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Innovation paths and the innovation performance of low-technology firms—An empirical analysis of German industry

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ABSTRACT

This paper analyses innovation paths and the innovation performance of low-technology firms in comparison to medium- and high-technology firms. Firstly, it shows that low-, medium- and high-technology sectors consist of a considerable mix of low-, medium- and high-technology firms. Thus, it is necessary to look at the firm level when analysing how innovation patterns differ depending on the level of R&D intensity. Secondly, the product and process innovation performance of low-technology firms in German industry is analysed based on data from 1663 firms in the German Manufacturing Survey 2006, applying a set of both product and process related innovation output indicators. The empirical results show that low-technology manufacturing firms lag behind their medium- and high-tech counterparts regarding their product and service innovation performance, to a large degree on purely definitional grounds, but that they seem to perform equally well and in some respects even better at process innovation.

1. Introduction

The notions “high-tech” and “low-tech” have become integral parts of the discussion of economic policy in recent decades. Starting with the classification of manufacturing industries into high-tech, medium-tech and low-tech sectors by the OECD, this distinction has been widely adopted, sometimes with further subdivisions. The division into high-tech, medium-tech and low-tech sectors is based on the respective sectors’ average share of expenditures for research and development (R&D). Adopting such a sectoral perspective necessarily implies an aggregative view of R&D intensity and does not apply in detail to the level of the single firm. The usefulness of the low-, medium- and high-tech classification as well as of the aggregative view on R&D intensity has recently been criticized by various scholars (Hirsch-Kreinsen et al., 2005; von Tunzelmann and Acha, 2005). The criticism refers to equating high R&D intensity with high innovativeness, since R&D is just one possible way in which innovativeness can be attained. Moreover, the sectoral approach itself might be criticized because it does not take into account differences at firm level. The present paper addresses both of these criticisms. We show that the high-, medium- and low-tech sectors themselves comprise a considerable mix of high-, medium- and low-tech firms. Thus, general statements about a sector as regards the link between R&D intensity and innovativeness may be compromised by intra-sectoral heterogeneity. To compensate for this, based on firm-level data we then analyse the product and process innovation performance of low-, medium- and high-tech concerns, identifying specific innovation strengths and weaknesses of low-tech firms.

Our empirical analysis draws on the latest available high-, medium- and low-tech classification proposed by Legler and Frietsch (2007), using sectoral R&D expenditure as benchmarks. Unlike the OECD definition (1994), this classification consists of just three categories instead of four. The thresholds identified by Legler and Frietsch for separating low-, medium- and high-tech sectors, based on the R&D expenditures in different industry sectors, are a >7% share of R&D expenditures in turnover for high-tech sectors, between 2.5% and 7% for medium-tech sectors and less than 2.5% for low-tech sectors. These categories are also applied to firm-level data in the following analysis.

2. Innovation: R&D and other innovation modes

In the classical linear understanding of the innovation process, R&D plays a leading role. R&D investments are expected to lead to the creation and development of prototypes and to the introduction of new products to the market (Freeman and Soete, 1997; Saviotti and Nooteboom, 2000). This linear R&D-based innovation paradigm has been challenged from different perspectives. Firstly, innovation is often in practice a non-linear, rather complex, collaborative and multi-level process which is embedded in innovation systems (Lundvall, 1992). Secondly, in addition to technological

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and R&D-based innovation, non-technological forms of innovation are also increasingly recognized as distinct innovation paths which can contribute to a firm's economic success (Damanpour and Evan, 1984; Piva and Vivarelli, 2002; Totterdell et al., 2002; OECD, 2005).

Innovation is also linked to complex mechanisms of knowledge distribution (Edquist, 1997) and can arise through different innovation modes. Jensen et al. (2007) distinguish between "Science, Technology and Innovation" and "Doing, Using, Interacting" modes. The first refers to traditional technological, mostly R&D-driven, modes of innovation, while the latter relies more on processes and experience-based know-how.

Given the different modes of innovation, the interdependent nature of innovation processes and their embeddedness in innovation systems, innovation can be assumed to be a diverse phenomenon which is taking place not only within R&D-intensive, high-tech sectors or by high-tech firms. As recently demonstrated by Robertson and Patel (2007), there is a reciprocal and close relationship between low-, medium- and high-tech sectors in developed economies which is crucial for overall economic success. Therefore, the levels of performance in low-, medium- and high-tech sectors are highly interdependent, resulting from reciprocal connections. Not only do innovations generated in high-tech sectors diffuse into sectors with lower levels of R&D intensity, but low- and medium-tech firms are also involved in knowledge-creating activities in high-tech fields (Robertson and Patel, 2007).

Innovation has often been equated only to R&D activities and innovation output to new products. In a Schumpeterian understanding, innovation is a means to an end, the end being economic success, increased competitiveness or growth (Schumpeter, 1934). Thus, the goal of increased business success can be reached in different ways. Firms can follow different innovation paths. Besides developing new products, manufacturing firms can also develop new product-related services, introduce innovative manufacturing technologies or implement innovative organizational concepts. Each of these innovation types can be a source of competitive advantage in itself. Two main types of innovation activity can be distinguished in this way – product and process innovation. If we look at manufacturing firms, product innovations might consist of either material (physical) or immaterial (intangible) products, and process innovations might involve technological or organizational aspects, which represent, on the one hand, the physical, and on the other, the intangible aspects of process innovations (Fig. 1).

In this paper, we are concentrating on output measures because we wish to analyse actual results by comparing the innovation performance of low-tech firms to that of medium- and high-tech firms based on the five performance (output) indicators shown in Table 1.

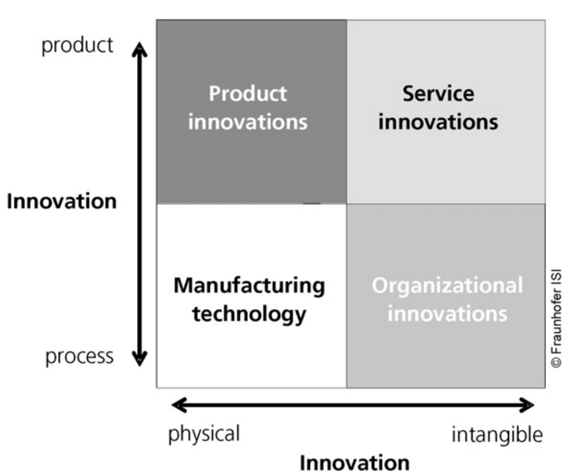

Fig. 1. Innovation fields in manufacturing firms.

Table 1
Innovation output indicators adopted.

Innovation output indicator	Measure
Share of turnover with new products	(%)
Share of turnover with product related services (introduced in last 3 years)	(%)
Labour productivity (turnover-input/employee)	(000 Euro)
Rework/scrap rate	(%)
Production lead time	(h)

The first two of these five indicators measure the results of product innovation and the last three are linked to process innovation results. Product innovation performance (material and immaterial) can be directly measured by the share of sales of products or services introduced within the past 3 years. While it is clear that new products play a key role for the success of manufacturing firms, the importance of services for manufacturing firms might need some further explanation. Services provided by manufacturing firms are understood to be product related and include maintenance, training, consulting, project planning, software development, help with the initial start-up, etc. By offering innovative services, manufacturing firms can gain a competitive advantage that differentiates the firm's products in the eyes of customers who are prepared to pay extra for the product-service combination as a value-adding complete solution. The relevance of service innovations for manufacturing firms can be measured – along the lines of product innovations – by the share of sales of services introduced within the past 3 years.

The shares of sales of new products and new services are direct monetary measures of the success of product and service innovations. As regards process innovations, however, there are different possibilities for measuring results because these cannot be directly measured by a specific share of turnover. According to Wheelwright and Clark (1992), the three most important "competitive imperatives" for firms in a globalised competitive market environment are speed, efficiency and quality. These performance measures can therefore be regarded as indicators of process innovation output. In the following discussion, we use three measures of process innovation output: the average manufacturing lead time to introduce a product as an indicator for speed; the firms' labour productivity, measured as value-added (sales minus purchased parts, materials and services) per employee, to indicate efficiency; and the average percentage of products that have to be scrapped or reworked, to indicate quality levels.

3. Low-, medium- and high-tech firms in German industry

3.1. Database: the German Manufacturing Survey

Our analyses are based on the German Manufacturing Survey 2006, which was conducted by the Fraunhofer Institute for Systems and Innovation Research (ISI) and is part of the European Manufacturing Survey (EMS) comprising surveys in 12 countries. The objective of this regular, questionnaire-based postal survey conducted in Germany is to systematically monitor manufacturing industries. The survey addresses firms with 20 or more employees from all manufacturing sectors (NACE 15-37). The 6-page questionnaire includes questions on the implementation of innovative manufacturing technologies, on organizational innovations, on cooperation, on relocation, on performance indicators, on products and services, as well as on general company data. The German Manufacturing Survey was first launched in 1993 and is conducted every 2 years. In 2006, 13,426 firms in manufacturing industries in Germany were asked to fill in the questionnaire, of which 1663 returned useable replies, a response rate of 12.4% (Jaeger et al.,

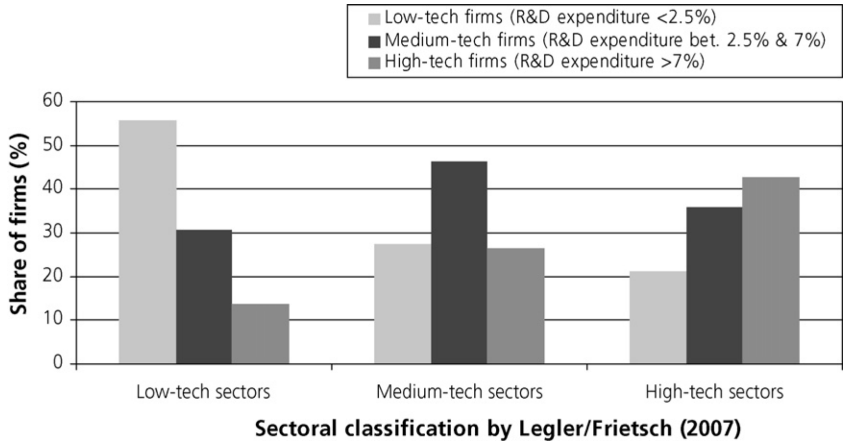

Fig. 2. Distribution of low-, medium- and high-tech firms within low-, medium- and high-tech sectors.

2007). The dataset represents a cross-section of the manufacturing sectors. Manufacturers of machinery and equipment represent 22% of the total, manufacturers of metal products 19%, manufacturers of electrical and optical equipment also 19%, producers of chemical and rubber and plastic products 16%, and the remainder come from firms in other sectors such as paper and publishing, wood and woodworking, food processing, textiles and transport equipment.

3.2. *High-, medium- and low-tech sectors versus high-, medium- and low-tech firms*

Our empirical analysis shows that a classification based on low-, medium- or high-tech sectors only partly reflects the actual R&D intensity of the firms belonging to these sectors. When the same sectoral thresholds proposed by Legler and Frietsch (2007) for low-, medium- and high-tech are applied at the firm level, we observe significant and substantial intra-sectoral heterogeneity regarding the R&D intensity of firms. There is a significant discrepancy between the sectoral classification and the firm-level reality as regards R&D intensity (see Fig. 2). Only around half of the firms (between 43% and 55%) actually match their respective sectoral classifications, while the others are either more or less R&D-intensive. This distribution is very similar if the older OECD definition of high-, medium- and low-tech (OECD, 1994) is applied. Therefore it seems that the analysis of the impact of R&D intensity on innovation performance needs to be carried out at firm level rather than sectoral level.

The detailed analysis of the composition of industrial sectors as shown in Fig. 3 reveals that, as is to be expected, typical low-tech sectors such as the food or paper industries are relatively dominated by low-tech firms and vice-versa, while high-tech sectors are typically dominated by high-tech firms. (For example, up to half of the firms in high-tech sectors such as medical devices are high-tech firms.) Nevertheless, low-tech firms can be found to differing but considerable extents in all industrial sectors.

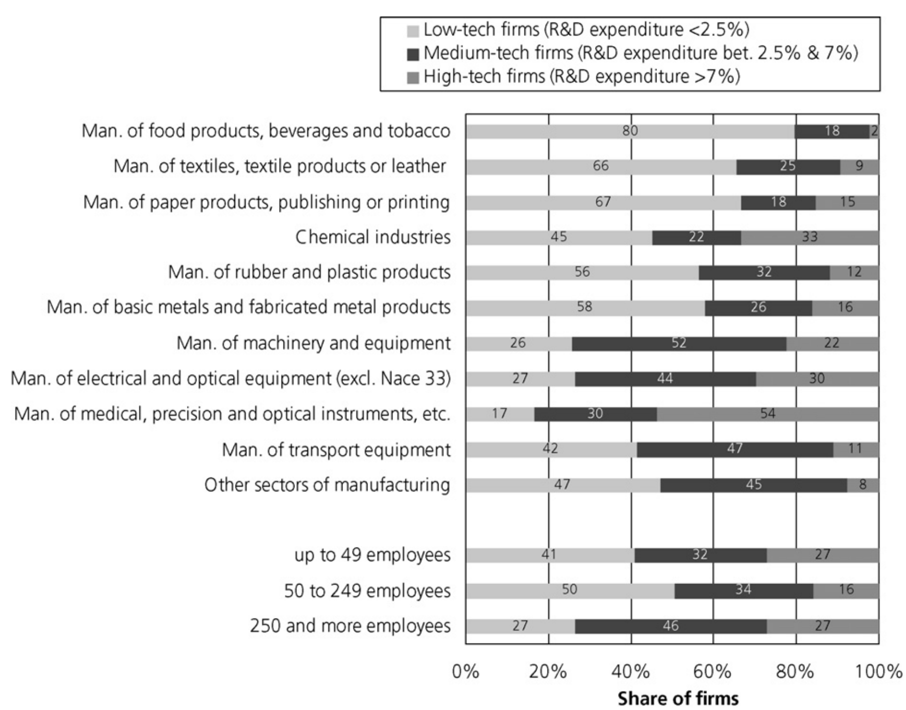

Fig. 3. Distribution of low-, medium- and high-tech firms by sector and firm size.

Low-tech firms are mainly to be found among SMEs (firms with up to 250 employees) while the share of high-tech firms is similar in both very small firms and large firms but lower in medium-sized firms. Many of the small concerns in German manufacturing are high-tech firms characterized by high expenditures for R&D, perhaps because a large number of these firms are start-up companies or spin-offs.

4. Innovation performance of low-tech firms

The following empirical analysis focuses on the innovation performance of low-tech firms. Based on the schema presented in Fig. 1, innovation performance is measured in respect of both product and process innovation.

4.1. Comparison of the average product and process innovation performance of low-, medium- and high-tech firms

As a first step, the average innovation performance of low-, medium- and high-tech firms is demonstrated by a descriptive analysis. The data reveal that low-, medium- and high-tech firms perform differently as regards product and service innovations, but at the same time no statistically significant difference can be found between low-, medium, and high-tech firms as regards performance indicators that are linked to process innovation, i.e. speed, efficiency and quality. The performance comparison of the three groups of firms (low-, medium- and high-tech firms) has been carried out using one-way ANOVA. Furthermore, to identify significant mean differences among the three groups, Scheffé's multiple comparison test and Bonferroni's test have been applied. The criterion of significance used is $p < 0.05$. As regards sales of new services, low-tech firms perform significantly worse compared to medium-tech and also to high-tech firms. Similar results can be found concerning the share of sales of new products. Here, low-tech firms again show weaker performance compared to their high-tech counterparts, even at a 1% level, but no statistically significant difference is found compared to medium-tech firms. Rather, medium-tech firms also seem to perform worse than high-tech firms in terms of their product innovation performance.

The overall weaker performance of low-tech manufacturing firms compared to high-tech firms in respect to the product innovation dimension is to be expected because the definition of low-tech and high-tech firms is itself based on the firms' share of expenditure on R&D. As high investments in R&D on the input side are closely linked in these industries to new products on the output side, it is not surprising that high-tech firms perform significantly better at product innovation compared to low-tech firms. However, in certain industries – particularly in a fashion-oriented industry such as the textiles – input activities in other areas such as marketing or design might also directly contribute to the increase of the share of sales of new products, irrespective of the level of investments in R&D. This specific aspect has not been explicitly considered in the present analysis. The results are consistent with earlier findings by Utterback and coworkers related to the product life cycle and dominant designs (e.g. Utterback and Suárez, 1991; Suárez and Utterback, 1991), showing that product innovation rates slow down as products mature. This is expected to be the case in low-tech firms, because (apart from the kinds of exceptions already noted) they typically manufacture mature products that have well-established 'dominant designs'.

As far as service innovations are concerned, low-tech firms on average also perform more poorly compared to their medium-tech and high-tech counterparts. Service innovations in manufacturing industry tend to be closely related to product innovations, often being developed in parallel with a new product. Hence, firms that perform weakly in product innovation might equally be weak performers as regards their share of sales generated by new services (Table 2).

In spite of the demonstrably poor product and service innovation performance of low-tech firms, no significant difference can be found between low-, medium- and high-tech firms regarding their labour productivity. Low-tech firms are surprisingly able to reach a level of labour productivity comparable to medium- and high-tech firms. Similar results can be found for the other two process-related performance indicators that have been analysed. On average, neither the level of quality (measured as scrap-rate), nor the production lead time indicating speed, differ significantly between low-, medium- and high-tech firms. The descriptive analysis reveals a clear pattern: low-tech firms perform worse in the product innovation dimension but their process innovation performance is comparable to that of medium- and high-tech firms, suggesting that process innovation might be the innovation path that is followed by low-tech firms.

4.2. Product and service innovation performance of low-tech firms: results of linear regression models

The descriptive analysis has already shown a general tendency in regard to different innovation strengths of low-, medium- and high-tech firms. However, to be able to identify and separate the numerous effects which might influence a firm's innovation performance, the data have been further analysed using linear regression models for each of the five selected performance indicators. In the regressions, a high-tech sector (medical, precision and optical instruments) has been taken as the reference sector, so we would expect low- and medium-tech sectors to show negative coefficients if their performance is poorer in each respect. The regression models aim at identifying whether any performance

Table 2
Average product and process innovation performance of low-, medium- and high-tech firms.

	Low-tech firms (R&D expenditure <2.5%)		Medium-tech firms (R&D expenditure between 2.5% and 7%)		High-tech firms (R&D expenditure >7%)	
	N	Mean (S.D.)	N	Mean (S.D.)	N	Mean (S.D.)
Share of turnover with new products (%)[*]	228	14.5 (12.9)	269	17.4 (14.1)	170	24.0 (19.7)
Share of turnover with product related services (introd. in last 3 years) (%)[**]	237	6.5 (10.3)	229	9.8 (13.0)	140	9.9 (14.5)
Labour productivity (turnover-input/employee) (000 Euro)	394	87.9 (73.3)	314	84.5 (40.6)	175	94.7 (61.8)
Rework/scrap rate (%)	414	2.9 (5.4)	343	3.3 (5.4)	204	3.6 (5.2)
Production lead time (h)	386	476.5 (1437.7)	327	658.8 (1153.8)	193	637.5 (1150.0)

Source: German Manufacturing Survey 2006.

[*] One-way ANOVA, significance level: $p \leq 0.01$.

[**] One-way ANOVA, significance level: $p \leq 0.001$.

differences between low-tech firms and medium- and high-tech firms are indeed due to their different R&D intensity or might result simply from other structural differences. Thus, as well as the share of R&D expenditures, the regression models include a number of structural variables such as product complexity, batch size, type of product development, firm size, qualification of employees, vertical range of manufacturing, industrial sector and export shares.

We have computed two regression models which address the product innovation dimension: one on the share of sales of new (physical) products and another on the share of sales of new services (intangible products).

4.2.1. Linear regression model of the share of sales of new products

The results of product innovation can be directly measured by the share of sales of products introduced within the past 3 years, one of the best-established and most widely used innovation indicators. The share of sales of new products indicates how well firms succeed in renewing their product portfolio and offering their customers improved solutions. As a result of the highly positively skewed distribution of the share of sales of new products, the model's assumptions of linearity are not met. Therefore, this construct needed to be transformed. The square root transformation seemed most appropriate according to Tukey–Anscombe plots and model fit parameters.

The corrected R^2 value of this model is relatively low (0.074), but still proves to be statistically significant, as there are over 500 degrees of freedom. The low R^2 indicates the heterogeneity of the data specified at firm level, in line with the basic point being made here. There appears to be no correlation between the firms' share of new products and variables indicative of batch size, firm size, graduates employed, etc.

The analysis thus shows that the share of sales of new products does not seem to differ significantly between the sectors when compared to manufacturers of medical, precision and optical instruments as a typical high-tech sector. The sectoral affiliation of firms as such does not have a significant impact on their product innovation performance. Manufacturers of complex products, however, clearly show a significantly higher share of sales of new products. Complex products tend to stand at the end of the supply chain and thus naturally incorporate various innovation steps along this chain. Innovations developed and introduced by different suppliers become part of the final product. An example of the incorporation of various innovation steps from different suppliers along the supply chain are mechatronic products, combining electronic, mechanical and software components in a complex end product (for further discussion see Freddi, 2009). Furthermore, firms that develop their products according to customers' specifications perform better in product innovations. It seems that those firms which are most successful at product innovations are so through strongly customizing their products and that they also tend to provide complex products. As regards the link between export orientation and product innovation performance, a significant positive relationship has been identified. Firms competing in international markets are under intense innovation pressure in general, which might be manifested in a constant need to provide innovative products to stay competitive.

After separating the different structural factors discussed above, the remaining question is whether the level of R&D intensity in itself is an influencing factor on firmsǐ product innovation performance. The analysis shows that high-tech firms indeed achieve statistically significantly higher shares of sales of new products compared to low-tech firms. Since this is the result of a regression analysis, it persists independently of the effect of other structural characteristics. Interestingly, however, no significant relationship can be identified when comparing low-tech firms with medium-tech firms. Low-tech firms perform significantly worse as regards product innovation only in comparison with high-tech firms but not with medium-tech firms. Nevertheless, the results confirm that a high level of R&D expenditure is indeed strongly linked to a high level of product innovation output as measured as by the share of sales of new products (Table 3).

4.2.2. Linear regression model of the share of sales with new services

Similar to the share of sales of new products, the immaterial dimension of product innovation has been analysed using a linear regression model computed for the share of sales of new services. Again, as in our first model, the distribution of the share of sales of new services is highly positively skewed. Thus the square root transformation of the dependent construct has again been applied.

The linear regression model yields – compared to the model of product innovation – a somewhat higher corrected R^2 value of 0.102 and is clearly statistically significant. Industrial sectors again do not seem to play a substantial role as regards differences in service innovation performance, with the exception of the rubber and plastics industry. Here, services seem to play a more important role compared to the reference sector of medical and optical instruments. We also find evidence for the significant positive influence of complex products and the employment of a relatively highly skilled workforce, yet a significant negative influence of firm size. Manufacturers of complex products tend to achieve higher shares of sales of product-related services. This might be explained by the direct interface with the customer related to the degree of complexity of the products (like machine tools) and also by the higher need for involvement of the manufacturer in the set-up, maintenance and adaptation of complex products to the specific needs of customers. As with the regression results on the share of sales of new products, it is the firms at the end of the supply chain that are directly offering new solutions to the customer, and these tend to be complex products. It seems likely that firms offering complex products achieve higher shares of sales both with the new products and also with the new product-accompanying services, which often are developed specifically for a new product. As regards the effect of a skilled workforce, there is a positive relationship between a high share of skills in the workforce and a high share of sales of services. The interaction with customers as well as the development of flexible, customer-oriented problem solutions might require high levels of skills. The analysis also shows that smaller firms are more successful in exploiting the potentials of service innovations than larger firms. This might be related to the greater proximity of small firms to their customers. Services are often developed in close cooperation with the customers and provide a specific problem solution. Thus, a close relationship to customers makes it more likely to succeed on a service innovation path.

As to the influence of R&D intensity on the service innovation performance of manufacturing firms, the analysis reveals that – as with the results already reported for product innovation – low-tech firms are weak performers, even when controlling for various structural variables. However, interestingly, the significant difference occurs only when compared to medium-tech firms, not to high-tech firms. As regards service innovations, medium-tech firms are the most successful, not high-tech firms; whereas in the case of product innovation, high-tech firms are clearly those which perform significantly better compared to low-tech firms. Instead, service innovation seems to be a core strength of medium-tech firms (Table 4).

Table 3
Regression on the share of sales of new products.

Square root of *share of turnover with new products*	Coeff.	S.D.	*p*-Level
Sector[(a)]			
Manufacture of food products, beverages and tobacco	0.043	0.502	0.932
Manufacture of textiles, leather and corresp. products	0.453	0.630	0.473
Paper and publishing sector	0.052	0.465	0.911
Manufacture of chemicals, chemical products, etc.	−0.415	0.427	0.332
Manufacture of rubber and plastic products	0.110	0.358	0.759
Manufacture of basic metals and fabricated metal products	0.184	0.316	0.561
Manufacture of machinery and equipment n.e.c.	−0.034	0.286	0.907
Manufacture of electrical equipment	0.061	0.308	0.843
Manufacture of transport equipment	−0.055	0.479	0.909
Other sectors	0.125	0.388	0.748
Complexity[(b)]			
Simple products	−0.341	0.215	0.114
Complex products	0.693	0.198	0.000**
No discrete parts production	−0.226	0.356	0.526
Batch size[(c)]			
Single unit production	−0.117	0.199	0.557
Large batch (>1000 p.p.m.)	0.157	0.206	0.446
No batch size	0.248	0.370	0.503
Product development[(d)]			
According to customers' specification	0.299	0.164	0.069+
Standard programme	0.362	0.230	0.115
No product development	−0.633	0.517	0.221
Size (log function of number of employees)	−0.022	0.070	0.756
Share of employees with graduate degree (%)	0.009	0.007	0.187
Vertical range of manufacture	−0.398	0.491	0.418
Export intensity	0.005	0.003	0.087+
R&D expenditure[(e)]			
Medium-tech firms	0.140	0.175	0.424
High-tech firms	0.606	0.220	0.006*
Intercept	3.304	0.567	0.000**
N		529	
R^2 corr.		0.074	
Significance		0.000**	

Reference group: [(a)]manufacturers of medical, precision and optical instruments, [(b)]medium complexity, [(c)]medium batch (≤1000 p.p.m.), [(d)]basic programme with alternative, [(e)]low-tech firms.
+ Significance level: $p < 0.1$.
* Significance level: $p < 0.01$.
** Significance level: $p < 0.001$.

4.3. Process innovation performance of low-tech firms: results of linear regression models

Similar to the regression models for product and service innovations, we have also calculated three multivariate regression models related to process innovation indicators. We again control for the impact of different structural variables on the firm, including sector, product complexity, batch size of production, the size of the firm and the degree of vertical integration. In each case, the assumptions of the model were met by using a logarithmic transformation to transform the dependent construct. The results of these three regression models are presented in the following discussion.

4.3.1. Labour productivity of low-tech firms compared to medium- and high-tech firms

Our regression model for analysing the productivity impacts of different independent factors yields a corrected R^2 value of 0.385, which can be regarded as high in this context of analysing a very highly aggregated performance measure like labour productivity at the level of very heterogeneous individual firms. The results show that only the textile and leather industry as a traditional 'low-tech sector' seems to have significantly lower labour productivity compared to the high-tech reference sector of medical and optical instruments. At the same time, firms in the chemical sector show significantly higher labour productivity compared to firms in the reference sector, even if only at the 10% level. At this point, it is important to note that these results do not reflect the low-tech orientation or different production structures of these sectors (e.g. product complexity or batch size), as these factors are controlled for separately in our model. The main argument for these results might be the market structures and the capital intensity in these sectors. Because many companies from low-wage countries are active in the global markets of the textile industry, price pressure is very high, which leads to reduced turnover and thus labour productivity when measured in terms of output value. However, physical output measured in pieces might still be high in the respective sector, but is then weighted with low price values. In the chemical industry, production processes are usually strongly capital-intensive, which could lead to reduced personnel intensity and higher labour productivity (Table 5).

The results also show that manufacturers of simple products or manufacturers of bulk goods which do not have discrete components show significantly higher labour productivity than manufacturers of medium or complex products. This might be due to the fact that is it easier to implement customer- and flow-oriented production processes and supply chains covering the whole value-added process if a company is not forced to organize parts of its production of complex products on shop floors and in assembly plants. Surprisingly, the batch size shows no correlation with labour productivity. This is an indication that not just large-

Table 4
Regression on the share of sales with new services.

Square root of *share of turnover with product-related services* (*introduced within last 3 years*)	Coeff.	S.D.	*p*-Level
Sector[(a)]			
Manufacture of food products, beverages and tobacco	−0.316	0.599	0.598
Manufacture of textiles, leather and corresp. products	0.667	0.688	0.333
Paper and publishing sector	0.224	0.541	0.679
Manufacture of chemicals, chemical products, etc.	−0.517	0.537	0.336
Manufacture of rubber and plastic products	0.922	0.419	0.028*
Manufacture of basic metals and fabricated metal products	0.381	0.371	0.306
Manufacture of machinery and equipment n.e.c.	0.534	0.331	0.108
Manufacture of electrical equipment	0.068	0.359	0.850
Manufacture of transport equipment	0.259	0.543	0.633
Other sectors	0.415	0.471	0.380
Complexity[(b)]			
Simple products	−0.192	0.268	0.473
Complex products	0.493	0.239	0.039*
No discrete parts production	−0.509	0.437	0.244
Batch size[(c)]			
Single unit production	0.052	0.244	0.831
Large batch (>1000 p.p.m.)	−0.363	0.250	0.147
No batch size	0.186	0.430	0.666
Product development[(d)]			
According to customers' specification	0.251	0.199	0.208
Standard programme	−0.114	0.288	0.692
No product development	−0.616	0.461	0.182
Size (log function of number of employees)	−0.209	0.088	0.018*
Share of employees with graduate degree (%)	0.023	0.009	0.009**
Vertical range of manufacture	−0.180	0.567	0.751
Export intensity	−0.004	0.004	0.271
R&D expenditure[(e)]			
Medium-tech firms	0.474	0.209	0.024*
High-tech firms	0.084	0.264	0.751
Intercept	2.403	0.655	0.000***
N		490	
R^2 corr.		0.102	
Significance		0.000***	

Reference group: [(a)]Manufacturers of medical, precision and optical instruments, [(b)]medium complexity, [(c)]medium batch (≤1000 p.p.m.), [(d)]basic programme with alternative, [(e)]low-tech firms.

* Significance level: $p < 0.05$.

** Significance level: $p < 0.01$.

*** Significance level: $p < 0.001$.

series production processes, but also single-unit and small-series production, can be organized productively.

Firms developing their products according to customers' specifications or firms which are not engaging in product development show significantly lower labour productivity than firms developing products for standard programmes, with variants. This is an indication that coordination between product development and production, enabling appropriate development and construction of products suitable for smooth production, is easier to organize in companies developing products for standard programmes. As has been reported in many previous studies, our model also shows a significant positive relation between labour productivity and the size of the firm (Lay et al., 1999). This is due to the fact that large companies are able to realize greater economies of scale within their boundaries than small firms, given their reduced and sometimes sub-critical mass in certain production and auxiliary functions.

Some interpretation is needed for the finding that manufacturing firms that are more highly vertically integrated, and thus outsource less, show a markedly higher labour productivity than less vertically integrated firms. Outsourcing of manufacturing processes, regarded by management as not belonging to the 'core competences of the firm', has been intensively discussed in the academic literature (e.g. Prahalad and Hamel, 1990). There are various conceptual models that attempt to support arguments to explain those decisions. They focus either on transaction cost economics (e.g. Williamson, 1985; Argyres, 1996) or on competence formation issues (e.g. Kogut and Zander, 1992; Grant, 1996), or they eventually try to synthesise both perspectives in a unified model (e.g. Conner and Prahalad, 1996; Jacobides and Winter, 2005). Thus, "many intuitively appealing arguments have been offered both for and against outsourcing as a means of achieving sustainable competitive advantage" (Gilley and Rasheed, 2000: 763), but empirical evidence is relatively scarce. According to our model it seems that in firms characterized by a higher outsourcing quota, the strategic risks of competence and capability drains and increased transaction costs may overwhelm anticipated reductions in direct costs and the enhanced efficiency potential of outsourcing initiatives in the medium and long term. This might also be due to the fact that cost and efficiency considerations dominate most outsourcing decisions at company level, whereas strategic positioning and core competence considerations play a rather minor role (Kinkel and Lay, 2003).

As other empirical studies have demonstrated, our model shows that the export share of the surveyed firms is positively correlated with labour productivity (Bernard, 2004; Sourafel et al., 2004; Wagner, 2002). Firms with high export intensity seem no longer able to operate in their protected national niches but rather have to face global competition in foreign markets. Hence, these companies have to build up capabilities to achieve internationally competitive prices, thereby realizing adequate productivity potentials at their

Table 5
Regression on labour productivity of low-, medium- and high-tech firms.

Log function of *labour productivity*	Coeff.	S.D.	*p*-Level
Sector[(a)]			
Manufacture of food products, beverages and tobacco	0.062	0.090	0.488
Manufacture of textiles, leather and corresp. products	−0.448	0.110	0.000**
Paper and publishing sector	−0.046	0.087	0.598
Manufacture of chemicals, chemical products, etc.	0.147	0.083	0.076+
Manufacture of rubber and plastic products	−0.107	0.069	0.121
Manufacture of basic metals and fabricated metal products	−0.054	0.061	0.376
Manufacture of machinery and equipment n.e.c.	0.021	0.057	0.713
Manufacture of electrical equipment	−0.001	0.061	0.993
Manufacture of transport equipment	−0.005	0.086	0.958
Other sectors	−0.136	0.075	0.069+
Complexity[(b)]			
Simple products	0.090	0.039	0.022*
Complex products	0.017	0.038	0.659
No discrete parts production	0.146	0.062	0.018*
Batch size[(c)]			
Single unit production	0.028	0.038	0.462
Large batch (>1000 p.p.m.)	0.036	0.038	0.349
No batch size	0.074	0.063	0.241
Product development[(d)]			
According to customers' specification	−0.061	0.031	0.048*
Standard programme	0.029	0.044	0.515
No product development	−0.154	0.061	0.012*
Size (number of employees)	0.000	0.000	0.090+
(log function of number of employees)	0.071	0.016	0.000**
Share of employees with graduate degree (%)	0.002	0.001	0.170
Vertical range of manufacture	1.067	0.097	0.000**
Export intensity	0.003	0.001	0.000**
Share of personnel costs in turnover	−0.019	0.001	0.000**
R&D expenditure[(e)]			
Medium-tech firms	−0.006	0.032	0.842
High-tech firms	0.058	0.042	0.168
Intercept	3.862	0.117	0.000**
N		788	
R^2 corr.		0.385	
Significance		0.000**	

Reference group: [(a)]Manufacturers of medical, precision and optical instruments, [(b)]medium complexity, [(c)]medium batch (≤1000 p.p.m.), [(d)]basic programme with alternative, [(e)]low-tech firms.
+ Significance level: $p < 0.1$.
* Significance level: $p < 0.05$.
** Significance level: $p < 0.001$.

production sites. The significantly negative impact of the share of personnel costs on labour productivity is also not surprising and is in line with existing empirical findings (Heshmati, 2003; Kossbiel, 2000). In high-wage countries such as Germany, firms that are highly productive are able to reduce the share of personnel costs effectively without risking the loss of their capabilities to innovate in products, services and processes, i.e. through replacing labour by capital or through implementing intelligent organizational concepts.

Last but not least, our model conclusively shows that the labour productivity of low-tech firms is neither higher nor lower than that of medium-tech and high-tech firms. To be able to interpret this result, different explanatory factors have to be taken into account. Firstly, most low-tech firms are facing stronger global competition than medium- or high-tech firms within their customer or technology niches. As a result of a higher level of price competition from low-tech firms in low-wage countries, they face higher price pressure on their turnover and thus reduced labour productivity measured in terms of output value. On the other hand, low-tech firms seem to be able to organize their value-adding processes at least as efficiently and profitably as medium- and high-tech firms, compensating for their disadvantages in pricing options. Overall, therefore, low-tech companies seem to put a stronger emphasis on the productivity of their production processes, as they are in most cases forced to be very efficient because of the high level of global competition in their markets.

4.3.2. *Process quality of low-tech firms compared to medium- and high-tech firms*

Besides productivity effects, technical and organizational process innovations can also aim at improving the quality of production processes and thus can enable a firm to pursue a quality differentiation strategy. Our multivariate regression model has been computed using the average percentage of products that have to be scrapped or reworked due to quality problems as a dependent variable for process quality. The overall quality of the model is low (a corrected R^2 of 0.042), due to the low statistical variance of the dependent variable and the dense accumulation of close-to-zero values, but is still significant (Table 6).

The results show that manufacturers of textile and leather products display significantly lower process quality (higher scrap rates) than firms from other sectors. This may be due to the fact that some important activities in this sector (e.g. sewing) are still mainly conducted manually. Manufacturers of bulk goods (with no dis-

Table 6
Regression on process quality of low-, medium- and high-tech firms.

Log function of *rework/scrap rate*	Coeff.	S.D.	*p*-Level
Sector[(a)]			
Manufacture of food products, beverages and tobacco	0.123	0.313	0.695
Manufacture of textiles, leather and corresp. products	1.023	0.396	0.010**
Paper and publishing sector	0.185	0.308	0.549
Manufacture of chemicals, chemical products, etc.	0.116	0.291	0.689
Manufacture of rubber and plastic products	0.275	0.240	0.254
Manufacture of basic metals and fabricated metal products	0.244	0.214	0.255
Manufacture of machinery and equipment n.e.c.	0.125	0.203	0.537
Manufacture of electrical equipment	−0.034	0.215	0.874
Manufacture of transport equipment	0.152	0.303	0.616
Other sectors	0.706	0.262	0.007**
Complexity[(b)]			
Simple products	−0.001	0.137	0.997
Complex products	0.177	0.134	0.188
No discrete parts production	−0.416	0.213	0.051+
Batch size[(c)]			
Single unit production	0.198	0.135	0.142
Large batch (>1000 p.p.m.)	−0.094	0.132	0.475
No batch size	0.127	0.219	0.562
Product development[(d)]			
According to customers' specification	0.164	0.108	0.132
Standard programme	−0.448	0.156	0.004**
No product development	0.155	0.208	0.456
Size (number of employees)	0.000	0.000	0.735
Share of employees with graduate degree (%)	−0.002	0.005	0.729
Vertical range of manufacture	0.117	0.302	0.698
R&D expenditure[(e)]			
Medium-tech firms	0.216	0.113	0.056+
High-tech firms	0.337	0.147	0.022*
Intercept	−0.088	0.288	0.761
N		790	
R^2 corr.		0.042	
Significance		0.000***	

Reference group: [(a)]Manufacturers of medical, precision and optical instruments, [(b)]medium complexity, [(c)]medium batch (≤1000 p.p.m.), [(d)]basic programme with alternative, [(e)]low-tech firms.
+ Significance level: $p < 0.1$.
* Significance level: $p < 0.05$.
** Significance level: $p < 0.01$.
*** Significance level: $p < 0.001$.

crete parts) show significantly lower scrap rates than discrete-part manufacturers. Firms in bulk industries traditionally produce in more capital-intensive ways than discrete-parts manufacturers, permitting them to reduce human mistakes by limiting manual value-adding processes to a minimum within their production chains.

Firms developing their products for a standard programme show significantly higher process quality than firms with a higher share of variants or customer specifications in their product development processes. The interpretation could be similar to the findings related to their superior labour productivity: a smooth coordination between product development and production is easier to organize in the framework of a standard programme development. Demands coming from the production side towards developing and constructing solutions which can be efficiently manufactured without a higher risk of failures and quality problems can be fulfilled more effectively in this context.

When examining the impact of R&D intensity itself, it becomes obvious that medium- and high-tech firms show significantly lower process quality (higher scrap rates) than low-tech companies. This fact cannot be explained by less complex product structures in low-tech companies, as we have simultaneously tested for product complexity as an independent variable. Therefore, it seems that low-tech companies pay more attention to achieving high levels of process quality in order to be able to compete globally through excellent product quality and reasonable prices. By contrast, medium- and high-tech firms seem to devote greater attention to the innovativeness of their products and processes, which sometimes leads to initial quality problems when new products are ramped up for serial production or new production technologies are introduced.

4.3.3. *Speed and production flexibility of low-tech firms compared to medium- and high-tech firms*

In our last regression model we analyse differences in production speed, measured as the logarithm of average manufacturing lead time. Overall model quality is quite good, with a clearly significant corrected R^2 of 0.260.

The results reveal that firms in the machinery sector are characterized by significantly slower production processes, measured as longer manufacturing lead times, if compared to the high-tech reference sector of medical and optical instruments. This might be due to strongly customer-oriented production processes in the machinery sector, which have to be partly organized in manufacturing cells comparable to construction sites, where it is more difficult to organize consistent flow-oriented production processes than in other sectors. The different manufacturing lead times of the sectors cannot be explained through the complexity of the products,

Table 7
Regression on lead time of low-, medium- and high-tech firms.

Log function of *lead time*	Coeff.	S.D.	*p*-Level
Sector[(a)]			
Manufacture of food products, beverages and tobacco	−0.454	0.445	0.307
Manufacture of textiles, leather and corresp. products	−0.126	0.592	0.832
Paper and publishing sector	−0.487	0.442	0.271
Manufacture of chemicals, chemical products, etc.	−0.133	0.417	0.750
Manufacture of rubber and plastic products	−0.598	0.343	0.082+
Manufacture of basic metals and fabricated metal products	0.083	0.308	0.788
Manufacture of machinery and equipment n.e.c.	0.586	0.285	0.040*
Manufacture of electrical equipment	−0.266	0.305	0.383
Manufacture of transport equipment	0.154	0.420	0.713
Other sectors	−0.435	0.374	0.245
Complexity[(b)]			
Simple products	−0.104	0.194	0.591
Complex products	1.075	0.189	0.000***
No discrete parts production	−0.477	0.307	0.120
Batch size[(c)]			
Single unit production	0.679	0.189	0.000***
Large batch (>1000 p.p.m.)	−0.143	0.187	0.443
No batch size	0.577	0.317	0.069+
Product development[(d)]			
According to customers' specification	0.255	0.153	0.098+
Standard programme	−0.507	0.219	0.021*
No product development	−0.295	0.309	0.340
Size (number of employees)	0.000	0.000	0.106
Share of employees with graduate degree (%)	0.004	0.007	0.564
Vertical range of manufacture	1.225	0.429	0.004**
Export intensity	0.006	0.003	0.030*
R&D expenditure[(e)]			
Medium-tech firms	−0.020	0.161	0.902
High-tech firms	−0.280	0.208	0.178
Intercept	4.066	0.373	0.000***
N		732	
R^2 corr.		0.260	
Significance		0.000***	

Reference group: [(a)]Manufacturers of medical, precision and optical instruments, [(b)]medium complexity, [(c)]medium batch (≤1000 p.p.m.), [(d)]basic programme with alternative, [(e)]low-tech firms.

+ Significance level: $p < 0.1$.
* Significance level: $p < 0.05$.
** Significance level: $p < 0.01$.
*** Significance level: $p < 0.001$.

as we have controlled for this variable. As expected, manufacturers of complex products have a significantly and considerably longer manufacturing lead time than manufacturers of less complex products (Table 7).

The batch size of production is also significantly correlated with the ability to realize short manufacturing lead times. Firms producing single units or small batches display significantly and considerably longer manufacturing lead times than manufacturers of medium or large batches. Single-unit and small-batch production processes are more difficult to organize on flow-oriented production principles, resulting in longer throughput times.

Companies developing their products according to customer specifications show significantly longer production lead times, whereas companies developing their products for a standard programme show significantly shorter throughput times. Once again, this is an indication that the development of products that fit easily into the companies' production processes can be speeded up much more easily than the development of products not explicitly designed for efficient production operations. The degree of vertical integration is also positively correlated with longer manufacturing lead times. This is due to the fact that deeper production ranges include more production processes, which leads to a longer lead time for the internal manufacturing of the product. The degree of export intensity surprisingly also shows a significant positive correlation with production lead times, but the effect is so marginal that we can conclude that there are no considerable differences regarding this variable.

Finally, the analysis of the R&D intensity of the surveyed firms shows no significant correlation with average production lead times. Low-tech companies experience a production lead time – and thus production speed – comparable to that of medium- and high-tech firms. Nowadays, the speed of production processes and thus the ability to deliver products to customers quickly and on time seems to be important for low-tech as well as for medium- and high-tech firms.

5. Conclusions

This paper has empirically analysed the innovation performance of low-tech firms in German industry. Using firm-level data, it has shown firstly that the sectoral classification into low-, medium- and high-tech industries does not adequately reflect the reality of the firms belonging to these industries as regards their respective R&D intensity. Only about half of the firms that belong to low-, medium- or high-tech sectors match that classification if measured by R&D intensity at firm level. This finding implies that, because of this high intra-sectoral heterogeneity, the analysis of the effects of R&D intensity on innovation performance needs to be conducted at firm level rather than at sectoral level.

Secondly, the product and process innovation performance of low-tech firms has been analysed in comparison to medium- and high-tech firms. The results reflect the same high degree of heterogeneity between firms and sectors, though often low corrected R^2 values. Allowing for this, the results confirm previous findings showing that low-tech firms perform more weakly as regards product innovations (sales of new products). They also show weak performance as regards product-related services, probably because product-related innovative services are often developed in close association with a new product.

With respect to process innovations, comprising technical and organizational aspects, we analysed specific output indicators for overall process performance as measures of the innovativeness of production processes. We used measures for the three process performance dimensions: productivity, quality and speed of the value-added processes of manufacturing companies. The analysis has shown that low-tech firms are able to organize and innovate their production processes at least as efficiently as medium- and high-tech firms, resulting in comparable productivity and process speeds. As regards process quality, low-tech firms seem to be able to innovate process designs continuously, resulting in a better quality of their value-added processes (measured as a lower rate of scrapped or reworked products) than was found in medium- or high-tech companies. Low-tech firms thus seem to put a higher emphasis on the quality of their production processes, enabling them to differentiate themselves from their global competitors via excellent product quality and reasonable process costs.

However, looked at from the input side of process innovations (which has not been the focus of this specific paper), there are some signs indicating that low-tech firms in high-wage countries like Germany have not yet exploited all internal potentials for technical and organizational innovations to improve their process performance. An earlier, more detailed analysis of the input side of technical and organizational process innovations showed no significant differences between low-tech and medium- or high-tech firms as regards the implementation of innovative production technologies and organizational concepts, but has identified noticeable unexploited potentials in the utilization of these innovative concepts (Kirner et al., 2007). A more comprehensive analysis in the future would include both the input and the output side of innovation, linking findings from both perspectives. Analysing the links requires more complex modelling of the different innovation paths.

Seen from a global perspective, an interesting question might be how low-tech firms in high-wage countries like Germany position themselves compared to their direct low-tech competitors in foreign low-wage countries. This could be an interesting stream for further research. Studies (e.g. Armbruster et al., 2005) have provided first indications that German firms, for instance, seem to be among the leaders in technical process innovations, whereas firms in, for example, the new member states of the European Union are leading in utilizing innovative organizational forms. It would be interesting to conduct a similar analysis differentiating between low-tech, medium-tech and high-tech firms in these countries, thus comparing technical and organizational process innovations of low-tech companies from an international perspective. In addition, future research might explore whether the concept of low-, medium- and high-tech is also applicable to service sectors and to service firms.

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