significantly due to an innovation mainly because, in most cases, innovations are imitated by competitors rather quickly. Therefore, the relevant size is ex-ante size, i.e., the output level at the time the firm decides about conducting the respective R&D. Furthermore, relating R&D expenditure to the size the firm has reached after harvesting the benefits of its R&D effort (ex-post size) may primarily reflect the effects of the respective R&D on the market performance of the firm and is, therefore, not appropriate to test for the role of firm size in the allocation of resources on different kinds of R&D.

Accounting for the costs of the R&D activities (r) leads us to the profits (p) of a process innovation

$$p_{\text{process}} = pc_{\text{process}}(r_{\text{process}})q - r_{\text{process}} \quad (3)$$

According to our assumption that the marginal returns from R&D effort are positive but decreasing (see Equation (1)), we assume that $pc'(r) = f/r$, with f being a constant that represents the technological opportunities. The higher the value of f , the more profitable are the alternative innovation projects. The resulting necessary condition for profit maximizing investment in process R&D is given by

$$r_{\text{process}} = fq, \quad (4)$$

i.e., there is a proportional relationship between profit-maximizing process R&D effort and size.

With regard to product innovation, Cohen and Klepper (1996a, b) assume that, due to differences in buyer's preferences, only a fraction of current customers (given by h , with $0 < h < 1$) will buy the new product feature at a higher price. It is not implausible to hypothesize that product innovations will also attract some new customers and will be used as a means to enter new markets. However, there are no strong arguments to believe that the volume of sales to these additional customers (K) will be related to ex-ante size. Therefore, it is assumed that the sales on new markets are unrelated to q and specify the total gross return (e) generated by a product innovation as

$$e = pc_{\text{product}}(r_{\text{product}})(hq + K), \quad \text{with } 0 < h < 1. \quad (5)$$

Based on (5), profit of product innovation activity is given by

$$p_{\text{product}} = pc_{\text{product}}(r_{\text{product}})(hq + K) - r_{\text{product}} \quad (6)$$

and the necessary condition for profit-maximizing product innovation expenditure results as

$$r_{\text{product}} = f(hq + K). \quad (7)$$

Comparing this expression to the respective condition for profit maximizing process innovation investment given in Equation (4), it becomes obvious that the relationship between innovation effort and size is by factor h weaker for product innovation than in the case of process innovation. Therefore, we may expect process innovation effort to rise stronger with size than the resources spent on product R&D. Another implication of this simple model concerns innovation activities when sales are zero, a case that represents an intended market entry. Because process innovation effort only depends on ex-ante sales, process innovation activity is zero if there are no sales. In contrast to that, some product R&D effort (given by fK in Equation (7)) may be undertaken in a situation before any sales have emerged. This suggests that market entry tends to take place on the basis of product innovation rather than by means of process innovation.³

Some empirical evidence suggests (Levin et al., 1987) that if an innovation is sold in disembodied form (e.g., licensing) this is much more likely for a product innovation than for a process innovation. As with regard to accessing new customers in new markets, it is plausible to assume that the volume of revenues from selling an innovation in disembodied form is unrelated to ex-ante size. If therefore, we allow for sales of an innovation in disembodied form, this may be included into the model in the same manner as the returns from selling to new markets, simply increasing K in Equations (5)–(7).

Numerous empirical studies of the relationship between firm size and R&D expenditure have found that the fraction of firms that perform R&D rises with size and approaches 100 percent for the large firms (see Cohen, 1995, for a review of the evidence). This observation can be accounted for in the model by introducing some indivisibilities of innovation activities together with heterogeneity of firms with regard to R&D productivity (cf. Cohen and Klepper, 1996a, pp. 933–935). Indivisibilities of innovation activities imply a certain amount of fixed costs of R&D projects that works as a threshold for the decision to engage in R&D activity at all. The probability to overcome this threshold rises with firm size according to the positive relationship between size and returns from R&D expressed in Equations (2) and (5), respectively. There may exist differences with regard to productivity of R&D expenditure between firms so that some manage to realize net-gains from R&D activities while others of the same size do not.

³ For a detailed analysis of the role of product and process innovation for market entry, see Klepper (1996).

2. EMPIRICAL EVIDENCE

Empirical analyses have found a pronounced relationship between R&D expenditure and firm size for those firms that are engaged in R&D (cf. Cohen, 1995). However, the elasticity of R&D expenditure with respect to size has remained unclear. While some studies resulted in a proportionate relationship (e.g., Scherer, 1984), some other studies found that R&D expenditure rises less than proportional with size (e.g., Lunn, 1982; Baldwin and Scott, 1987; Arvanitis, 1997). The empirical research suggests that industry characteristics like product complexity, market structure, and type of technology applied may have considerable effects on the level as well as the composition of R&D expenditure (see for example Arvanitis, 1997; Scherer, 1991; and the survey by Cohen, 1995).

The relationship between product R&D, process R&D and size has remained largely unexplored. According to our knowledge, there exist only some few sources in the literature that provide empirical evidence on this issue. The first of these pieces is the observation by Pavitt et al. (1987, p. 309) that in a sample of British firms the share of process R&D expenditure in relation to overall R&D expenditure tended to rise with size (number of employees).⁴ Second, Scherer (1991) estimated a regression for the fraction of R&D effort devoted to process R&D based on data for large U.S. companies and found a significant positive sign for the size variable (measured by sales).⁵ Third, Arvanitis (1997) investigated the determinants of expenditure for process and product R&D in a sample of Swiss firms. In the diverse estimations presented, no systematic stronger relationship of process R&D expenditure with size compared to product R&D expenditure can be recognized. Cohen and Klepper (1996a, b) provide only rather indirect empirical tests of their hypothesis. They analyze the relationship between the business unit size (measured by sales) and the share of process R&D on total R&D using the same data as Scherer (1991) for a sample of rather large U.S. firms that includes information on the different business units for those firms that supply more than one product line. They estimate the share of process R&D using the proportion of patents that have been classified as representing process innovations.⁶ Based on this classification, Cohen and Klepper find that the share of process R&D tended to rise with the size (sales) of the respective business unit.

One may object against Scherer's empirical analysis of the issue (Scherer, 1991) that his sample did not contain small businesses and that he, therefore,

⁴ In this analysis, an innovation was classified as process innovation if the 2-digit SIC sector the innovating firm belonged to was the same as that of the user sector and it was classified a product innovation if these 2-digit SIC's were different.

⁵ The data are from the U.S. Federal Trade Commission's Line of Business Program and contains largely Fortune 1 000 firms (see Scherer 1982, 1984).

⁶ Cohen and Klepper (1996a, b) use Scherer's (1982, 1984) classification of U.S. patents granted in the relevant period of time into product and process innovations. According to this approach, a patent is classified as representing a process innovation if it is mainly used in its industry of origin. If it is mainly used in other industries it is classified a product innovation.

analyzed differences between larger and smaller giants not large and small firms. This problem has been overcome to a degree by Cohen and Klepper (1996a, b) who, using Scherer's data set, based their analysis on business units with a part of these business units being relatively small. In contrast to the data used by Scherer, our sample contains a relatively high share of rather small enterprises.

III. Data

Our analysis is based on data gathered by postal questionnaire from manufacturing enterprises in three German regions.⁷ This largely unbiased random sample contains information on more than 1 800 enterprises. As already stated, our sample is characterized by a relatively high share of small enterprises that do not belong to a larger multi-plant firm.⁸ The data set contains information on certain characteristics of the enterprises and, particularly, the resources devoted to process and product innovation. In the questionnaire, a definition of process and product R&D was given that is in accordance with the definition of the "Oslo-Manual" by the OECD (1992). The information on the amount of R&D expenditure was gathered for the 1993–1995 period and included payments for licenses and for R&D contracted out to other firms. Our measure of ex-ante enterprise size is the number of employees at the end of the year 1992.

Our data confirms the result of numerous other studies that the share of those enterprises that carry out R&D activities rises with size. In all size classes, the share of enterprises with product R&D expenditure as well as the amount of resources devoted to product R&D is considerably higher than the share of enterprises with process R&D and average process R&D expenditure, respectively. However, there is no clear tendency of a growing share of process R&D expenditure as size increases. For the whole sample, the share of product R&D expenditure on all R&D expenditure amounts to about 61 percent. There is immense variance in these figures among different industries suggesting that there exist strong industry specific effects that should be accounted for in an empirical analysis.

⁷ The postal questionnaire had been sent out in October 1995. The regions were Baden, the south-western part of the State of Baden-Württemberg, Hanover-Brunswick-Göttingen in the State of Lower Saxony and Saxony, one of the new German States until 1990 under a socialist regime. For more information on the sample and a comparative analysis of innovation activities in these three regions see Fritsch et al. (1999) and Fritsch and Lukas (1999). A data-set with the variables used in the analysis reported here is available from the authors upon request.

⁸ Because the focus of the questions was on innovation one could expect a relatively low representation of non-innovative enterprises in the data. A non-response analysis revealed that there is no such bias with respect to the share of innovative enterprises, however, the innovative enterprises in the sample tend to have a slightly higher share of R&D personnel than the entire population of enterprises. In 1992, about 33 percent of the enterprises had less than 20 employees and only about 11 percent had 200 and more employees. The share of enterprises with less than 20 employees in 1995 amounted to 24 percent and the share of enterprises with 200 and more employees in 1995 made about 13 percent.

IV. Estimation Approach and Variables

Applying the approach used by Cohen and Klepper (1996a, b) to test their hypothesis to our data does not lead to any significant results for the influence of size on expenditure devoted to product and process R&D. In Tobit, estimates with the fraction of process R&D effort to overall innovation expenditure as dependent variable and the number of employees as well as a number of industry-dummies as independents, the coefficient for the size-variable in a linear form as well as in diverse kinds of other specifications (e.g., log, square, relative size etc.) remained insignificant at the 5 percent level. Moreover, the fit of these models was very unsatisfactorily, with values for the pseudo R^2 of not more than 0.015.⁹ We must, therefore, conclude that there is no direct relationship between size and the fraction of process R&D in our data.

In order to test the hypothesis that process R&D expenditure is closer related to size than effort devoted to product R&D, we used a different approach that focuses on the *changes* of the two types of R&D expenditure with size. According to this approach, the relationship between R&D expenditure and size can be expressed as

$$\text{R\&D expenditure} = a \text{size}^b, \quad (8)$$

with a as a constant factor and b as the elasticity by which R&D expenditure varies with size. Taking the natural logarithms of both sides we get

$$\ln(\text{R\&D expenditure}) = \ln a + b \ln \text{size}. \quad (9)$$

This equation can be estimated by standard linear regression methods. By running the regressions for product- and process innovation effort separately, we attain estimates for the size elasticity of both types of R&D. A higher size elasticity for process R&D expenditure as compared to product R&D effort would indicate that process R&D activity is closer related with size than product R&D. This would be in accordance with Cohen and Klepper's hypothesis.¹⁰

Our measure for size is the ex-ante number of employees. Estimations with non-linear specifications of the size variable did not lead to any plausible results.¹¹

⁹ About the same result was attained when size was measured by (ex post) sales. Unfortunately, our data set does not provide information on ex ante sales.

¹⁰ As stated earlier, R&D expenditure as raised by our questionnaire includes licensing fees. As far as such fees are dependent on the sales volume of the respective product, this is not in accordance with Cohen and Kleppers's (1996a, b) approach that assumes, that R&D-cost are independent of firm size or the volume of sales, respectively. However, since the data for both, product and process innovation expenditure, include licensing fees, they are "biased" in the same manner. Therefore, this aspect should have no significant impact on the outcome of our analysis that is aiming to compare the relationship between the two types of R&D and size.

¹¹ It could be argued, that not absolute size but the *relative size*, i.e., the size of the enterprise in relation to the industry average, is relevant for the decision on the amount of process and product R&D expenditure. In order to account for this objection, we estimated a version of the models in

According to Cohen and Klepper (1996a, b), the business units would be the appropriate entities for testing their hypothesis on innovation expenditure and size. Unfortunately, we do not know if the enterprises in our sample represent business units or not. An enterprise in our sample may comprise more than one business unit or it may be only a part of a larger business unit with more than one location. However, many of our enterprises are rather small and it can be assumed that they do not entail more than one business unit. We know from our inquiry if an enterprise is part of a larger multi-plant firm but we have no information on the overall number of employees or the R&D expenditure of the respective firm as a whole. To control for effects of belonging to a larger firm we include a dummy variable that is zero if the enterprise constitutes a single-plant firm and that assumes the value one if the enterprise is part of a larger entity. Twelve dummy variables for industry groups represent influences that stem from the sector an enterprise belongs to.¹² A dummy variable for location in Eastern Germany (the former GDR) is included to account for the specific situation of the East German enterprises in our sample.

Another factor determining the amount of resources spent on R&D could be the requirement to build up some absorptive capacity, i.e., a certain expertise that is necessary to identify and apply relevant external knowledge (cf. Cohen and Levinthal, 1989). Assuming that R&D cooperation with other actors represents a major channel for transferring information that is important for R&D activities, the existence of cooperative relationships may be an indication for the need of respective absorptive capacity. In our data we have information if an enterprise maintains cooperative relationships with other organizations like customers, suppliers, competitors and public research institutions. Testing for the influence of dummy variables for the existence of cooperative relationships with the different types of partners, we find that only cooperative relationship with public research institutions has some influence on R&D expenditure while the indicators for relationships to other types of partners remained always insignificant. Therefore, we include a dummy variable for the existence of a cooperative relationship with public research institutions in our model and do not account for relationships with other kinds of partners.

Our data set provides a number of indicators for the objectives and on certain features of R&D activities. With respect to product innovation, respondents were asked to indicate on a three grade scale in how far they aimed at generating completely new products in contrast to a further development of products that were already part of their product program (product modification). The answers may be

which size was measured as the number of employees of an enterprise divided by the median number of employees in the respective two digit-industry. These estimations, however, lead to more or less the same results as our standard version, in which size was measured as the (ln) number of employees without accounting for the average of the respective industry. Therefore, we restrict our presentation to the standard version of the model and do not report results based on alternative size measures here.

¹² The industry groups are based on the German two-digit classification which has 22 industries in manufacturing. We had to aggregate some of these industries in order to secure a sufficient number of cases in each industry group.

regarded as an indication for the aspiration level of product innovation activities, particularly, in how far product innovation effort in the respective enterprise is aiming at the acquisition of new groups of customers. Because the generation of completely new products should normally lead to higher returns to product R&D than incremental product modification, we expect a positive sign here. We also asked respondents for an assessment of the importance of different objectives of process innovation activities on a three grade scale. The answers to the response category "reduction of total production time" may be interpreted as an indication for the emphasis attached to cost saving as an outcome of process innovation activities.¹³ This might indicate the cost-spreading effect of process innovation that plays a central role in Cohen and Klepper's model. We therefore expect a positive sign for this variable. Finally, we include a variable for the average length of the product life-cycle of the main product. This variable is 0 if the length of the product life-cycle is less than two years, it is 1 if the duration of the product life-cycle is between two and five years and it assumes the value 2 if the product life-cycle lasts longer than five years. We expect that expenditure for product R&D decreases with the length of the product life-cycle due to lower market pressure to generate completely new or substantially modified products. Because the logarithm of zero is not defined, all enterprises which reported no expenditure for process or product R&D were excluded from our regressions.¹⁴

V. Results

In regressions for the total amount of R&D expenditure the coefficient for size is below one indicating that overall R&D expenditure rises less than proportional with enterprise size (Table I).¹⁵ This corresponds to the result of many of the previous analyses of the relationship between size and total R&D effort (see e.g., Arvanitis, 1997; and the literature reviewed by Cohen and Klepper, 1996a). The coefficient for the size variable is slightly higher in the regression for process R&D than in the estimation for product R&D what is in accordance with Cohen and Klepper's hypothesis. However, the difference is rather small and is (according to a Wald-test)

¹³ On an enterprise level, cost savings are very frequently due to a reduction of production time which represents a good indicator for many kinds of rationalization effects (see Ewers et al., 1990, for an analysis of the different effects of process innovation on a firm level).

¹⁴ In order to avoid the omission of enterprises without any R&D expenditure, we also ran a version of the regressions where we assigned a very small value of R&D expenditure in those cases where zero expenditure was reported. In these estimations we found that the values of the coefficients for the effect of size tended to be slightly lower than in the versions where enterprises without product- or process R&D effort were excluded. The difference between the estimates for the two size variable in regressions with product- and with process R&D expenditure became somewhat smaller. Because these estimates largely confirmed the results of the basic version (with enterprises without any R&D omitted), we restrict our presentation to this model.

¹⁵ According to a Cook-Weisberg test there is some moderate degree of heteroscedasticity in the data, but this does not affect the values of the size elasticities that are in the center of our interest here.

not statistically significant at any conventional level. Other specifications of the size variable (e.g., squared, number of employees relative to the industry average) did not lead to any significant improvements of the estimation results. In particular, the difference between process- and product innovation effort with regard to size tended to be even smaller in these alternative specifications.

The dummy variable for being part of a multi-plant firm is statistically significant with a positive sign. The explanation for this result that our data suggests is that belonging to a larger legal entity may help to overcome liquidity problems that – at least in our sample – tend to hamper innovation activities.¹⁶ In the estimation for product R&D the length of the product life-cycle assumes the expected negative sign and for process R&D we find a positive sign. This indicates that the shorter the product life-cycle the higher the amount of product R&D expenditure. In both cases, however, the coefficient is not statistically significant at the 5% level. If a main objective of product R&D is the development of a completely new product, expenditure tends to be higher but the amount of total R&D expenditure is left largely unaffected. The importance of cost saving as an objective for process innovation leads to an increase of process R&D expenditure and also results in a rise of total R&D expenditure. The existence of a cooperative relationship to publicly funded research institutions tends to increase process as well as product R&D effort suggesting that some investment in absorptive capacity is necessary in order to draw benefits from such a relationship. Quite a number of the industry dummies turn out to be highly significant indicating that the respective technology or the market environment has a strong influence on the level of R&D activity. Comparing the results for the overall impact of these industry dummies on the two categories of R&D expenditure these industry effects are more pronounced for product innovation behavior. The dummy variable for location in Eastern Germany is statistically significant with a negative sign indicating that, despite the high subsidies available in the East, the enterprises there tended to spend less on R&D than their western counterparts. The reason might be the poor economic condition of many East German enterprises caused by the dramatic changes of their economic environment in the recent years (cf. Fritsch and Mallok, 1998). Another explanation could be based on the lower wages in East Germany leading to lower costs of R&D.

Things become more complicated if we account for the possibility that product and process innovation activity may be related with each other (Flaig and Stadler, 1998; Kraft, 1990; Lunn, 1986). There are good arguments to suspect a pronounced interrelation of these two types of economic activity (for details see Ewers et al.,

¹⁶ Many of the respondents declared that availability of financial resources constituted a severe bottleneck for their innovation activity. In analyzing our data, we find that the significance of this bottleneck decreases with enterprise size and is much lower for those enterprises that belong to a larger multi-plant firm. If we include a variable for the weight respondents attached to the availability of financial resources as a bottleneck for their innovation activity the coefficient of the dummy variable for being part of a multi-plant firm decreases but is still statistically significant (on the 10 percent level).

Table I. R&D expenditure and size – Regression results (ordinary least squares)

	Total R&D expenditure (ln)	Product R&D expenditure (ln)	Process R&D expenditure (ln)
Constant	3.594 ^a (13.979)	-4.055 ^a (15.448)	-5.347 ^a (19.398)
Number of employees (ln)	0.696 ^a (20.019)	0.689 ^a (18.471)	0.706 ^a (17.323)
Dummy for being part of a multi-plant firm	0.287 ^a (2.835)	0.296 ^a (2.713)	0.291 ^b (2.442)
Length of the product life-cycle	-0.019 (0.275)	-0.087 (1.168)	0.134 (1.654)
Importance of new products as an objective of product innovation effort	0.106 (1.486)	0.312 ^a (4.052)	- -
Importance of cost reduction as an objective of process innovation effort	0.101 (1.600)	- -	0.204 ^a (2.743)
Dummy for cooperation with research institution	0.473 ^a (5.044)	0.512 ^a (5.054)	0.352 ^a (3.193)
Dummy for location in East Germany	-0.223 ^b (2.379)	-0.234 ^b (2.324)	-0.227 ^b (2.052)
Industry dummies, joint significance	<i>F</i> value 2.83 ^a	<i>F</i> value 4.68 ^a	<i>F</i> value 2.45 ^a
<i>R</i> ² _{adjusted}	0.5652	0.5568	0.4718
<i>F</i> value	43.83	44.69	32.06
Number of cases	627	627	627

^a Statistically significant at the 1 percent level.

^b Statistically significant at the 5 percent level.

1990). On the one hand, implementation of a product innovation can make corresponding process innovation necessary. On the other hand, process innovation may enable a firm to considerably improve the quality of its products or to produce completely new products. In our questionnaire, respondents were asked to assess the importance of process innovation for their product innovation activities on a three grade scale (“unimportant”, . . . , “very important”). While only about 25 percent of respondents classified process innovation as being “unimportant” for their product innovation activities, 36.2 percent stated that it was “important” and 38.7 percent declared it as being “very important”. We also asked for an assessment of an “increase of product quality” as an objective for process innovation on the same three grade scale. 72.2 percent of the respondents stated that an increase of product quality was “very important” and 24.1 percent declared it “important” as an objective of their process innovation activities. These results suggest that both types of R&D are in many cases interrelated to a relevant degree and that these effects should be accounted for in the empirical analysis.

To test for simultaneity of process- and product innovation behavior we estimated the reduced form of the model. The residuals of this estimate were found to be significantly different from zero at the one-percent level indicating, that a simultaneous estimation approach should be applied (see Gujarati, 1995, pp. 670–671). We used two-stages least square regression to estimate a simultaneous model that includes product and process R&D expenditure as endogenous variables.¹⁷ According to the results, the difference between process and product R&D with regard to their relation to size comes out much clearer now (Table II). In the simultaneous model the coefficient for the size-elasticity of process R&D expenditure is by about 0.24 higher than that for the size elasticity of product R&D expenditure. Again both, expenditure for product and for process R&D, rise less than proportionate with size. However, the difference between product- and process R&D expenditure with regard to size is not statistically significant.

Surprisingly, expenditure for process and product R&D are not statistically significant as explanatory variables in this simultaneous model (Table II). The dummy variable for being part of a multi-plant firm proves to be statistically significant and, likewise, the indicator for the importance of developing completely new products as well as the variable for the importance of cost reductions for innovation activities turn out to be significant with a positive sign. The same holds true for the dummy variable indicating the existence of a cooperative relationship with public research institutions. The impact of the industry dummies is stronger for product- than for process R&D expenditure. The dummy for location in Eastern Germany still has a negative sign but is no more significant at the 5 percent level.¹⁸

Looking at the variation of absolute expenditure for product and process R&D with enterprise size we find that the small firms tend to spend much more resources on the generation of new products than on new processes. Our two stage least square regression analysis (Table II) indicates that product R&D expenditure of an enterprise with only one employee, the smallest possible size, is about 12 times higher (22 000 DM) than the resources spent on process innovation (1 800 DM; see Figure 1.). This is in accordance with the respective hypothesis that product innovation is far better suited as a means of market entry than process innovation

¹⁷ Note, that the equation for product innovation expenditure contains a variable for the importance of completely new products as an objective of product innovation effort and that this variable is not included in the equation for process R&D expenditure. This form of specification implies that the effect that an emphasis on generating completely new products might have for process innovation effort is completely represented by the product innovation expenditure, that is included in the equation for process innovation. Likewise, the equation for process innovation activities includes a variable for the importance of cost reduction that is not incorporated in the estimation for product R&D expenditure. Again, we assume that the effect of an emphasis of cost reduction might have on product innovation activities is sufficiently accounted for by including process innovation expenditure in the respective equation.

¹⁸ The estimates of the reduced form of our model (not given here) show relatively high *t*-values indicating that the so-called weak instrument problem (Bound et al., 1995; Nelson and Startz, 1990) is not relevant here.

Table II. R&D expenditure and size – results of two stage least square regressions

	Product R&D expenditure (ln)	Process R&D expenditure (ln)
Constant	-3.814 ^b (2.293)	-6.314 ^a (5.345)
Process R&D expenditure (ln)	0.487 (0.147)	- -
Product R&D expenditure (ln)	- -	-0.268 (0.852)
Number of employees (ln)	0.653 ^a (2.706)	0.895 ^a (3.954)
Dummy for being part of a multi-plant firm	0.282 (1.949)	0.377 ^b (2.192)
Length of the product life-cycle	-0.094 (1.091)	0.114 (1.166)
Importance of new products as an objective of product innovation effort	0.317 ^a (3.895)	- -
Importance of cost reduction as an objective of process innovation effort	- -	0.202 ^b (2.324)
Dummy for cooperation with research institution	0.494 ^a (3.146)	0.499 ^b (2.315)
Dummy for location in East Germany	-0.222 (1.725)	0.292 (1.946)
Industry dummies, joint significance	<i>F</i> value 4.88 ^a	<i>F</i> value 1.85 ^b
R^2 ^{adjusted}	0.5841	0.2787
<i>F</i> value	45.12	22.28
Number of cases	627	627

^a Statistically significant at the 1 percent level.

^b Statistically significant at the 5 percent level.

(cf. Section II). Due to the higher size-elasticity of process R&D expenditure the proportion of process R&D rises with the number of employees. But only in rather large enterprises one can expect to find that a greater part of the R&D budget is spent on process innovation than on product innovation. According to our estimation, at an enterprise size of about 30 000 employees the expenditure for both types of innovation will reach about the same amount. However, this is a rather speculative extrapolation because the biggest enterprise in our sample has “only” about 11 000 employees.

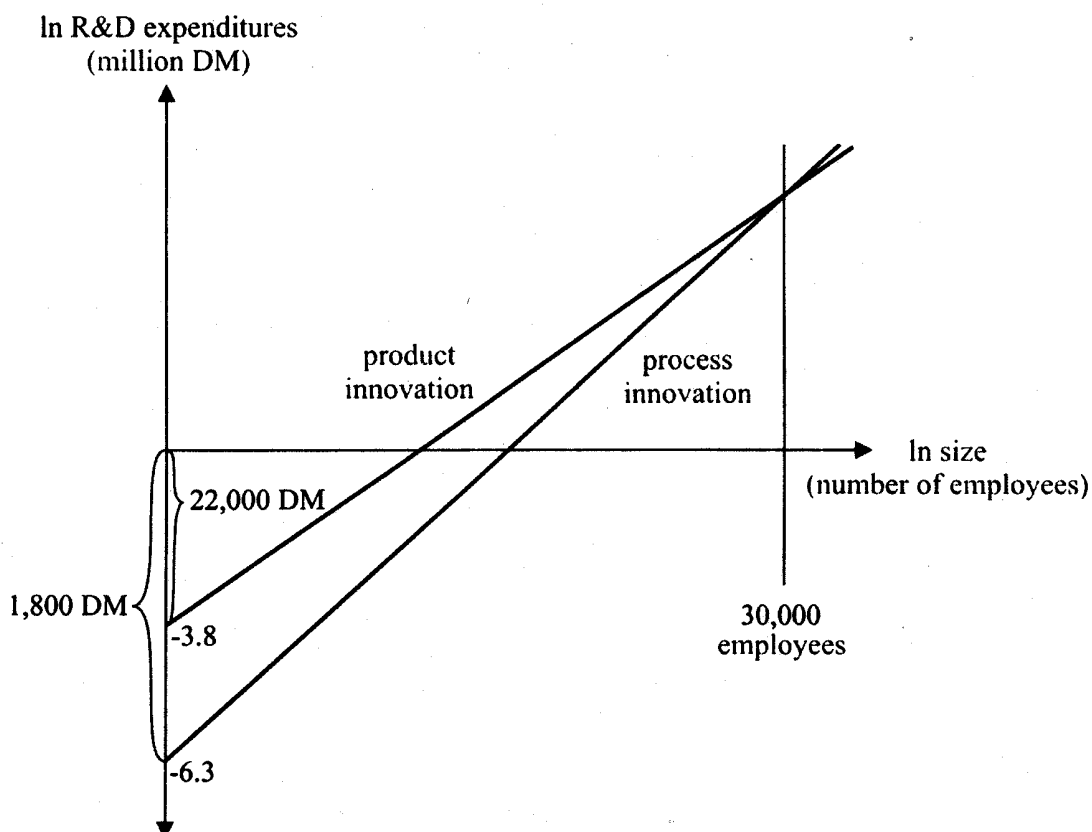


Figure 1. Variation of expenditure on process and product R&D with enterprise size.

VI. Conclusions

Our analysis has shown that, generally, R&D expenditure rises less than proportional with size. With regard to R&D inputs this indicates that those small enterprises that perform R&D tend to be more innovative than large enterprises. Analyzing the resources devoted to product and process R&D we found that the amount spent on process R&D rises somewhat stronger with size than the budget for product R&D. This confirms the hypothesis recently developed by Cohen and Klepper (1996a, b). The difference of size elasticity between process- and product R&D expenditure is considerably more pronounced when accounting for possible simultaneity between process- and product R&D. However, this difference is not statistically significant. Looking at the amount of resources devoted to both kinds of R&D we find that, on the average, small enterprises spend a much higher proportion of their R&D budget on new products than on new processes. This result suggests that product innovation may be much better suited as a means of entry into a market than process innovation. This result is also in accordance with the model and with further theories that are based on its main assumptions (see Klepper, 1996).

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