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Embodied and disembodied technical change: a multi-factorial analysis of German firms

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Abstract

Major determinants of innovation and their interrelation are analysed using regression and factorial analyses for 240 German firms. Apart from the analysis of research and development expenditures, the appropriation of disembodied technical progress along with embodied progress (capital investment in innovative goods) have to be considered in order to get a concise picture of innovation. Size and industry effects seem to be weak determinants in innovation as industry branches are quite heterogeneous. A distinction between firms absorbing disembodied and embodied change seems to be more important.

1. Innovation Model

The measurement of innovation is a demanding task for both economic theory and applied econometrics. If real world statistical variables are used as operational concepts in order to analyse innovation issues and the results are interpreted as if theoretical constructs, e.g. for technical progress in production functions, had been used, the problem of statistical adequation or correspondence between statistical indicators and theory formation must be solved.[1] Innovation research, in particular, has to cope with the problem of measuring complex issues which are -hopefully- well-defined, but in reality scarcely observable. Furthermore, a formal innovation theory, which can directly be checked by empirical observations, does not exist. Hence the aim of this contribution is to demonstrate that measuring innovation activities needs a set of indicator variables to give an adequate picture of the various aspects of the innovation process. In distinction to other papers on this subject and because of space limitations, we put emphasis on innovation constructs, their definition, their interrelation and their shortcomings, but use simple, mostly descriptive statistics and non-sophisticated econometric models.

Measuring innovation activities is not an aim itself. The aim is to either explain the innovation process using its economic or technological determinants, or to show its economic (or technological) effects. In reality, determinants and effects are part of an independent process. We seek to explain innovation activities by such determinants as firm size, technological and sectoral factors for a set of 240 individual German firms observing their technological appropriation. For inferential statistics we need theory based hypotheses and simple models. In the microeconomic neoclassical approach, profit maximizing is the main underlying assumption. Oversimplified, the innovation case is dealt within terms of market structure. The early models[2] have been more and more refined, i.e. by introducing dynamics, uncertainty (i.e. Kamien and Schwartz [1982]), or interdependency as in the game theoretic approach.[3] Another theorectical line, heterogeneous in itself, is the institutionalist or evolutionary approach, which explains technological change by certain rules of behaviour (i.e. Nelson and Winter [1982]), institutions and interdependency between technology, economy and society (i.e. Dosi [1988], Freeman [1982]). The disadvantage of this school of economic thought is that no formal mathematical framework is provided which can be taken as the starting point for statistical measurement.

Empirical innovation research is sometimes poorly based on theory with the danger of (unknown) adequation errors. We argue that proper operational concepts will show that the innovation process is too complex to be expressed

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1 For a general discussion of the statistical adequation of mental constructs see Menges (1974). A definition of the terms operational concepts and costructs can be found in Machlup (1960).

2 The pioneering work has been done by Arrow (1962).

3 I.e. Scherer (1967a), Dasgupta and Stiglitz (1980a,b), Reiganum (1981,1982), Levin and Reiss (1984,1988)

by a single relation, even if this were a complex one.[4] Therefore, we use a less-formulised model which lets enough room for various statistical representations: There exists no measure of innovation that permits readily interpretable cross-industry comparisons. Moreover, the value of an innovation is diffucult to assess,(...) (Cohen and Levin [1989], p.1062).

Innovations are taken as the results of problem solving processes: The intersectional determinants of technological change that are responsible for different patterns of innovation in different branches consist in technological opportunities, appropriability and market incentives. The appropriability of market rents depends on the sort of technology prevailing in the sector. That means how easily can it be kept secret, protected by patents or how soon can it be introduced to the market. Market incentives result from the size and growth of demand, from income elasticities and changes in relative factor prices. On the one hand, these incentives influence the extent and direction of technological change within a technological paradigm, on the other hand, the search for new paradigms is stimulated. Finally the sectoral technological change results in avery complex way from the interaction of determinants mentioned whereby competition nurtures the discovery process.[5]

Other factors are responsible for individual innovation behaviour that may well differ from the sectoral innovation pattern. Apart from their size, firms are different with respect to their performance and their innovation strategies. Technological performance depends on the firm's own accumulated technological knowledge as well as the general diffusion of technological knowledge. Innovation strategies are also closely connected with firm size. The very nature of technology may promote a certain size of firm and thus the type of industrial structure. For instance, the tendency towards automatic production leads to large firms which take advantage of scale effects, whereas the use of micro-electronic control mechanisms favours the smaller specialised firms, which produce small series in a rather flexible way.[6] Finally, market competition rewards the succesfully innovating firm and thus leads to firm

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4 The following studies, for instance, discuss the use of patents versus R&D expenditures as innovation indicators: Mueller (1966), Pavitt (1982,1985), Scherer (1983), Bound et al. (1984), Greif (1985), Schmoch et al. (1988), Grupp (1994b, 1995), Grupp and Schwitalla (1989), Griliches (1988, 1990). See also the handbook edited by Stoneman (1995). In a review Cohen and Levin summarise the situation as folloes (1989, p.1061): 'Equations have loosely specified, the data have often been inadequate to analyse the qiestions at hand; and, until recently, the econometric techniques employed were rather primitive.'

5 See von Hayek (1978).

6 For a firm and sectoral typology according to the prevailing technology see Pavitt et al. (1987).

growth, while correspondingly punishing the less succesful.

Innovation is an 'investment' into the future of a firm. Investments of innovating companies may include investments in technology-intensive equipment, advanced materials or components. Principally, an innovating firm can make strategic choices between intramural research and development (R&D), external R&D by contracts to other firms, or public laboratories and technical consultancies, but may also adopt new technology by paying fees for know-how (royalties). It always results in disembodied technology. When measuring innovation and its effects, one should also take account of the embodied technology. Investment is an other important adjunct to the innovation process as it partly covers industrieswhich use technology advances for improved production or as intermediate products. The capital inputs to the innovation proces are sometimes equated with the term indirect technology inputs. The relative importance of indirect to direct inputs varies widely among companies due to differences in product composition of output.

There is an increasing amount literature which points to the importance of investments as an innovation variable. While classical economists such as Smith, Ricardo and Marx regarded technical progress as largely embodied, post-war innovation literature mostly emphasised disembodied technology and the production of knowledge so that investment in new machinery has progressively lost its central position in the analysis of technical change (Edvangelista, 1996 : 139). Very recently, however, the study of embodied change seems to have regained its place.[7]

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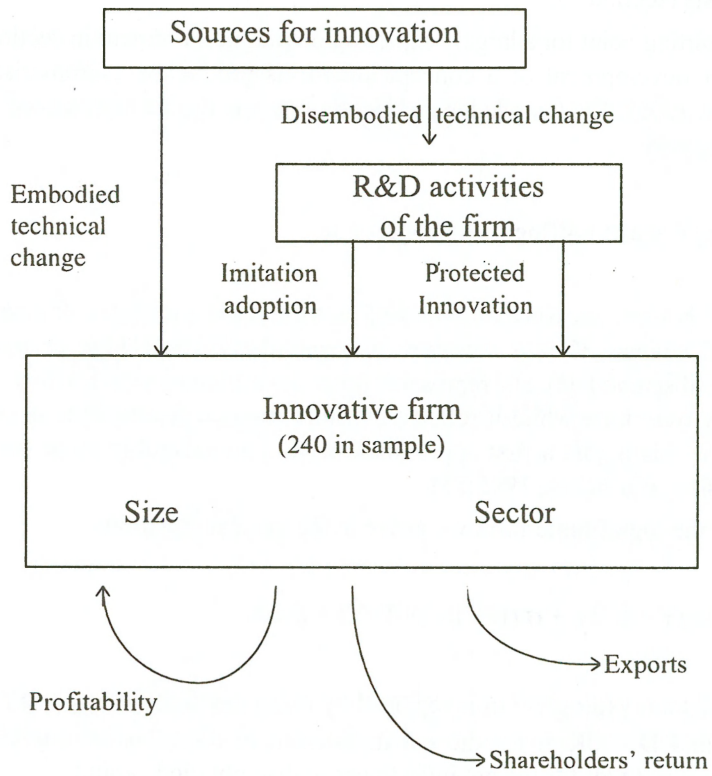
7 See Scott (1988), Amendola et al. (1993), Harhoff and Licht et al. (1996) and Evangelista (1996) amoong others.

Figure 1

Simple sketch of the innovation complex



In this paper, we distinctly model both embodied and disembodied technical change as innovative sources, i.e., as inputs. Further we differentiate, with respect to appopriability, between protected disembodied sources and imitation and adoption. Our entities of observation are individual firms which we may group according to size and industry sectors. In section 3 and 4 we investigate how the inputs relate to each other and in section 5 we suggest a two-dimensional composed innovation measure by which we reconsider the size hypothesis (section 6).

The starting point for a largely exploring output measurement in section 7 is a further development of a concept known as production (summarised by Griliches, 1995). The knowledge production function can be represented in the following way:

$$\log Y = a(t) + \beta(\log X) + \gamma(\log K) + u$$

where Y is some measure of output of the firm, X is a measure of embodied technical change, K is a measure of accumulated knowledge or research "capital" (disembodied), a(t) represents other determinants which affect output and vary over time while u reflects all other random fluctuations in output. Certainly, this is just a first approximation to a considerably more complex relationship. (Griliches, 1995:55).

From the logarithmic form we arrive at the growth equation:

$$d\log Y \,/\, dt = a + \sigma\,(E/Y) + \rho\,(D/Y) + du/dt$$

where the term $\gamma\,(d\log K) \,/\, dt$ is replaced by using the definitions $\rho = dY/dK = \gamma(Y/K)$ and $D = dK/dt$ for the net investment in disembodied capital, and similarly $E = dX/dt$ for the net investment in disembodied capital.

2. Variable description and data sources

The annual reports of large companies are the main source of data[8] for this study. We were able, for the first time to take advantage of the new German Accounting and Reporting Law according to the 4th and 7th EU Directives. From 1987 on, large[9] corporations (Kapitalgesellschaften) must publish their company reports in a very detailed way in the official newspaper 'Bundesanzeiger' no later than nine months after the end of the business year. Another novelty is that they must comment on their involvement in R&D. Unfortunately, it is up to the company whether it reports descriptively or quantitively. Overall, 270 firms could be identified which gave quantitative information on R&D in their 1987 annual reports. 236 firms revealed their R&D expenditure, but only 108 firms their R&D personnel. While we wanted to use as much information on firms' innovation behaviour as possible, and as we did not accept missing data in our analysis, we dropped R&D personnel as an innovation variable and estimated corresponding R&D expenditures by branch averages for those branches with enough companies reporting on both items. This left us with 240 firms. Apart from this R&D data, other diverse data like investment, labour and capital intensity, and firm size could be extracted from the company reports.

The annual company reports were supplemented by domestic patent data. Patent applications to the German or the European Patent Office (only if the destination country was West Germany; i.e. domestic applications on the 'European route') with the priority date between January 1985 and June 1988 were taken from the PATDPA data base. For a stronger temporal correlation, it would have been better to use data of a later period, but those were not available at the time of data compilation. Because of the discontinuity of patent applications, a period of 3.5 years was chosen and a yearly average was calculated. Of the 240 firms, 34 firms had not applied for patents; we treat these zero cases with special attention. All other variables have no zero cases.[10]

From the construction of the sample it is clear that is not a random sample of

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8 For a detailed description of the data, see the list of variables in the appendix. The data was compiled by B. Schwitalla. The data were not only used for this paper but also for previous work, see Grupp (1996b).

9 Companies are defined as large when two of the following conditions are fulfilled: Sales ≫DM 32 million, balance sheet total ≫ DM 15.5 million or employees ≫250. See Hilke (1991, p.14)

10 i.e., only for the patent variable, we observe some zero cases. In addition to the stastistical investigations discussed in this article we performed several additional analyses with censored models, the results of which are available from the authors upon request. As the principle results remain unchanged we do not report on these in detail.

West German companies. It includes only companies with inactive R&D and -among these- most of them with a business strategy that allows for an application of at least one patent in 3.5 years. It is representative of West German innovation-intensive firms, is weak in sectors where little or no technological innovation takes place, and it is heavily biased towards the manufacturing sector. By disaggregating the companies according to industrial sectors and comparing the total R&D expenditures as well as the total patent numbers as compiled from official sources (see next section), we conclude that the degree of representation is about 50% for innovating firms. The degree of representation in terms of turnover and employment is -for the reasons given above- considerably lower and somewhat below 30%. Thus, the sample is clearly oriented towards larger enterprises and towards R&D-intensive firms.[11]

3. Measuring innovation activities by R&D and patent indicators

The more established indicator variables for innovation, i.e. R&D expenditures and patent applications, were used in order to describe innovation activities at the firm and branch level. In table 1, the 240 firms were reclassified according to 16 narrower and five broader branches, and R&D and patent intensities, respectively, were calculated. This means the innovation data were weighted by size indicators sales and R&D, respectively. Variable names are explained in the appendix. Also given is an index for sector heterogeneity which compares the weighted branch average with the standard deviation of the unweighted means.

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[11] From a later innovation survey we know that in West Germany firms with R&D activities above 1000 employees account by number for a much smaller share than in our sample (Harhoff, Licht et al. 1996). However, as the R&D-intensity distribution is highly skewed due to the presence of very large enterprises, we arrive at roughly comparable results (see section 3). Our R&D-intensity distribution is uni-model and skewed to the left and thus conforms with Cohen and Klepper (1992) for the United States. The cumulative size distribution is as follows: 49 firms (20%) employ more than 5000 persons, 38% more than 2000, 54% more than 1000, 75% more than 500. The small and medium-sized companies which comprise less than 500 employees account for 25 % (61 firms).

Table 1

Innovation Index Numbers for 16 Branches of the West German Industry

	Sector	n	R&D intensity (R&DESa)	Sector hetero-geneity	Official R&D intensity*	Patent intensity	Sector hetero-geneity
1	**Chemical industry**	55	6.5	1.2	4.6	570	0.7
	11 Chemistry, oil processing, nuclear materials	41	5.7	1.2	–	637	0.6
	12 Pharmaceutical ind.	14	1731	0.4	–	294	0.7
2	**Materials processing**	32	2.5	0.6	–	615	1.4
	21 Synthetic goods production	9	1.9	0.8	2.9	485	2.6
	22 Stone, clay, ceramics,glass	10	3.2	0.5	2.1	974	0.9
	23 Metal, steel	8	2.5	0.6	1	513	1.2
	24 Paper, wood	5	2.1	0.5	1.4	975	0.5
3	**Machinery**	61	4.8	0.7	3.7	659	2.1
	31 Tools machinery	9	4.6	0.4	–	222	10.7
	32 Machinery for food and chemical industries	11	4.2	0.5	–	984	0.9
	33 Other machinery	41	4.9	0.7	–	681	1.8
4	**Vehicles**	20	5.9	1.7	–	198	2.3
	41 Motor Vehicles	8	4.3	0.7	3.9	177	1.3
	42 Motor vehicles part	7	6.9	0.3		1091	0.5
	43 Aircraft and space	5	28.8	0.3	27.1	119	0.4
5	**Electrical industry**	49	9.1	0.4	–	336	0.9
	51 Communications, equipment, electronic devices	28	11.7	0.3	9.4	374	0.9
	52 Other electronic and electrical industries	14	6.8	0.4		582	0.8
	53 Office machines, computers	7	6.5	0.6	–	69	1.7
	Scientific and professional instruments, optical industry	13	7.9	0.7	5.7	360	1.5
	Manufacture industry	230	6.7	0.9	4.5	383	2.1
	Non-manufacturing sectors	10	2.3	2.2	–	248	2.1
	All businesses	240	6.6	0.9	–	383	2.1

Source: Calculations based on the databases PATDPA and FORKAT and on firms' annual reports from Bundasanzeiger 1988, nos 42-244, and 1989, nos. 1-86; Echterhoff-Severitt et al. (1990 p.66) for official data

The indicators give an impression of the ranking of sectors to which we are accustomed. The sectors aircraft and space, the pharmaceutical industry and the electronic industry are especially R&D intensive. But when using the patent indicator, differences in 'innovativeness' are no longer as clear cut. The aircraft and space and the electronics industry lose their leading places. Extremely high patenting is observed in the motor vehicles parts industry, whereas it is extremely low in motor vehicles manufacturing itself.

When comparing the innovativeness measured by the R&D indicator on the branch level with the index for sector heterogeneity, the high R&D intensity of some firms in seemingly less innovative sectors is striking. This is true especially for the chemical and the other machinery sector. Apart from the small aircraft and space industry, which does not 'fit' into the motor vehicles sector, the sectoral definition for chemistry is much too wide to measure technological issues. Sectors are often quite heterogeneous.[12] The leading firms in the chemical industry, for example, are specialised in the development of rocket fuels and nuclear materials. The leading firms in the other machinery sector work on nuclear apparatus, are military-oriented, deliver high technology investment equipment (e.g., vacuum process technology for the semi-conductor industry or laser and digital technology for the production of printing machines). R&D-intensive firms in other sectors like 'scientific and professional instruments and optical industry' and 'motor vehicles parts', endow their goods to a great deal with micro-electronic components. We can observe that some traditional mechanical industries converge with the electronic industry. This tendency can be interpreted within the ruling technological paradigm as explained in section 1. In the era of micro-electronics, technical problems in various fields are solved by applying this key technology.

The analysis of firms by various innovation indicators reveals not only the most innovative sectors, but also that for a technologically meaningful interpretation of the innovation indicators, official R&D statistics are aggregated at a too high and sometimes very heterogeneous level. At this level, exposed in Table 1, however, R&D intensities in our sample and official statistics compare well interms of the rank order of sectors.[13] Because the sample consists of firms engaging inR&D, all numbers are about 1.5 higher. The only exception is the synthetic goods industry which is differently

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[12] See Scherer (1982) for a matrix of industries and technologies. Sectors here were defined according to SYPRO, the official German industry classification system. The disaggregation level here is 16 branches. Also consideration of spillovers blurs the sector analysis, see for example Grupp (1996a).

[13] The Spearman rank coefficient is significant at the 0.1 level.

demarcated in the official statistics (includes the rubber industry). An adequate measurement solution to the theoretical notion of intrasectoral determinants for progress seems to require at least that existing R&D statistics should be broken down to a finer level of disaggregation.

The knowledge of the relationship between the better established R&D indicators and the still less usual patent indicator helps to reduce the measurement and data problem. The patent indicator can be easily extracted from electronic data bases at a very fine level of disaggregation. But it has often been suggested that the patent-to-R&D relationship is different for different industrial sectors. The reasons for different sectoral behaviour originate from technology-specific input-output relations and sectorally different propensities to patent once an invention has been made. There are also firm-specific determinants such as the firm size or the individual technology base already accumulated. In Table 1, average patent-to-R&D relationships are shown for some industries and sub-branches.

Based on the average of all firms, 393 patent application resulted from DM 1000 million of R&D expenditures or, alternatively, one patent application required 'factor costs' of around DM 2.6 million spent on R&D. One thousand R&D employees achieved an output of 64 patent applications per year, or one patent application needed the yearly labour input of 16 R&D employees. There are large differences in the patent application rates between sectors, as well as within sectors. The patent application rates are extremly low in the office machines and computer industry, the aerospace industry, the motor vehicle manufacturing industry and the pharmaceutical industry. The patent application output in relation to R&D is very high in sectors such as stone, clay,ceramics and glass, other and chemical machinery chemical industry and traditional electrical industry. The patent aplication rate is extremly high in the motor vehicles' parts industry.

Apart from the motor vehicles industry, strong differences within sector exist also in the electrical and electronics industry. The patent application rate is lower in the communication equipment and electronic device industry than in the more traditional electrical industry. The is a larger dependency on science and software in the communications and electronic industry than in the electrical industry.

Thus we have ample evidence that appropriability conditions differ considerably across industries. Specifically, we have shown with Table 1 that the effectiveness of protecting the outcomes of R&D projects and thus the innovation rents vary across industries. In some industries patent application is actually not very effective in satisfying appropriation and is replaced by secrecy, 'head starts' and alert marketing. Thus the early work of Scherer (1965, 1983) and others on appropriability and market structure still leaves us with a paradox concerning the role of innovation protection. Here we try a new attempt.

Table 2

Two-stage explanation of patenting
(t values of coefficients in brackets)

Variable	PROBIT	OLS
n	240	206 (PA>0)
R&DESa	0.042 (1.46)	0.117 (3.58)***
InvSa	0.047 (1.39)	0.019 (0.40)
EquBST	-0.002(-0.30)	0.017 (-0.59)
ExS	0.002 (0.37)	0.017 (1.85)
Medium	-1.236 (-2.37)*	-0.964 (-1.90)
Medsme	-1.903 (-3.91)***	-1.171 (-2.24)*
Smalls	-1.648 (-3.51)***	-0.370 (-0.77)
Chemical	-0.413 (-1.07)	0.004 (0.01)
Materls	0.200 (0.43)	0..032 (0.05)
Machine	0.442 (1.06)	0.473 (0.85)
Electro	0.154 (0.36)	0.167 (0.29)
Constant	1.872 (2.79)**	1.850 (2.41)**

* Significant at the 5% level
** Significant at the 1% level
*** Significant at the 0.1% level

Some firms probably take a decision not to apply for patents since this requires some kind of disclosure of the firm's R&D details (concerning the contents of the successful invention, its principle aims, its potential application and so forth) and can limit confidentiality. A two-stage model for statistical analysis seems to be appropriate: First the binary qualitative choice is analysed as to whether firms seek patent protection and accept disclosure or not (probit model). Secondly those firms which go for patents have to decide on the number of R&D projects they want to disclose and protect (OLS model).[14]

We test again firm size, sectors, R&D intensity as well as investment and export share. The literature is full of hints that patent applications are related to innovate exports.[15] Proper adequation of embodied technical change would require that we take investments on new machinery only. Such a variable is not contained in aou data set, but rather gross investment. We know however, from a carefull analysis of investment strategies of larger German firms in the same year by Littkeman (1995), that about 66% of gross investments concern tangiblefixed assets therein 68% technical apparatus and machinery. Further we know that actual capital investment is typical for expanding firms. We also include a variable for financial capability. Preferable for internal funds is cash flow, see Cohen (1995:198), a variable which is unfortunately missing for many companies in our sample. As larger firms typical for our sample appear to finance their R&D through equity (Cohen, 1995:199), i.e., by external sources, unlike smaller firms (see Goodacre and Tonks, 1995:302), we think shaeholders' equity is an adequate variable.

From Table 2 we learn, that none of the proposed variables explains the prospensity to patent (yes or no), but only the size of firms. Regarding the most significant probit coefficients in relation to OLS, the notion of an 'inverted U' seems to hold for patents as well, may be technology based start ups, and larger firms do better in patenting. The most serious problems occur fot the firm size class between 500 and 1000 employees.[16] Whereas R&D intensity offers no explanation for the yes-no decision but largely determines the amount of patenting for those firms that decided to seek protection. Sector-specific patenting is not observedas sectors as so heterogeneous in technology. If we control for firm size, financing patents is not a feature of its own , but of course, for smaller companies it is a problem.

From a more technological point of view, patent output may be significant when R&D involves a lot of basic research (see Grupp 1994, 1996a,b for a treatment of the science base of technology). Patenting is also obsolete in software development and the integration of systems consume the larger part

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14 Regressions for single sectors in order to obtain marginal relationships were not calculated, as the samples for some sectors were too small. As we suspected a great heterocedasticity, t statistics was checked on the basis of robust standart errors.

15 See, e.g., Griliches (1990), Grupp (1995a), Pavitt (1985) and Schmoch et al. (1988).

16 The 'inverted U' originates from R&D intensity and concentration, see Cohen (1995), p.192.

of R&D efforts as in the computer and the telecomunication industry. Low patenting arises when the developing and testing of prototypes and design play a larger role, e.g., in the motor vehicles industry. R&D for military goods also leads to different ways of protection. But these determinants are not represented in size or industry structures.

The sectoral analysis of patent applications gives an impression of the various types of innovation activities. It becomes clear that describing R&D activities one-dimensionally by R&D expenditures is largely inadequate for the complex innovation processes. R&D expenditures include development, applied research and basic research and thus include (basic) research, whereas basic applications represent appropriation of rents in more market-directed product development. As patent applications per R&D vary across firms by size, patent applicatons and R&D indicators should be used complementarily rather than substitutively. The substitutive use of patent applications shoul not happen on a sectoral, but rather, on a subsectoral or market (product) or firm level.

4. Relations between innovation indicators by factorial analysis

So far, innovation activities have been measured by the most common single indicators. The aim of this section is to explore the relation between different innovation indicators in order find out whether indicators can be used as valid substitutes for each other, or whether and to what extent they represent special aspects of innovative activities. In Table 3, as the usual first step in factor analysis, correlation coefficients have been computed for the innovation indicators used in the above probit model but normalised differently: R&D expenditures per sales (r&DESa), R&D labour intensity (R&DEm), patent intensity (PASm), patent labour intensity (PAEm), gross investment per sales (InvSa), gross investment per employment (InvEM), gross investment per disembodied knowledge (InvR&D), and equity ratio (EquBST).

Table 3

Correlation coefficients of innovation indicators for industrial firms (n=240; significance levels as in table 2)

Indicator	R&DESa	R&Dem	PASa	PAEm	InvSa	InvEm	InvR&D	EquBST
R&DESa	1.00							
R&Dem	0.67***	1.00						
PASa	0.29***	0.05	1.00					
PAEm	0.25*	0.11	0.90***	1.00				
InvSa	0.24***	0.04	0.11*	0.09	1.00			
InvEm	-0.01	0.09	-0.12*	0.00	0.61***	1.00		
InvR&D	-0.37***	-0.26***	-0.24***	0.20***	0.37***	0.50	1.00	
EquBST	-0.09	-0.05	-0.05	0.01	-0.02	0.08	0.03	1.00

Source: Correlation coefficients of innovation indicators for industrial firms (n=240; significance levels as in table 2)

Although the firms of the sample cover very different branches, there is a very good correlation between some innovation indicators. In each row and column there is at least one very good correlation with the exception of equity. Correlations should normally improve when they are computed seperately for single branches which is indeed the case in the chemical and electronics industry. However, the correlations deteriorate in the machinery sector, which is a technologically quite heterogeneous industry. This leads to the assumption that, apart from a general correlation, the relations between innovation indicators are technologically determined. Our results are consistent with studies by Scherer (1982), and Acs and Audretsch (1988) for the US economy, who also calculated correlation coefficients for R&D and patents. The correlation in Table 3 are likewise strong between indicators for embodied and disembodied technical change.[17]

The use of factorial analysis is a proper statistical concept to adequate the theoretical construct of innovative strength which is a latent multi-faceted variable which cannot be observed directly, but is strongly related to several directly measurable determinants. The operational concept then is to collect as

[17] There is also a sampling effect because of some zero observations for the patent indicator; see the probit model in section 3.

many innovation variables as possible representing the various aspects of innovation activities and to extract one or a few latent variables, so called factors, by explorative factor analysis, which is/are characteristic for the different kinds of innovative activity. In this way the complexity of innovation theory is well covered and at the same time reduced to few essential aspects. Factor analysis techniques are more frequently applied in the social sciences than in economics. Since the studies by Blackman et.al. (1973) and by Schlegelmilch (1988) factor analysis has come into more frequent use in order to measure innovation activities.[18]

In the following innovation factors for the 240 firms are exstracted from the eight innovation indicators displated in Table 3. Both sales and employment are intentionally used for size standardisation. Barlett's test of sphericity is highly significant (<0.1%), so it appears unlikely that the correlation matrix (Table 3) is an identity. The Kaiser-Meyer-Olkin measure (see Kaiser, 1974) of sampling adequacy is acceptable but not marvellous; therefore, a principle factor analysis was carried out. According to Kaiser criterion, two factors with an eigenvalue >1 were extracted.[19] Table 4 presents the unrotated[20] loadings, which represent the correlation coefficients between variables and factors.

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18 Very recent applications of factorial analysis in innovation studies, one of them being the Italian innovation survey, can be found in Evangelista (1996).

19 A third factor with an eigenvalue slightly above 1 could not be interpreted in the meaningful way and does not load any variable > 0.6. It is not always a good criterion to include all factors >1, (see Backhaus et al. 1990: 91).

20 A varimax rotation did not lead to essentially different loadings.

Table 4
Factor loadings and shares of variance of the innovation factors

Variables	Factor1 Internal innovation activity (disembodied)	Factor2 External innovation activity (embodied)	Communality
R&DESa	0.705	0.199	0.570
R&Dem	0.529	0.269	0.319
PASa	0.766	0.186	0.621
PAEm	0.740	0.242	0.606
InvSa	-0.049	0.870	0.760
InvEm	-0.286	0.838	0.784
InvR&D	-0.633	0.524	0.675
EquBST	-0.117	0.015	0.140
Sum			4.347
Eigenvalues	2.409	1.838	
Share of total variance	30.1%	24.2%	
Share of cumulative variance	30.1%	54.3%	

As R&D expenditures reflect mainly internal innovation activities, R&D personnel exclusively so, and patent applications refer mainly to product innovations, the first factor is interpreted as internal disembodied innovation activity according to the variables with high loadings. The second factor has a high loading due to the investment variables. Hence, it is assumed to represent external embodied innovation activity.

Apart from the factor loadings, Table 4 contains shares of variance of two innovation factors. The communalities express the share of variance of the respective indicator variables. Hence the variable InvEm, which has the highest communality value, is explained best by the two innovation factors. The unexplained varience reflects indicator specific factors as well as measuremant errors. The unexplained variance does not contradict the concept of two latent innovation factors, as there is rarely an economic or technological indicator that reflects a latent variable better.

5. Measuring innovation activites by factor scores

Factor analysis does not only allow the identification of latent variables and the estimation of their values but also provides indications of specific components of the variables and their proximity to the latent variables. Factor scores were estimated for all the firms and aggregated in order to compare innovation activites of different sectors. The factor scores are standardised variables with mean 0 and standard deviation 1. They serve as index values for internal disembodied and for external embodied innovation activity. Table 5 presents the rankings of the industrial sectors with respect to both innovation factors. Sectors with positive values show about average, sectors with negative values below average innovation activities.

Table 5

Factor loadings and shares of variance of the innovation factors

	Sector	Disembodied innovation activity (factor 1)	Embodied innovation activity (factor 2)
1	**Chemical industry**	0.36	0.05
	11 Chemistry, oil processing, nuclear materials	0.25	0.08
	12 Pharmaceutical ind.	1.10	-0.17
2	**Materials processing**	-0.89	-0.02
	21 Synthetic goods production	-1.56	0.76
	22 Stone, clay, ceramics,glass	-0.57	0.14
	23 Metal, steel	-0.74	-0.57
	24 Paper, wood	-1.00	-0.92
3	**Machinery**	-0.19	-0.18
	31 Tools machinery	-1.00	-0.17
	32 Machinery for food and chemical industries	-0.19	-0.05
	33 Other machinery	-0.11	-0.21
4	**Vehicles**	0.53	-0.14
	41 Motor Vehicles	-0.99	-0.07
	42 Motor vehicles part	0.48	-0.20
	43 Aircraft and space	1.12	-0.48
5	**Electrical industry**	0.31	0.19
	51 Communications, equipment, electronic devices	0.55	0.24
	52 Other electronic and electrical industries	0.18	-0.05
	53 Office machines, computers	-1.07	0.52
	Scientific and professional instruments, optical industry	-0.13	-0.38
	Manufacture industry	0.01	0.00
	Non-manufacturing sectors	-1.83	-0.19
	All businesses	0.00	0.00

With respect to internal innovation activity, the top positions[21] are held by the pharmaceutical industry, aircraft and space industry, motor vehicles parts, communications equipment and electronic devices. The air craft and space industry does not dominate to the same extent when compared with its ranking by the R&D indicator alone (Table1). This results among other things from its low patent application activities as already reported above. In contrast to this, the motor vehicles part producing industry achieves a very high ranking according to the factor analytic index due to its high patenting. The lower ranking of the software-intensive sectors office machines and computers and tools machinery is also the result of considering patent indicators when extracting the latent innovation variable. Howerver, when considering investment as an indicator of external process-oriented innovation input, these sectors appear to be especially innovative with respect to buying new technology and introducing new production processes.

The positions of the office machinery industry and the producers of synthetic goods demonstrate that measuring innovativeness using only indicators of internal innovation activities is heavily biased. While these sectors rank last with respect to the internal innovation factor, they take front places when the external process-oriented innovation factor serves as yardstick. As Table 5 clearly indicates, chemistry and communications equipment and electronic devices are only the sectors to develope above average activities in both innovation dimensions. The sectors other machinery, metal and steel and paper and wood show below average innovation activities in both respects. The factor scores of the latter sectors correspond to Pavitt's (1984) postulated features for the group of supplier-dominated firms. These firms are, in general, small and stem from traditional industries. Innovations mostly refer to new processes which are developed and produced by the suppliers of the equipment and materials.

The other sectors also show typical patterns which resemble Pavitt's sectoral industry calssification. The scientific and professional instruments and optical industry and the motor vehicles parts industry belong to the group of specialised equipment suppliers with emphasis on product innovations (more likely by internal technical change). The science-based firms also show high activities with regard to product innovations and new processes. In each case, a high degree of in-house R&D is becomming ever more necessary. This category of

[21] The term 'top position' should be understood only within the sectors of this particular sample, because sectors like the textile or the food industry are missing in the sample (since not enough companies meet the required publication conditions, see section 1).

firm may be reflected in the positions of pharmaceutical and communications equipment aand electronic devices. Motor vehicles manufacturers are typical for the group of scale-intensive firms which show a proportion of process innovations (more likely embodied technical change).

Sectoral and technological influences on innovation activities were implicitly assumed when innovation activities were measured separately for each sector. A relation to firm size was also implicitly established by calculating relative innovation indicators. In the following sections, the theoretically postulated relations between innovation and firm size is examined, and special attention is paid to an adequate correspondence of different indicators of firm size.

6. Explaining innovation activities by firm size

The firm size hypothesis, which can be interpreted as a sub-species of the Schumpeter hypothesis, or which is sometimes seen as a hypothesis of its own and attributed to Galbraith (1952), proposes a relation between firm size and innovation efforts. The type of the relation between our latent - and more balanced - innovation indicators and different size indicators will be examined in the following. Indicators expressing firm size are the traditional sales (Sa) and employment (Em) indicators. Furthermore three balance sheet items representing different categories of firms' assets are introduced as variables. They are balance sheet total (BST), fixed assets (FA) and tangible fixed assets (TFA).

As this is an empirical investigation, we cannot review the past literature on the size hypothesis in innovation. Suffice to follow two handbook contributions (Cohen and Levin 1989 and Cohen 1995). These conclude that the advantage of larger firms may not be due to size per se but may arise from common characteristics, namely the appropriability conditions and limited firm growth due to innovation. There seems to be a consensus now that size has little effect on innovation. The many emprical findings to the contrary are flawed by the single-indicator approach, non-random samples, or because the importance of the size variables is minute both in termms of variance explained and magnitude of coefficents. Cohen and Levin (1989:1069) consider the emprical research on size and innovation as inconclusive and suggest to move to more complete models of technological change (Cohen and Levin:1078).[22] It is therefore a

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[22] Earlier work, i.e. Scherer (1965, 1976b) and Levin et al. (1985), has shown that market structure and tecnological opportunities as well as appropriability compete with each other in

diffucult task to examine to what extent the two latent innovation indicators we propose here are explained by size.

As the various size variables in a simultaneous model produce severe multicollinearities, we test them one by one in an OLS model with industry dummies. We find no autocorrelations ($1.76 \leq DW \leq 1.88$) and can infer that only size as measured by tangible fixed assets may influence the embodied part of innovation.[23] All other size relations are significant, in particular those for the disembodied part. Only the vehicles branch with its very few very large car manufacturers is so ill-composed that disembodied change is effected. If we drop this branch the results remain largely unchanged.

The general tendency of these does not spotlight the innovation activities of larger firms. We emphasise the fragility of this issue in industrial economics but size hypothesis cannot be rigorously rejected because of a weak influence of the assets indicator. The balance sheet total indicator can be seen as a relatively 'neutral' size indicator, which is neither biased towards personnel, nor towards establishments and which does not so much depend on business cycles.[24] Thus the balance sheet total seems to be a more adequate yardstick for the measurement of innovation activities in relation to firm size than the more usual size variables of sales and employment. Based on the results for this 'neutral' size indicator, we confirm for our sample that there are neither advantages nor disadvantages in innovation on the part of large firms.

The new findings show that diffrences in innovation activities due to firm size are highly dependent on the selective choice of an indicator. Different innovation indicators correspond to different aspects and qualities of innovation activities. Therefore, we would like to draw attention to another question that has been raised by Pavitt et. al. (1987) and that seems to be more important than merely discovering quantitative size effects. The question is what are the different kinds of innovation activities of small and large firms? These authors discuss that firm size and technology have to be seen as an interdependent relationship and that the quality of innovations differs between small and large companies in terms of a division of labour (see also Cohen 1995:197) These qualitative aspects of innovation activities are reflected by interfirm differences in innovation behaviour. The following section is devoted to these interfirm

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order to explain innovation activities. Others (Pavitt et al., 1987, Acs and Audretsch, 1988) explicitly stated that the distribution of the firm size and innovational strength are simultaneously determined by technological opportunities and appropriability.

[23] Significance level is about 2%, the coefficients are very small.

[24] For details, see Schwitalla (1993, p.213).

differences and thus the short term consequences of innovative activities.

7. Short-term concequences of firm's choice between embodied and disembodied technical change

The focus of this paper is on the roles of embodied vis-a-vis disembodied technical change. The new data set exploited does not presently allow for long-term observations. Work is in progress to prepare cross-section data for subsequent years and to derive panel data of German firms since 1987, overcoming artifacts from unification. However, in this paper we deal only with the short-term effects of innovation. The point is made here that while medium-term welfare effects have every right to be in the center of innovation literature (see, e.g. van Reenen (1996) on wage effects in British firms occuring four or more years after innovation), the discussion of possible short-term detrimental effects on innovation may be a concern for firm's decisions. The literature is full of claims that innovation is hampered by 'short-sightedness'. Can we contribute to the understanding of short-term concequences of innovation?

If we want to test the knowledge production function (see section 1), another problem of statistical adequation arises as there is no direct measure of production output available in firms' annual reports. As an output indicator, the sales variable may be used, which is, apart from changes in stocks, almost identical with the gross value added product.[25] But more interesting variables can be taken from the firms' reports.

First, we are interested in the short term profitability of firms. As a variable, cash flow seems to be appropriate. However, often cash is considered as a measure of internal financial capability, i.e. liquidity, and thus as a measure of future profitability of innovative investment (see Cohen 1995:198). We prefer to start from the trading result (operating result), i.e. either net profit or loss. We are well aware that these data may be subject to the vagaries of accounting procedures (van Reenen 1996:205). On the other hand, a favourable profit turn over ratio (or net operating margin) is always an indication of competitiveness (Hanusch and Hierl 1992). This variable is important for firm's management, but probably less so for the shareholders. So we add shareholders' equity return on the agenda of potentially interesting short-term effects.

International technological competition is becoming an increasingly

[25] Sales are also used as an output measure in order to estimate the R&D productivity of West German pharmaceutical firms by Brockhoff (1970).

important issue. However, there is no straightforward answer to the question of what defines technological competitiveness abroad. Most contributions measure the export shares despite ongoing internationalisation of firms. Most German companies are oriented towards important segments of international markets and try to compete with foreign rivals in offering better (innovative) products. It is, therefore, of interest to know to which extent the operating margins are sensitive to turnover abroad.

We first apply a probit model to investigate which innovators are at all profitable in the year of the innovative activity (yes-no-decision). In the second stage we analyse by the knowledge production model to what extent returns on sales, investment and equity are determined by innovation or else.[26] This constitutes a first exploratory approach to tackle short-term and is scoping in character. A more in-depth investigation would need panel data.

Table 6

Two-stage statistical explanation of short-term effects of innovation
(Plus value of coefficients in brackets; significance level as in Table 2)

Variable	Probit	OLS	OLS	OLS
n	240	197	197	197
Effect	OR	In (RetSa)	In (RetEqu)	In (ExS)
Dis TP	-.0170 (-2.35)*	-0.760 (-1.31)	-0.033 (-1.27)	0.115 (2.30)*
EmbTP	0.206 (2.07)*	0.093 (1.01)	-0.101 (-2.46)*	0.029 (0.36)
Chemind	0.397(1.09)	-0.077 (-0.25)	0.217 (1.56)	-0.415 (-1.54)
Materls	-0.090 (-0.23)	-0.390 (-1.11)	-0.013 (-0.09)	-0.243 (-0.81)
Machine	0.091 (0.27)	0.042 (0.13)	-0.064 (-0.45)	0.211 (0.77)
Vehicle	0.072 (0.16)	-0.658 (-1.63)	0.053 (0.30)	0.047 (0.14)
Electro	-0.295 (-0.85)	-0.369 (-1.11)	-0.032 (-0.22)	-0.511 (-1.78)
Larges	0.040 (0.13)	0.011 (0.04)	0.057 (0.45)	-0.208 (-0.84)
Medium	-0.081 (-0.27)	0.327 (1.12)	0.129 (0.99)	-0.449 (-1.78)
Medsme	-0.123 (-0.40)	0.143 (0.50)	0.263 (2.07)*	-0.208 (-0.85)
Smalls	0.340 (1.12)	0.374 (1.40)	0.185 (1.56)	-0.243 (-1.06)
Constant	0.526 (1.47)	1.373 (4.26)***	-0.127 (1.56)	3.890 (13.98)***

[26] For variables names see the appendix.

None of the sector and size dummies explain why some firms are not profitable (OR≤0). We have 43 such firms. They face one common feature: they strongly relate on internal, disembodied innovation and significantly not an external sources. We offer two explanations: First, for the accounting systems, R&D expenditures are costs and are thus directly related to the operating result. Secondly, R&D projects are risky and some are not succesful. If innovative steps are achieved by embodied sources, the firm profits from the succesful innovation of other firms. Large companies test their investment goods in so far as these are new and take deliberate decisions on what to purchase. This certainly minimises innovation risks. However, if we try to explain the amount of returns of the 197 profitable companies, both innovation indicators (as well as sector and size dummies) fail to offer an explanation. This result may be disappointing, but we are concerned here with short-term growth - our findings contribute nothing to medium-term growth and they relate to individual firms, not to welfare effects of industry branches, spillover or the whole economy.

A different snapshot is possible if we look at the equity returns. As we definitely do not observe multicollinearities (the variance inflation factors are around 1), it is embodied technical change which significantly reduces shareholders value. This seems to be other coin of the same medal: if a firm relies on disembodied, risky innovation, the prospensity to be not profitable in the short run is higher, but on the other hand, heavy reliance on embodied, less-risky innovation reduces shareholders equity return (which is more likely to be positive after all). A firm does not always have free choices which pathway to innovation to go. To the extent it has, the short-term consequences do not point in the same direction.

In international competition and as far as the companies are exporting their innovative goods, those with internal, disembodied innovation are the most successful. It may well be that embodied technology sourcing is still more limited to national environments. If a company in an 'innovation race' competes largely with foreign rivals, it seems to rely more on internal R&D and patenting (factor 1). But here again we analyse short-term effects and do not want to expand the scoping part of this study too much. Suffice to say that differentiation of the two dimensions of innovation matters in terms of profitability, indeed.

8. Concluding remarks

In this paper, the major determinants of innovation and their interrelation are analysed using probit and factorial analyses for 240 West German firms based on a new set of data from 1987. The empirical analysis starting from theory-based models, throws new light on economic phenomena associated with innovation to which not enough attention has been paid either by economic theory or by applied economics or econometrics. After decades of emphasis on diesembodied technical change we think the re-integration of embodied sources of innovation in economic analysis is in this place.

Naturally, in the analysis, the empirical situation in only one 'national system of innovation' was captured, which may have typical features for Central Europe, but not for other triad regions. Also the survey represents a cross section in the late eighties before the unification of Germany. It is not clear how the German situation compares to other economies in the nineties. There is a need for more such treatise, to find out which findings are specific to a national endowment and which have general validity fot the economics of innovation.

In conclusion, we put forward the argument that empirical innovation research is prepared to measure many aspects of technical change if the measurement procedures and indicators are based on well adequated theoretical constructs and, in particular, give attention to internal and external sources of innovation in a firm. Although the modern innovation theories are very complex, there are ways to explore the interplay of technological opportunities, appropriately, market incentives and competition quantatively.

Appendix: List of variables

BST	Balance Sheet Total
Chemind	Chemical industry incl. pharmaceutics and oil proc.
DisTP	Disembodied technical progress from factor scores (factor 1)
Electro	Electrics and electronic industries, office machines, computers
Em	Employment
EmpTP	Embodied technical progress from factor scores (factor 2)
Equ	Shareholders' (total) equity
EquBST	Ratio of equity to total assets (Equ/BST)

Ex	Turnover abroad, i.e. all direct supplies of goods and services to a consignee abroad plus the deliveries to German export houses
ExS	Export share (Ex/Sa)
FA	Fixed assets
Inv	Gross capital formation (investment)
InvEm	Gross investment per employee (Inv/Em)
InvR&D	Gross investment per R&D (Inv/R&DE)
InvSa	gross investment per sales (Inv/Sa)
Larges	Firms with between 2000 and 4999 employees
Machinery	Machinery other than electrical
Materls	Material processing industries (Resigns, ceramics,metals etc.)
Medium	Firms with between 1000 and 1999 employees
Medsme	Medium-sized firms with between 500 and 999 employees
OR	Operating results (I.e., net profit or loss)
PA	Domestic patent applications in West Germany
PAEm	Patent applications per employee(PA/Em)
PAR&DE	Patent applications per DM 1000 million R&D expenditures (PA/R&DE)
PASa	Patent applications per year and DM million sales (PA/Sa)
R&DE	R&D expenditures
R&DESa	R&D intensity (R&DE/Sa)
R&Dem	R&D labour intensity (R&DE/Em)
RetEqu	Shareholders' equity return (OR/Equ)
RetSa	Returns on sales (OR/Sa)
Sa	Sales (turnover) for sold products and services
Smalls	Firms with below 499 employees
TFA	Tangible fixed assets
Vehicles	Motor vehicles, pacts, aircraft, spaces

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Özet

İçerilmiş ve içerilmemiş teknik değişme: Alman firmaları üzerine bir çoklu-faktör analizi

Üretim sürecindeki yenilikleri belirleyen etkenler ve bunların karşılıklı ilişkileri regresyon ve faktör analizi yapılarak, 240 Alman firması için incelenmiştir. Yenilik sürecinin anlaşılabilmesi, araştırma-geliştirme masrafları dışında, içerilmiş teknik ilerleme ile birlikte içerilmemiş teknik ilerlemenin de incelenmesini gerektirir. Sanayi dalları heterojen olduğu için, ölçek ve sanayi etkilerinin yenilik üzerinde zayıf bir etkiye sahip olduğu görülmektedir. İçerilmiş ve içerilmemiş teknoloji temin eden firmalar arasındaki ayrım daha önemli bulunmuştur.