Measuring Output of Process Innovation at the Firm Level: Results from German Panel Data

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Abstract

Process innovation is an important part of firms' innovation activities and supposed to significantly contribute to positive returns from innovation. Measuring process innovation output at the firm level is still in its infancy, however. This paper reports empirical evidence on measures of process innovation output that have been collected in the German Innovation Survey over the past 20 years. Distinguishing between the share of cost reduction and the increase in sales due to quality improvement the paper finds low item non-response for the qualitative (yes/no) part of both indicators. Item non-response is much higher for quantitative information and does not decrease when questionnaire experience of a firm increases. For both cost reduction and quality improvement, response to quantitative indicators is categorical in nature, and firms tend to report the same set of values when participating frequently in the survey. The determinants of realising the two types of process innovation output are very similar. The observed variance in the quantitative part is difficult to explain for both measures. The impact of process innovation output on firm performance is limited. While cost reduction seems to spur the export share, sales increase due to quality improvement is associated with higher profitability.

JEL: O31, O32, O33

1 Introduction

Process innovation is a main part of firms' innovation activities. Results of the Community Innovation Surveys (CIS) of the European Commission reveal that the number of process innovators is similar to that of product innovators. According to the CIS 2012, 204.0 thousand enterprises in Europe introduced one or more product innovation during the years 2010 and 2012 while 187.4 thousand enterprises introduced one or more process innovation. In 15 out of 31 countries covered by the CIS 2012, the number of process innovators exceeded the number of product innovators. Firms invest a significant amount of financial resources into process innovation. Recent data from the German Innovation Survey show that 27 percent of the firms' total innovation budgets are devoted to process innovation, compared to 53 percent spent for product innovation and 20 percent for activities that could not be assigned to either process or product innovation. These results are in line with similar findings from the German R&D survey which reports a share of 23 percent of R&D expenditures devoted to new or advanced processes, 62 percent devoted to new or advanced products and 15 percent that cannot be assigned to either of the two categories.

Despite the significance of process innovation, there is no established measure for measuring the output of process innovation. Most empirical works that examine the drivers and impacts of innovation output of firms either restrict to product innovation (e.g. the CDM models, see Crépon et al. 1998; and many papers in the management literature, see e.g. Laursen and Salter 2006, Leiponen and Helfat 2010) or use a simple binary measure for process innovation that indicates whether a firm has introduced at least one process innovation or not within a certain period of time (see Mairesse et al. 2005, Griffith et al. 2006). For product innovation, in contrast, a quantitative output measure has been established – the share of sales that result from product innovation. This measure is well accepted and widely used both in innovation policy research (see for example the European Innovation Scoreboard, European Commission 2016) and academic research (see Klingebiel and Rammer 2014). This quantitative measure of product innovation success proofed to be superior to a simple binary measure as it allows to linking the successful introduction of an innovation with its likely direct economic returns.

For process innovation no similar quantitative output measure has been established yet, though the role of cost reduction from process innovation has been stressed as an important output dimension of innovation (see Mairesse and Mohnen 2010). This measurement gap comes rather as a surprise since theoretical works on the output effects of R&D regularly consider cost reduction from innovation as a key variable (see e.g. Kamien et al. 1992, d'Aspremon and Jacquemin 1988, Levin and Reiss 1988). Nevertheless, attempts have been made to collect quantitative indicators on process innovation output through innovation surveys. The perhaps most comprehensive effort has been made by the German innovation survey. While this survey is part of the CIS exercise coordinated by the European Commission, it goes beyond the harmonised methodology by conducting the survey annually as a panel survey (see Peters and Rammer 2013) and by posing additional questions to the firms. Among these additional questions, data on the amount of unit cost reduction resulting from process innovation has been collected for manufacturing firms since 1993 and for service firms since 1997. In 2003, a question on an additional output dimension of process innovation has been added, collecting data on the increase in sales due to quality improvements resulting from process innovation.

There are other national innovation surveys that also collect quantitative data on process innovation output. The Flemish innovation survey includes both a question on the size of cost reduction and the sales impacts of quality improvement. The phasing of these questions is very similar to those in the German survey. The Swiss innovation survey contains a question on cost reduction from process innovation which has been part of the survey since 1999. The Norwegian innovation survey had a question on cost reduction from process innovation in the 1998 survey only. This question was repeated in the R&D survey of 2000 which also contained questions on innovation output but was never used again.

The Oslo Manual (OECD and Eurostat 2005) which provides guidelines for the collection and interpretation of innovation data, frequently mentions cost reduction as an important dimension of innovation output (§§ 20, 77, 78, 139, 164, 187, 193, 195, 196, 384, 389) and less frequently quality improvement (§§ 11, 164, 168, 193, 196, 389). It also proposes to use the amount of cost reduction as a quantitative output measure for process innovation (§ 406-407). Despite these recommendations and the isolated national efforts in measuring process innovation output, no quantitative indicators on process innovation output have yet been implemented in international innovation statistics yet. One explanation is that such variables deemed as being too difficult to answer with sufficient reliability (Mairesse and Mohnen 2010). Interestingly, the available measures of process innovation output from national innovation surveys have only rarely been used in academic papers, compared to frequent use of quantitative measures of product innovation output.

The aim of this paper is to present empirical evidence on the relevance and reliability of quantitative measures of process innovation output that have been collected over the past 20 years as part of the German innovation survey. By doing so, we want to evaluate the usefulness of these measures and how they might help to better understand the innovation process in firms and its impacts.

The paper consists of four main parts. The first part provides a short summary of empirical literature using indicators on process innovation output and discusses potential indicators for measuring the direct economic impact of process innovation at the level of the innovator. The second part examines measurement issues of output indicators for process innovation based on data collected through the German innovation survey. This includes item non-response issues, variation of firm level responses over time, and the relevance of cost reduction as process innovation outcome vis-à-vis other likely outcomes of process innovation such as quality improvement or enabling of product innovation. Differences between manufacturing and services are another important aspect to be examined.

The third part analyses the drivers of process innovation success, including different types of innovation expenditure, a firm's absorptive capacities, as well as scale economies and market structure. In addition, we look at the contribution of public funding. We also examine likely complementary effects of other types of innovation, including product, organisational and marketing innovation. The fourth part aims at identifying performance impacts of process innovation output as compared to performance impacts of product innovation output. We use a series of performance measures, including sales growth, profit margin and export share. We also examine the impacts of cost reduction on a firm's labour demand employing the model of Harrison et al. (2014).

2 Measuring Process Innovation Output

In the literature on the economics of innovation, process innovation is usually seen as a type of innovation that leaves product characteristics ('product quality') unchanged while lowering the cost of production of one unit of a product (Adner and Levinthal, 2001). Lower unit costs either allow for reducing the price and increasing the demand of the product (and hence a firm's market share) or result in a higher profit margin. The dichotomy of product innovation that alters product quality and process innovation that reduces unit costs was also used in the literature on technology life cycle which describes the dynamics of product and process innovation and the role of cost reduction through process innovation (Utterback and Abernathy 1975, Clark 1985, Klepper 1996). While earlier stages of the technology life cycle are characterised by a competition over innovative product characteristics, product design stabilizes after some time, and process innovation to lower costs becomes the dominant innovation mode. As successive process innovations and price cuts may put pressure on profit levels, product innovation can become more attractive in later stages and lead to a second cycle (Adner and Levinthal, 2001).

But Adner and Levinthal (2001) also point to the fact that separating between quality improving product innovation and cost reducing process innovation is not always so clear. On the one hand, product design (e.g. ‘design for manufacturing’) can play an important role in cost reduction. On the other hand, process innovation can also increase flexibility of production and, for example, the ability to adjust products to changing demand requirements quickly (see Robin and Schubert, 2013), which rather changes product characteristics than unit costs. For example, flexible production systems in car manufacturing allow the production of customer-specific combinations of equipment components. Other innovations in production methods may improve quality characteristics of products such as durability, recyclability or variety of use. In services, process innovation is often associated with improving the quality of the service and not just only or necessarily reducing costs (see Snyder et al. 2016). For example, the introduction of online banking will certainly reduce the operating costs of a bank, but it will also increase the value of the service for the customers by allowing them to use banking services at any time, from any place and at virtually zero own costs.

The different dimensions of output potentially produced by process innovation complicate output measurement. Cost reduction effects can be measured quite directly as the change in the costs of one unit of output or in the costs of providing a certain type of service. Such a measure is also proposed in the Oslo Manual. The innovation surveys in Germany, Flanders, Switzerland and Norway applied this metrics already, typically by asking for the average change in unit costs or cost per operation resulting from process innovation.

Quality improving effects of process innovation are more difficult to quantify. In the context of lean management and total quality management approaches (Shah and Ward 2003, Arnheiter and Maleyeff 2005, Powell 1995), a number of metrics for measuring quality dimensions of process performance have been developed. One set of metrics refers to timeliness of processes (e.g. lead time, processing time, on-time delivery), another one refers to the quality of process outputs (e.g. customer satisfaction, defect rate, accuracy rate, reworking rate, scrap rate). Other metrics include process complexity (e.g. number of steps) and employee satisfaction. Many of these metrics fit well to manufacturing firms (particularly those that produce distinct units of output while they are less suited for manufacturing continuous output such as chemicals). For service firms, many metrics can be less readily applied. For that reason, surveys dedicated to manufacturing are frequently using quality-related metrics of process performance, e.g. the European Manufacturing Survey (see Jäger et al. 2015).

In order to implement process output measures in innovation surveys that cover a wide variety of manufacturing and service firms, metrics would be needed that can be applied to all sectors. In the German innovation survey, based on expert interviews and cognitive testing, it was decided to use one single measure for quantifying quality-related process innovation output. This measure is the change in sales that could be attributed to quality improvements resulting from process innovation. Though most firms may only provide a rough estimate on the sales impacts of quality improvements, this measure is uniformly applicable for both manufacturing and service sectors. In addition, it is measured at the same scale as the quantitative indicator for product innovation output (as a percentage of total sales), and it can be compared to the measure on cost reduction as long as the cost-to-sales ratio is known. The measure on change in sales due to quality improvement has been implemented in the German and Flemish innovation surveys.

Empirical studies on process innovation outcome so far mainly confined to qualitative measures, particularly to a binary measure on whether a process innovation had been introduced during a certain period of time. In studies on productivity effects of innovation, Mairesse et al. (2005) found that firms having introduced process innovation yield higher returns than product innovators while Griffith et al. (2006) in a four country study did not find significant positive impacts of process for Spain, Germany and the UK. This finding is in line with Roper et al. (2008) based on data for Irish manufacturing plants. Parisi et al. (2006), in contrast, found a positive productivity effect for process innovation based on data for Italy. Huergo and Jaumandreu (2004) showed for a sample of younger firms that process innovations leads to extra productivity growth at some point in time which tends to persist for a number of years. Studies focussing on employment effects of innovation found that process innovation tends to displace employment, though the effect is only weak (Harrison et al. 2014).

Some waves of the Community Innovation Surveys (CIS) contained questions on output effects of innovation measured on a 4-point Likert scale, including items closely related to process innovation (cost reduction, increase in flexibility, increase in capacity). Robin and Schubert (2013) used this information to analyse the impact of cooperation with public research on product and process innovation output using CIS data from France and Germany. They found that the determinants of process innovation output where very similar for both cost reduction and increase in flexibility or capacity.

Studies using quantitative measures of process innovation output are rare. Czarnitzki and Kraft (2008) used data from the German innovation survey to analyse the impacts of employment incentive systems on process innovation results, employing the quantitative measures on both cost reduction and sales increase due to quality improvement. They found that employee suggestion schemes are positively related to both cost reduction and quality improvement. The delegation of decision to lower levels of hierarchy spur cost reductions only while new forms of labour organisation such as team work raise the output of process innovation in terms of quality improvement. Salge and Piening (2015) investigated the impacts of different types of innovation activities on the extent of cost reduction through process innovation and found that a broad range of activities increases the amount of cost reduction until a certain number of different activities. Another driver of process innovation success is market turbulence (uncertain demand, competitors' action difficult to foresee). They also found a positive impact of the process innovation on profit margins.

3 Process Innovation Output Measures in the German Innovation Survey

The German innovation survey includes two questions on process innovation output that follow the standard CIS question on process innovation (see Figure 1). The questions collect information whether the process innovations introduced by a firm did reduce the average costs per unit or operation, or lead to improvements in product quality. If firms answer 'yes', they are asked to provide an estimate of the reduction in average unit costs, and the increase in turnover due to these quality improvements, respectively. The question on cost reduction was for the first time included in the German innovation survey in the survey year 1994 for manufacturing. For service sector, this question was part of the questionnaire from the survey year 1997 onwards. The question on quality improvement has been part of the survey since the survey year 2003.

Figure 1: Questions on product innovation output in the German innovation survey 2015

Did the process innovations introduced by your enterprise during 2012 to 2014 reduce the average costs (per unit / operation)**?**

Yes .... ☐ ➔ What was the reduction in average unit costs due to these process innovations in 2014 .... ca. ☐ %

No .... ☐

Did the process innovations introduced by your enterprise during 2012 to 2014 lead to improvements in product quality?

Yes .... ☐ ➔ What was the increase in turnover due to these quality improvements in 2014 .... ca. ☐ %

No .... ☐

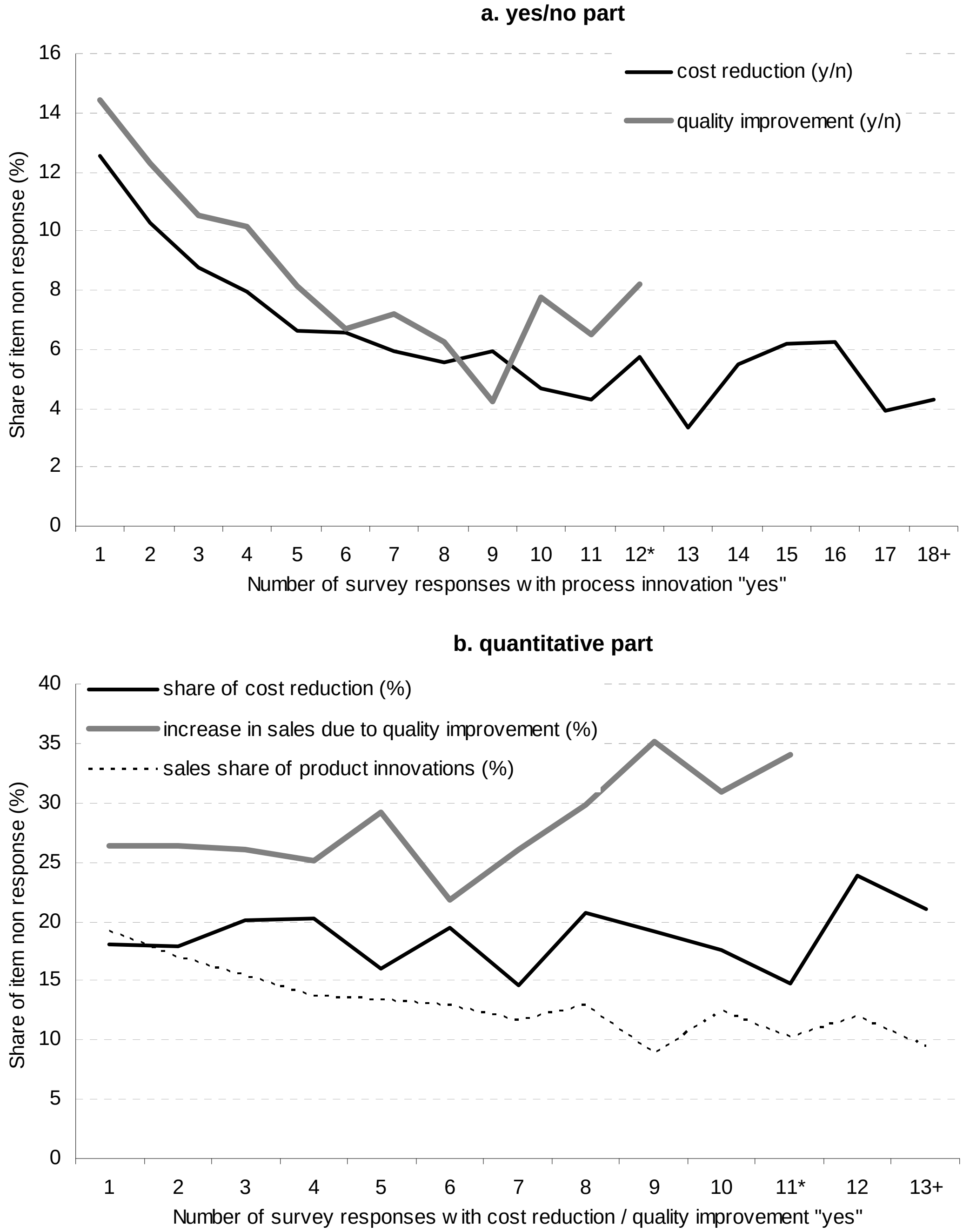
In contrast to most other innovation surveys, the German innovation survey is designed as an annual panel survey. Each year, the same sample of firms is contacted. Every second year the panel sample is refreshed in order to compensate for panel mortality as well as for changes in the sector coverage of the survey. This panel innovation survey is called the Mannheim Innovation Panel (MIP) after the city where the research institute that conducts the survey - the Centre for European Economic Research (ZEW) - is located. The panel nature allows to investigating the response behaviour of firms depending on their familiarity with the question. The gross sample of the MIP is currently around 35,000 firms. Every second year when the survey is not part of the CIS, a smaller sample of around 24,000 firms is surveyed. This sample focuses of firms that have participated in earlier years without distorting the sector and size class distribution. Unit response rate is about 25 percent in CIS years and about 35 percent in years with a smaller sample. Though the MIP is a panel survey, only few firms participate every year. Most firms show a discontinuous participation pattern (see Peters and Rammer 2013 for more details).

Item non-response for the yes/no part of the question on cost reduction is 12.6 percent for firms in the first year they respond to this question (Figure 2, part a.). This falls almost continuously to 4.3 percent for firms that have responded to the question for 11 times. Firms with more frequent participations do not show a consistent pattern. Their item non-response rate is between 4 and 6 percent. For the question on quality improvement, item non-response of firms that responded to that question only a few times is about 2 percentage points higher than for the question on cost reduction. From the 6th time a firm responded to the quality improvement question, the share of item non-response is at a similar level compared to the question on cost reduction, but increases for firms that responded 10 or more times. Since the question on quality improvement has been added to the MIP questionnaire in 2003 only, the maximum number of times a firm could respond is 13.

The item non-response results on the qualitative part of the two process innovation outcome questions suggest that there is a kind of learning effect. As firms repeatedly deal with the questions, they seem to become more familiar with them and find ways to translate the concepts of cost reduction and quality improvement resulting from process innovation into their actual business situation. When it comes to the quantitative part of the two questions, such learning effects do not seem to be in place. The share of item non-response rather tends to stay the same (share of cost reduction) or even tends to increase (change in sales due to quality improvements) with the number of times a firm responded to the questions (see Figure 2, part b.). Item non-response is significantly higher than for the qualitative part. For the amount of cost reduction, 15 to 20 percent of firms that stated to have yielded cost reduction refused to provide an estimate for the average share of cost reduction. For quality improvement, 25 to 30 percent of firms reporting quality improvements did not provide an estimate on the change in sales associated with these quality improvements. Note that firms with quality improvements which had no impact on the sales volume have a value of zero (which applies to 18 percent of all firms with quality improvements).

The fact that the share of item non-response does not fall the more frequent a firm positively responded to the qualitative part of the question comes rather as a surprise and is not in line with the finding for the quantitative output measure for product innovation, the share of sales generated by product innovations. For this measure, item non-response is declining with the times a firm responded to the question, falling from 20 percent for first-time respondents to 7 percent for firms that responded to that question 9 to 11 times. One may explain this result by the different level of efforts that is required for regularly reporting quantitative output measures. For product innovation output, firms can often rely on existing internal reporting systems that allow to link sales volumes of products with the date a product has been introduced to the market for the first time. If such a reporting procedure has been established, it is easy to produce follow-up reports in later years.

Figure 2: Item non-response for questions on cost reduction and quality improvement due to process innovation, differentiated by the number of questionnaire responses per firm



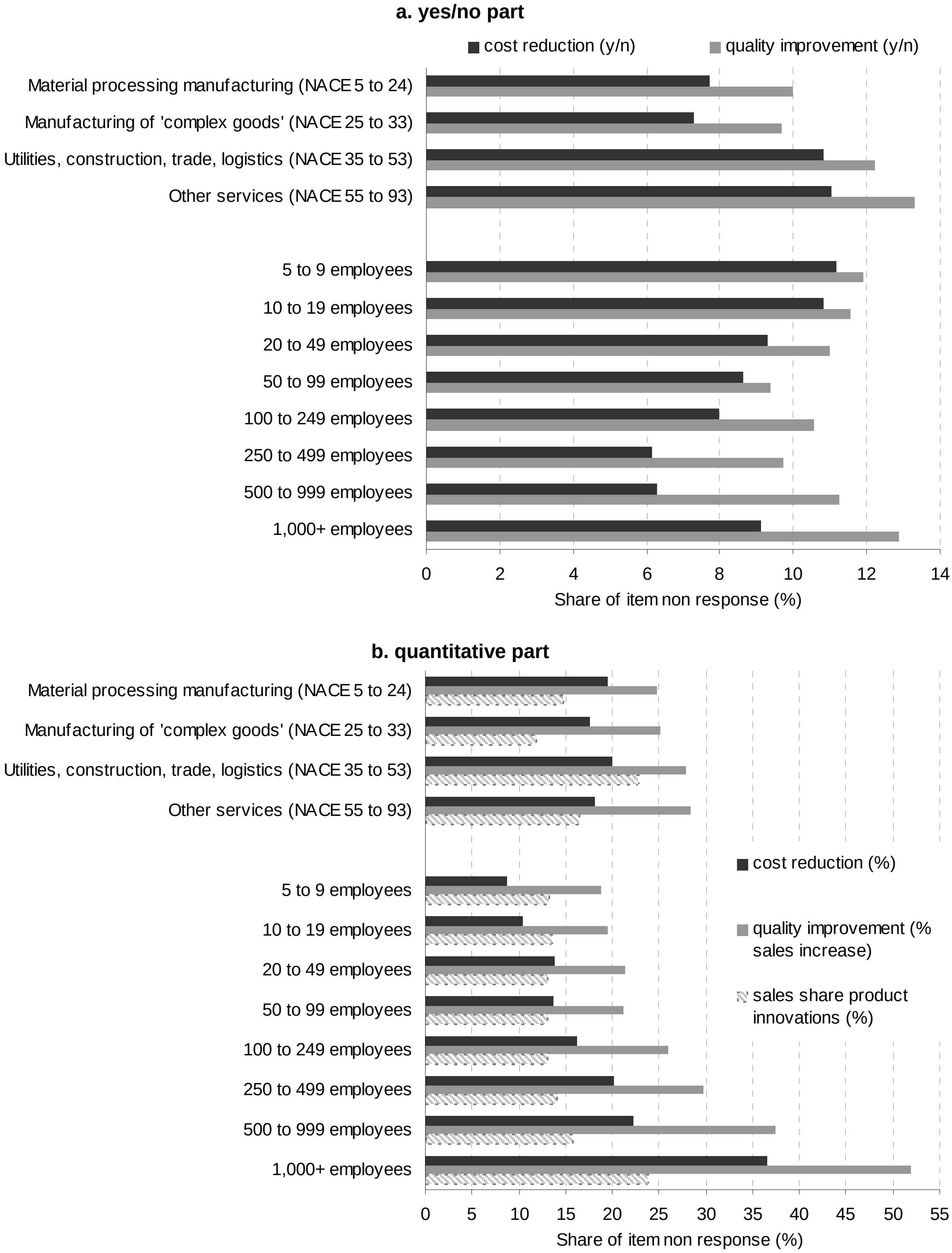
* For quality improvement: 12 or more responses (part a.) and 11 or more responses (part b.).
Based on 38,310 observations for cost reduction (y/n), 24,119 observations for quality improvement (y/n), 21,079 observations for share of cost reduction, 15,356 observations for increase in sales due to quality improvement, and 48,693 observations for sales share of product innovations.
Source: Mannheim Innovation Panel

For process innovation, the effects on cost reduction and quality improvement will have to be evaluated for each process innovation again. As the nature of individual process innovations often differs a lot, firms usually do not have a single process innovation reporting system in place from which output data could be derived. This means that the effort of reporting process innovation output measures does not decrease if an output figures has been established once. Firms may rather get tired of evaluating their process innovation results again every year and opt for not reporting the quantitative figures.

Item non-response on the qualitative part of the two process innovation output questions is higher in services than in manufacturing and decreases by firm size, except for large firms with 1,000 or more employees which show a rather high item non-response rate (Figure 3). For all sectors and size classes, item non-response is higher for quality improvement than for cost reduction. The difference in item non-response rates between the two output dimensions increases by firm size, suggesting that larger firms face particular difficulties in reporting sales impacts of quality improvements. This does not come as surprise as larger firms usually have a larger product portfolio. Quality improvements may be quite frequent for many products, but identifying them for the entire product range may be a burdensome exercise. Some survey respondents in large firms will hence not be in a position to establish whether such quality improvements took place.

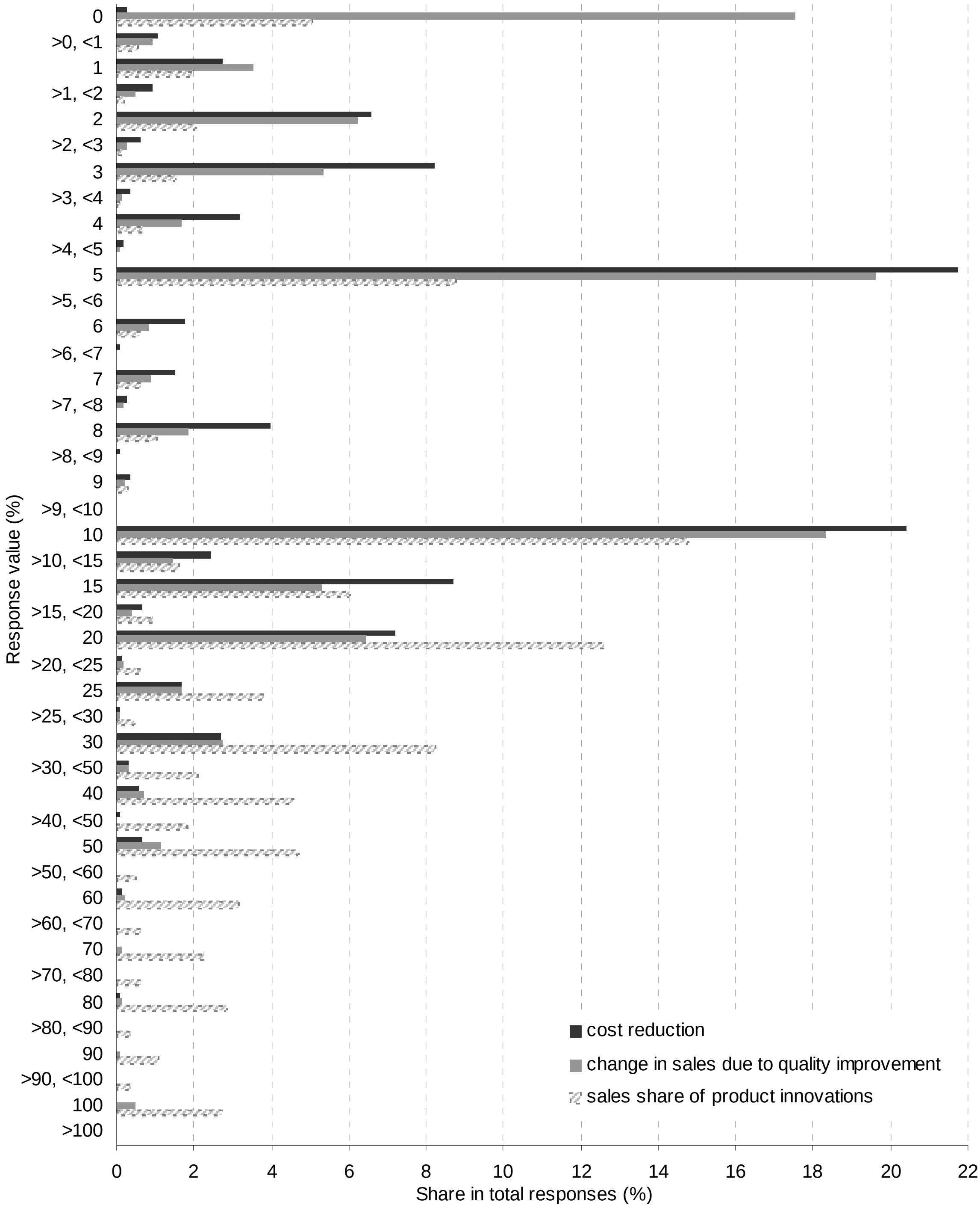
With respect to the quantitative part of the question, the share of item non-response does not vary greatly by sector while smaller firms are better able to report the amount of cost savings and the change in sales due to quality improvements than larger firms. Item non-response for the change in sales resulting from quality improvements is substantially higher compared to the share of cost reduction in all sectors and size classes. Interestingly, item non-response for the share of cost reduction in the service sectors is not significantly higher than item non-response for the sales share of product innovations. In manufacturing, cost reduction non-response is about 5 percentage points higher than item non-response for the sales share of product innovations. Small firms show a lower item non-response for cost reduction than for product innovation sales while medium-sized and large enterprises seem to have more difficulties to report the amount of cost reduction compared to the share of sales generated by product innovations.

Figure 3: Item non-response for questions on cost reduction and quality improvement due to process innovation, differentiated by sector groups and size classes



Based on 38,262 observations for cost reduction (y/n), 24,119 observations for quality improvement (y/n), 21,044 observations for share of cost reduction, 15,356 observations for increase in sales due to quality improvement, and 48,628 observations for sales share of product innovations.
Source: Mannheim Innovation Panel

Figure 4: Response values on quantitative measures process innovation and product innovation output



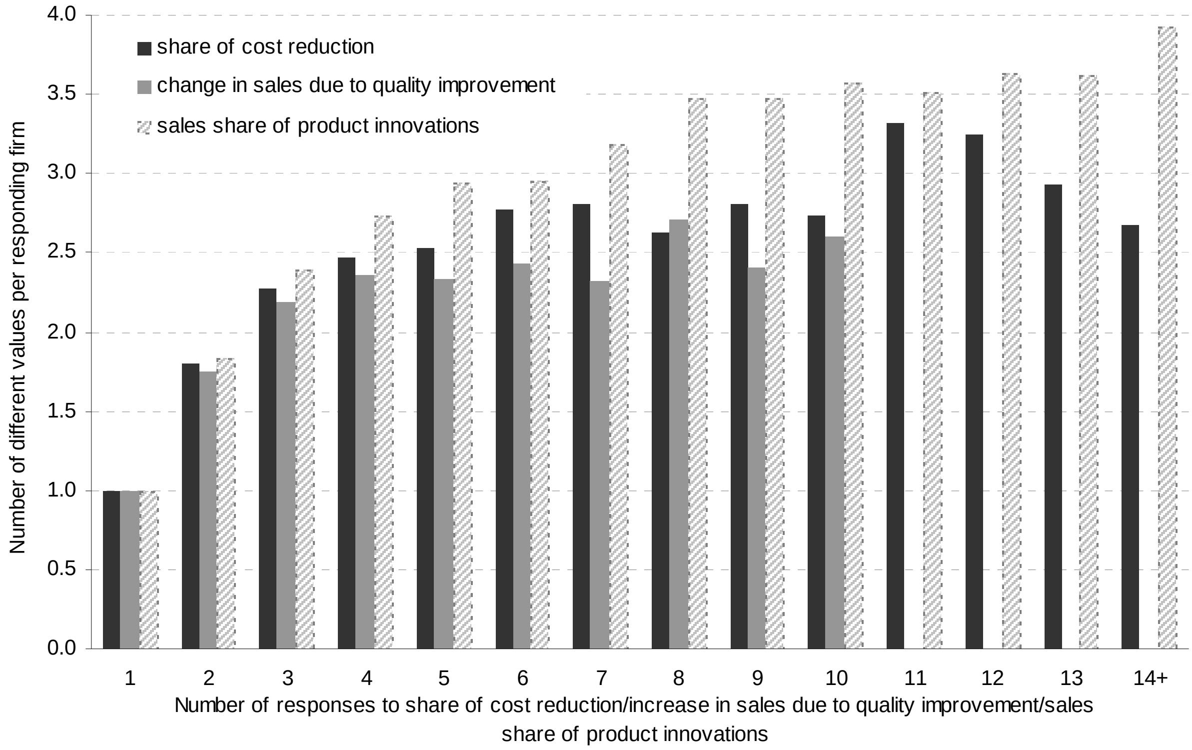
Based on 17,189 observations for share of cost reduction, 11,296 observations for increase in sales due to quality improvement, and 42,426 observations for sales share of product innovations.
Source: Mannheim Innovation Panel

The responses to the quantitative part of both questions tend to be rather categorical in nature. For both measures, the five most frequently reported values represent 72 percent of all responses. In case of the share of cost reduction, these are 5, 10, 15, 20 and 3. In case of the increase in sales due to quality improvements, the most frequently reported values are 5, 10, 0, 20 and 2. In total, 93 percent of all responses to the share of cost reduction are either integer values between 0 and 10, or full decades between 10 and 100. For the increase in sales due to quality improvement, 95 percent of all responses include such values. This result indicates that firms rather estimate and rarely actually calculate the quantitative measures of process innovation output. This result is in line with findings on the response to the quantitative measure for product innovation output, the sales share of product innovations. 89 percent of all responses are either one-digit integers or full decades. The variance in response values is larger, however, as the five most frequently reported values (these are: 10, 20, 5, 30, 15) represent 57 percent of all responses. Figure 4 shows the distribution of response values for the two quantitative process innovation output measures and the sales share of product innovations.

Firms' responses to both indicators of process innovation output do vary at the firm level. This can be demonstrated be the number of different response values per firm, broken down by the total number of responses a firm provided to the indicator. Firms that provided values for the share of cost reduction for two times, in 80 percent of cases the second response differs from the first one. For the increase in sales due to quality improvement, the respective figure is 76 percent. The variety of response values per firm increases further with the number of responses, but at a diminishing rate (Figure 5). From about 6 responses on, the variety does not increase anymore, except for firms reported cost savings from process innovation for eleven or twelve times, though the variety of response values decreases for firm with 12 or more responses. For the change in sales due to quality improvement, a similar pattern emerges. This result suggests that regularly participating firms with process innovations tend to repeat values when reporting process innovation outcome or choose among a limited set of values. One should note that the questionnaire does not show the response a firm gave to a certain question in previous survey waves. But anecdotal evidence suggests that many firms keep copies of the completed questionnaire forms of previous years and are hence in a position to recall the values they provided in earlier years.

For product innovation output, the variety of response values increases up to firms with 8 responses and then remains rather constant. Firms with a very high number of responses (14 or more) show a somewhat higher variety of response values. But also for product innovation output, a kind of constant response behaviour emerges as a large share of regularly responding firms report from a limited set of values.

Figure 5: Number of different values for quantitative measures of process innovation and product innovation output per responding firm

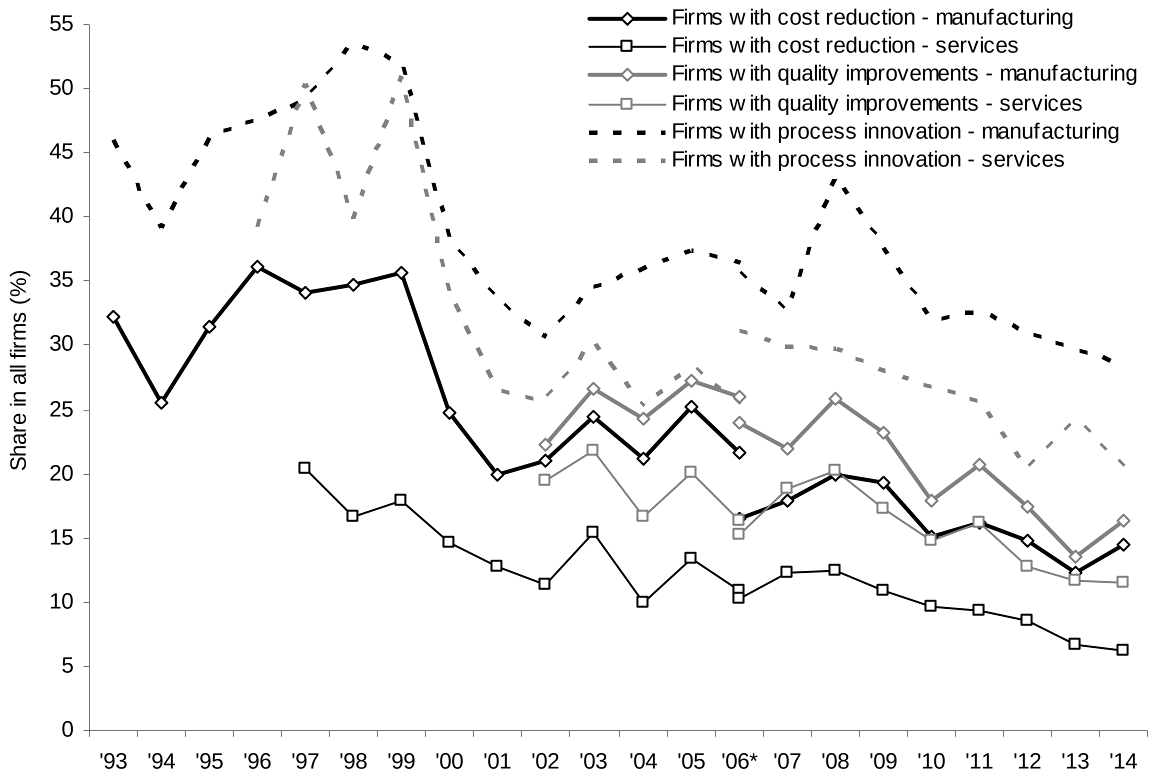


Based on 17,190 observations for share of cost reduction, 11,301 observations for increase in sales due to quality improvement, and 42,007 observations for sales share of product innovations.
Source: Mannheim Innovation Panel

The weighted results for both indicators yield a number of interesting results. First, the share of firms reporting cost reductions from process innovation is smaller than the share of firms that obtained quality improvements (Figure 7). The difference is less pronounced in manufacturing (three percentage points in average) but bigger in the service sectors (6 percentage points in average). This result implies that a single output measure for process innovation that focuses on cost reduction (as suggested in the Oslo Manual) would miss the major part of process innovation outcome, with a particularly high gap in services.

Secondly, a significant share of process innovators do not yield cost reductions. The share of process innovators with cost reductions ranges in manufacturing between 76 percent (in 1996) and only 41 percent (in 2013). In services, between 51 percent (in 2003) and 27 percent (in 2013) of process innovators reduced their unit costs through process innovation. This result means that the widespread assumption made in both theoretical and empirical models that process innovation is always linked to cost reduction is incorrect.

Figure 6: Share of firms in Germany with process innovation by type of process innovation outcome, 1993-2014

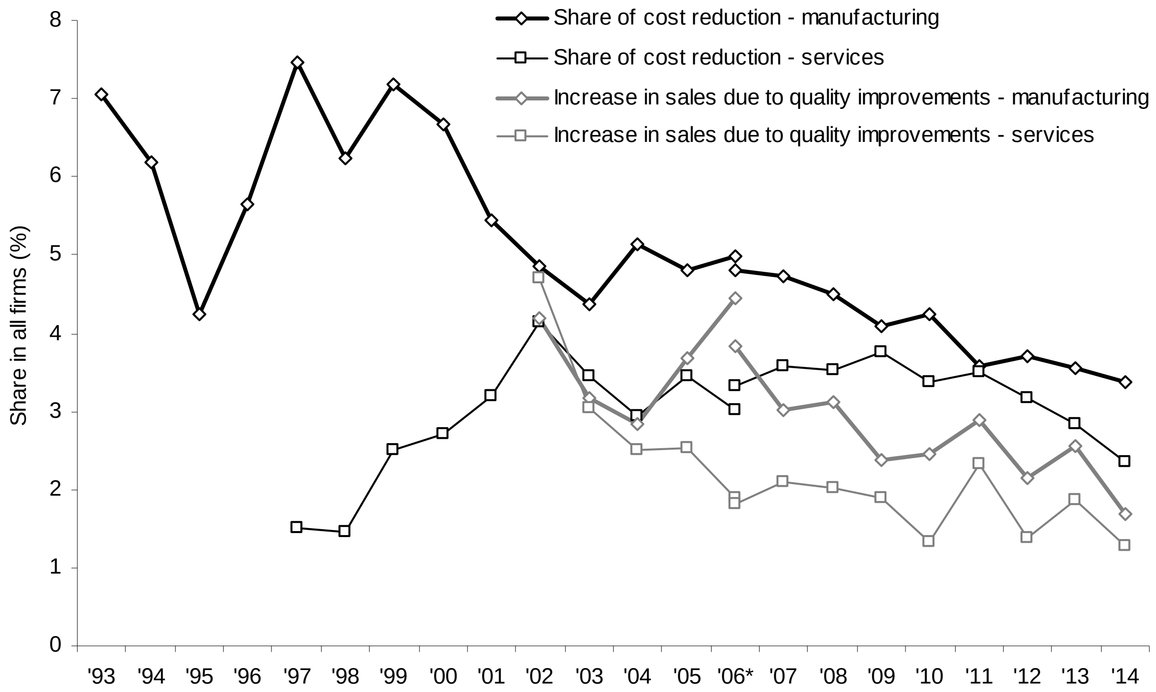


Weighted results. - Manufacturing: divisions 5 to 33 (NACE 2), divisions 10 to 37 (NACE 1); Services: divisions 35-39, 46, 49-53, 58-66, 69-74, 78-82 (NACE 2), divisions 40-41, 51, 60-67, 72-74, 90 and groups 92.1, 92.2 (NACE 1).
* Break in series due to change in economic classification systems (from NACE 1 to NACE 2) and change in the statistical source for total firm population figures (introduction of the official business register in 2006).
Source: Mannheim Innovation Panel

Third, the share of firms with either cost reduction or quality improvement resulting from process innovation tends to decline over the past 20 years. In manufacturing, more than a third of all firms in Germany reported cost reduction owing to process innovation in the second half of the 1990s, compared to only around 15 percent in the first half of the 2010s (though a part of this decline is due to methodological changes in the survey and the weighting procedure resulting from a change in the sector coverage and the underlying business register data). In services, this share fell from around 15 percent at the end of the 1990s to just 7 percent in 2013/14. For quality improvement, the share of firms with this type of process innovation was almost ten percentage points lower in recent years compared to the early 2000s. We do not know the reasons for this decline. One hypothesis is that the impact of new information and communication technologies for realising both unit cost reduction and higher output quality is diminishing over time.

The weighted results for the quantitative indicators confirm this declining trend (Figure 7). The average reduction in unit costs obtained in manufacturing was about 6-7 percent in the late 1990s and fell to 3.4 percent in 2014. Note that these figures refer to the entire economy, including all firms without process innovation and with process innovation not yielding to cost reduction. In services, the average share of unit cost reduction peaked 4.1 percent in 2002 and fell to 2.3 percent in 2014. The increase in sales that can be attributed to quality improvements was highest in 2002 in the service sector (4.7 percent) and in 2006 in manufacturing (4.4 percent) and showed the lowest values for both sectors in 2014 (1.7 percent in manufacturing, 1.3 percent in services).

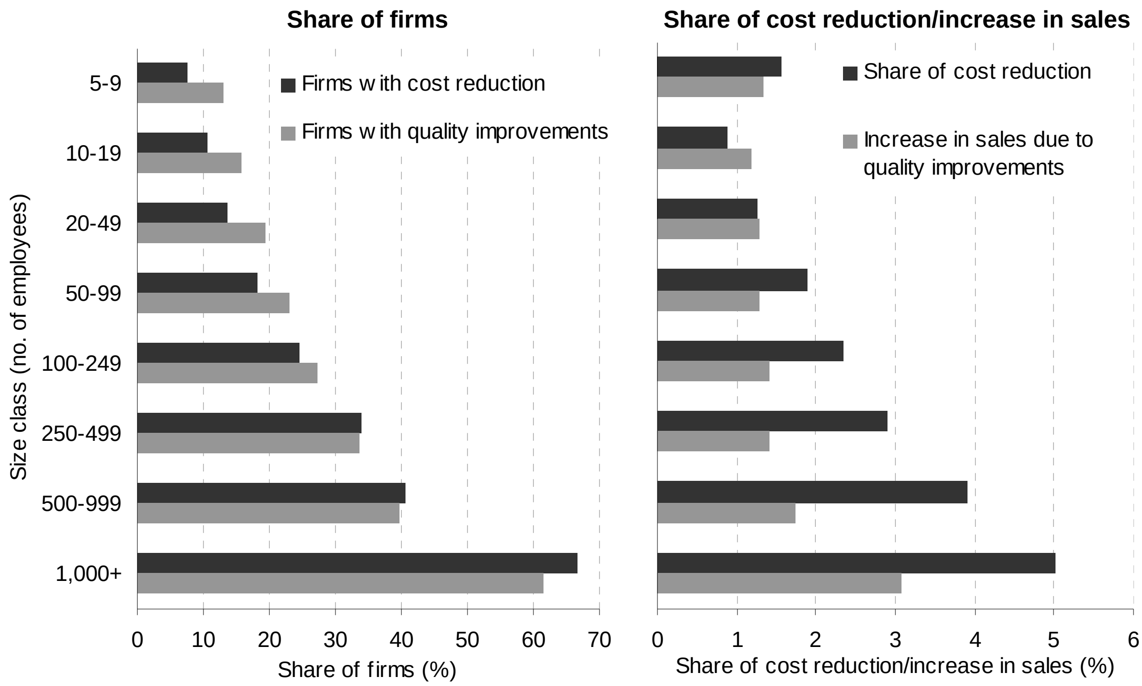
Figure 7: Share of cost reduction from process innovation and increase in sales due to quality improvement resulting from process innovation in Germany, 1993-2014



Weighted results. - Manufacturing: divisions 5 to 33 (NACE 2), divisions 10 to 37 (NACE 1); Services: divisions 35-39, 46, 49-53, 58-66, 69-74, 78-82 (NACE 2), divisions 40-41, 51, 60-67, 72-74, 90 and groups 92.1, 92.2 (NACE 1).
* Break in series due to change in economic classification systems (from NACE 1 to NACE 2) and change in the statistical source for total firm population figures (introduction of the official business register in 2006).
Source: Mannheim Innovation Panel

The relatively high total economy values for the two quantitative process innovation output indicators despite the small shares of firms that have yielded corresponding innovation results are driven by large enterprises. Firms with 1,000 or more employees frequently introduce process innovation that result in cost savings or quality improvements (67 and 61 percent, respectively, for the 2006-2014 period) and at the same time generate the highest output values among all size classes (5.0 percent average cost reduction and 3.1 percent average increase in sales for the 2006-2014 period) (Figure 8). Small and medium-sized firms do only rarely realize cost reductions or quality improvements, and the average quantitative effect per firm is much lower than for large firms. However, average cost savings per firm with cost reducing process innovation is quite similar across size classes (8-10 percent). For sales increases due to quality improvements, small firms with such type of process innovation even show twice the value (8-10 percent) compared to large firms with quality improving process innovation (4-5 percent). In general, size class differences are less pronounced for quality improvements than for cost reduction both with respect to the share of firms introducing such innovations, and to the quantitative indicators. This suggests that there may be substantial fixed cost and scale economies for cost reducing process innovation and less for quality improvements.

Figure 8: Indicators of process innovation output in Germany by size class (average for 2006 to 2014, %)



Weighted results.
Source: Mannheim Innovation Panel

The process innovation output indicators also vary significantly by sector. The sectors with the highest share of firms with cost reducing process innovation (average of the 2006-2014 period) are insurance (NACE 65), manufacturing of tobacco product (NACE 12) and manufacturing of refined petroleum products (NACE 19) while water supply (NACE 36), land transport (NACE 49), water transport (NACE 50) and cleaning and other building services (NACE 81) show the lowest shares (see Table 6 in the Appendix). For the share of firms with quality improvements, telecommunications (NACE 61), insurance (NACE 65), R&D services (NACE 72) and manufacturing of computer, electronic and optical products (NACE 26) report the highest figures, while it is again water supply, land transport and water transport that show the lowest ones. The highest average unit cost reduction is found in manufacturing of computer, electronic and optical products, followed by manufacturing of automobiles (NACE 29), mechanical engineering (NACE 28) and telecommunications. Very low shares of cost reduction are reported by the film industry (NACE 59), employment-agencies (NACE 78) and cleaning and other building services. High sales increases due to quality improvements are found in the manufacturing of other transport equipment (NACE 30), R&D services and manufacturing of computer, electronic and optical products. Water supply, sewerage (NACE 37) and water transport are the sectors with lowest sales increases resulting from quality improvements.

4 Determinants of Process Innovation Output

This part of the paper explores some of the determinants of process innovation output. We examine the firms' propensity to introduce cost reducing or quality improving process innovation, and the extent of direct economic results in terms of average unit cost reduction and increase in sales due to quality improvements. We run three types of regressions: (a) probit models on the propensity to generate cost reducing or quality improving process innovation, (b) tobit models on the share of cost reduction and the increase in sales due to quality improvement, including firms with no such innovations, and (c) OLS models on the the share of cost reduction and the increase in sales due to quality improvement only for the group of firms which did introduce such innovations. In addition, we run the same models for new-to-market product innovations and only new-to-firm innovation in order to compare the results found for process innovation output with those for product innovation output. We test four groups of explanatory variables:

- *Internal resources*: Many empirical studies on the determinants of innovation at the firm level stressed the role of a firm's internal resources, including size (no. of employees), accumulated experience (age) and available knowledge (share of highly skilled employees).

- *Investment in productive assets*: In addition to the stock of resources, current investment in tangible and intangible assets can be important to develop and leverage innovative capabilities. Such investment includes capital expenditure in fixed assets and software, marketing expenditure, training expenditure or investment in organisational capacities.

- *Market environment*: The type and intensity of competition in the market has been found a key determinant of innovation incentives and a firm's capability to transfer innovations into economic results. We include a number of measures on a firm's market environment, including the number of competitors and firm assessments on the competitive situation (substitutability of own products by competitor products, threat from new entrants, speed of product life cycle, technological uncertainty, demand uncertainty, uncertainty about competitors' actions, competition from abroad).

- *Organisation of the innovation process*: The way a firm manages the innovation process is certainly critical for yielding high innovation success. We consider the amount of financial resources devoted to innovation[1], whether a firm conducts in-house R&D, whether a firm engages in co-operation with other firms or organisation and whether a firm received financial support from government for innovation.

In addition, we control for sector and business cycle effects by adding sector and year dummies. All models are estimated as random effects panel models for a 13 year period (2002 to 2014) since data on quality improvement is available only from 2002 onwards. For the probit and tobit models, we estimate two variants. One includes all firms, the other only firms with product or process innovation activity since variables on the organisation of the innovation process are only available for this subgroup of firms. The second variant contains all variables of the first variant plus the innovation-related ones.

The estimation results for the qualitative (yes/no) output variables show for both cost reducing and quality improving process innovation that young firms and larger firms are more likely to introduce such innovations (Table 1). Expenditure in intangible and tangible assets is also

[1] The CIS and also the MIP do not separate between innovation expenditure for product and process innovation. We hence can include only total innovation expenditure.

positively associated with the two types of process innovation outcome, as is organisational innovation. The same results are found for product innovation output, both in terms of new-to-market and new-to-firm innovations. Marginal effects of intangible and tangible investment variables are slightly higher for quality improvement than cost reduction while size exerts a stronger effect on the propensity to introduce cost reducing process innovations. A firm's human capital endowment is positively linked to quality improving but not to cost reducing process innovation. In this respect, quality improvement is closer related to product innovation output as the latter is also positively driven by a firm's human capital resources.

The market environment in which a firm operates shows some different results for the two indicators on process innovation output. Firms with short product life cycles (rapid aging of own products) are more likely to realise quality improving process innovation (as well as product innovation) while there is no statistically significant impact on cost reducing process innovation. On the other hand, uncertainty about demand development restricts cost reducing process innovation but has no effect on the other output measures. Firms facing strong competition from abroad are more likely to react by realising cost reducing process innovation (and new-to-market product innovation), but are not more likely to go for quality improvements of their existing products.

If firms have difficulties to predict competitor behaviour, both types of process innovation output are more likely to emerge while no effect on product innovation is found. Firms in a market environment characterised by uncertainty about technological change are more likely to introduce product and process innovation, with a higher effect on quality improvement than on cost reduction. For both process and product innovation output we find a negative impact of a high number of competitors (and a positive one of few competitors for new-to-market product innovation), suggesting that very intensive competition in product markets restricts innovation results, which is in line with findings on an inverse U-shaped relation between competition and innovation (see Aghion et al. 2005).

In firms with innovation activities, the amount of innovation expenditure as well as continuous in-house R&D activities are positively associated with the propensity to introduce cost reducing or quality improving process innovation. The marginal effect is higher in case of cost reduction, but significantly smaller than for product innovation. Firms that conduct in-house R&D only occasionally are more likely to introduce cost reducing process innovations, but not quality improving ones. This may suggest that realising quality improvements is closer linked to systematic R&D activities and higher absorptive capacity compared to cost reductions, which would also be in line with the finding on human capital.

Table 1: Determinants of process and product innovation output (yes/no): marginal effects of random effects panel probit models

	Cost reducing process innovation		Quality improving process innovation		New-to-market product innovation		New-to-firm product innovation	
Part 1: all firms								
Age	-0.080	**	-0.078	**	-0.116	**	-0.054	**
Size	0.318	**	0.224	**	0.318	**	0.221	**
Human capital	0.090		0.318	**	1.186	**	0.487	**
Training expenditure	0.162	**	0.197	**	0.297	**	0.192	**
Marketing expenditure	2.021	*	3.356	**	8.066	**	6.311	**
Capital expenditure	0.869	**	1.055	**	0.649	**	0.827	**
Organisational innovation	0.782	**	0.756	**	0.372	**	0.441	**
Uncertainty: competitors	0.110	**	0.060	*	0.018		0.032	
Threat from new entrants	0.006		-0.022		-0.046		-0.025	
Uncertainty: technology	0.108	**	0.185	**	0.194	**	0.162	**
Rapid aging of products	0.027		0.137	**	0.222	**	0.292	**
Easy substitutability	0.059		0.024		-0.163	**	0.035	
Uncertainty: demand	-0.098	**	-0.032		0.052		0.019	
Competition from abroad	0.097	**	0.013		0.118	**	0.050	
Few competitors	0.012		-0.004		0.287	**	0.001	
Many competitors	-0.088	**	-0.113	**	-0.273	**	-0.132	**
Constant	-4.092	**	-3.290	**	-4.122	**	-2.469	**
No. of observations	59,981		59,834		60,289		56,708	
No. of firms	12,985		12,989		13,025		12,955	
Log likelihood	-17,116		-20,417		-15,843		-25,050	
Wald Chi^2	2,606	**	2,716	**	2,642	**	3,740	**
Part 2: innovative firms[1)]								
Innovation expenditure	0.092	**	0.087	**	0.090	**	0.035	**
Continuous R&D	0.223	**	0.190	**	0.761	**	0.358	**
Occasional in R&D	0.118	**	0.052		0.270	**	0.086	**
Co-operation	0.088	*	0.151	**	0.331	**	0.177	**
Public funding	0.070		0.041		0.099	*	0.077	*
No. of observations	23,358		23,344		23,480		22,656	
No. of firms	9,897		9,894		9,951		9,874	
Log likelihood	-10,954		-12,558		-10,412		-13,592	
Wald Chi^2	1,491	**	1,446	**	1,980	**	1,561	**

1) These models include all variables of part 1.
All models include 12 year dummies and 45 sector dummies.
* / **: significant at the 0.05 / 0.01 level.
Source: Mannheim Innovation Panel

Innovative firms that co-operate with others are more likely to generate cost reducing or quality improving process innovation, as they are also more likely to introduce product innovation. The co-operation effect is stronger for quality improvement than for cost reduction. Firms that received public financial support for innovation (which is in Germany always based on grant or loan funding for specific innovation projects based on project proposals to be submitted by firms and evaluated by programme administering agencies) are not more likely to introduce either type of process innovation while public funding has a positive effect on the propensity to introduce product innovation.

Table 2: Determinants of quantitative process and product innovation output: marginal effects of random effects panel tobit models

	Share of cost reduction		Increase in sales due to quality improvement		Sales share of new-to-market product innovat.		Sales share of new -to-firm product innovat.	
Part 1: all firms								
Age	-0.012	**	-0.018	**	-0.026	**	-0.018	**
Size	0.022	**	0.012	**	0.029	**	0.029	**
Human capital	0.009		0.020		0.187	**	0.152	**
Training expenditure	0.022	**	0.035	**	0.041	**	0.037	**
Marketing expenditure	0.246	*	0.287	*	1.329	**	1.341	**
Capital expenditure	0.111	**	0.145	**	0.129	**	0.165	**
Organisational innovation	0.093	**	0.115	**	0.063	**	0.093	**
Uncertainty: competitors	0.007		0.011	*	0.006		0.006	
Threat from new entrants	0.003		-0.002		-0.011		-0.006	
Uncertainty: technology	0.012	**	0.023	**	0.028	**	0.030	**
Rapid aging of products	0.004		0.023	**	0.040	**	0.078	**
Easy substitutability	0.006		-0.010	*	-0.037	**	0.005	
Uncertainty: demand	-0.008	*	-0.006		0.004		0.004	
Competition from abroad	0.014	**	0.004		0.022	**	0.015	**
Few competitors	0.001		-0.004		0.045	**	0.002	
Many competitors	-0.012	**	-0.002		-0.052	**	-0.030	**
Constant	-0.428	**	-0.429	**	-0.455	**	-0.461	**
No. of observations	44,610		43,580		44,820		44,599	
No. of firms	12,819		12,675		12,911		12,849	
Log likelihood	-5,788		-6,632		-7,391		-13,577	
Wald Chi^2	2,019	**	1,756	**	2,889	**	4,345	**
Part 2: innovative firms[1)]								
Innovation expenditure	0.010	**	0.012	**	0.017	**	0.010	**
Continuous R&D	0.026	**	0.025	**	0.123	**	0.055	**
Occasional R&D	0.010	*	0.009		0.041	**	0.014	*
Co-operation	0.006		0.014	*	0.031	**	0.023	**
Public funding	0.006		0.007		0.009		0.015	*
No. of observations	19,786		18,950		20,036		19,908	
No. of firms	8,581		8,418		8,709		8,657	
Log likelihood	-2,967		-3,820		-4,624		-7,033	
Wald Chi^2	1,100	**	971	**	2,236	**	2,033	**

1) These models include all variables of part 1.
All models include 12 year dummies and 45 sector dummies.
* / **: significant at the 0.05 / 0.01 level.
Source: Mannheim Innovation Panel

The results for the propensity to introduce cost reducing and quality improving process innovation by and large hold if the amount of process innovation output (i.e. the share of cost reduction and the increase in sales due to quality improvements) is taken into account, too (Table 2). Only a few differences can be found. Human capital is not statistically significant anymore for quality improvement, suggesting that highly qualified staff is helpful for identifying and realising potentials for improving the quality outcome of processes, but not for translating the results into higher sales volumes. Uncertainty about competitor actions is not statistically significant anymore for cost reduction while easy substitutability of own products significantly restricts the increase of sales due to quality improvements. With regard to innovation indicators, the positive impact of co-operation on cost reducing process innovation disappears when looking at the extent of cost reduction implying that co-operations do not help to yield high cost savings but are helpful for implementing cost reducing innovations.

The results shown in Table 1 and Table 2 mainly remain the same if a one year time lag between determinants and process innovation output is considered (see Table 8 and Table 9 in the Appendix). In the probit model, a few competition indicators become insignificant (uncertainty about competitors' actions, large number of competitors, strong competition from abroad). For quality improvements resulting from process innovation, public funding exerts a significant positive impact in case of a one year time lag for both the qualitative and the quantitative indicator. Occasional R&D activities become statistically significant for the propensity to realise quality improvements while innovation co-operation is positively associated with the amount of cost reduction if a one year lag is used.

The third group of models analyses the determinants of the amount of process innovation output (as well as product innovation output) for the group of firms that have introduced the respective innovation. The results, shown in Table 3, differ quite substantially for those found in Table 2. Most variables that are significant when looking at both the variance of introducing cost reducing or quality improving process innovation and the extent of the achieved output are not significant for the variance of quantitative output only. This means that the results in Table 2 are mainly driven by the dichotomous part of the variable. Explaining the variation of the share of cost reduction and the increase in sales due to quality improvement for firms with such innovations is difficult with the explanatory variables at hand, which is revealed by the low adjusted R^2 of 0.12 and 0.09, compared to the higher levels for product innovation output. Interestingly, the amount of investment in intangible assets is not correlated with quantitative process innovation output while capital expenditure on fixed assets is positively linked to the share of cost reduction and the sales share of new-to-market products. Firms with highly qualified staff are more likely to yield high cost savings form process innovation.

The innovation-related variables are all insignificant or are – in case of occasional R&D activities and cost reduction – even negative. This result is in contrast to product innovation output which is both strongly driven by high innovation expenditure. The findings change, however, if a one year time lag between innovation input and process innovation output is considered (see Table 10 in the Appendix). Then innovation expenditure becomes significant for both cost reduction and increase in sales. The insignificant results for intangible investment remain, however, except for organisational innovation which is positively linked to increase in sales.

Table 3: Determinants of quantitative process and product innovation output: marginal effects of random effects panel OLS models (firms with respective innovation only)

	Share of cost reduction		Increase in sales due to quality improvement		Sales share of new-to-market product innovat.		Sales share of new -to-firm product innovat.	
Age	-0.004	**	-0.011	**	-0.024	**	-0.015	**
Size	-0.011	**	-0.013	**	-0.020	**	-0.015	**
Innovation expenditure	0.001		0.001		0.006	**	0.003	**
Continuous R&D	0.007		0.002		0.009		0.013	*
Occasional R&D	-0.008	*	0.000		-0.014		0.004	
Co-operation	0.003		-0.002		-0.006		0.000	
Public funding	0.001		0.001		-0.008		0.003	
Human capital	0.024	**	0.006		0.083	**	0.079	**
Training expenditure	0.000		0.004		0.001		-0.004	
Marketing expenditure	0.158		-0.028		0.050		0.174	
Capital expenditure	0.046	**	0.007		0.117	**	0.022	
Organisational innovation	0.000		0.006		0.005		0.001	
Uncertainty: competitors	-0.003		0.009	*	-0.003		-0.005	
Threat from new entrants	0.007	*	0.003		0.005		0.005	
Uncertainty: technology	0.005		0.003		0.010		0.003	
Rapid aging of products	0.003		0.008		0.012		0.050	**
Easy substitutability	-0.005		-0.018	**	-0.030	**	-0.009	
Uncertainty: demand	-0.001		-0.005		-0.005		0.001	
Competition from abroad	0.005		0.003		0.011		0.015	**
Few competitors	0.005		0.003		0.031	**	0.008	
Many competitors	0.001		0.008		-0.001		0.017	**
Constant	0.087	**	0.130	**	0.336	**	0.251	**
No. of observations	4,781		5,124		5,499		10,488	
No. of firms	2,864		3,185		2,940		5,358	
R^2 adjusted	0.12		0.09		0.19		0.13	
Wald Chi^2	510	**	402	**	806	**	989	**

1) These models include all variables of part 1.
All models include 12 year dummies and 45 sector dummies.
* / **: significant at the 0.05 / 0.01 level.
Source: Mannheim Innovation Panel

The market environment is of little influence on quantitative process innovation outcome. The only strong effect is found for firms with easy to substitute products. They generate lower sales increases from quality improvements. When considering a one year time lag, firms with a low number of competitors yield a higher share of cost reductions.

5 Impacts of Process Innovation Output

This section analyses impacts of process innovation output on two measures of firm performance, the export share and the profit margin. The first performance indicator is particularly relevant for SMEs as the ability of SMEs to expand beyond their home market is a key performance criterion and most often a pre-condition to growth. The second performance indicator is a standard measure for a firm's ability to compete in markets. The export share can be calculated directly from data on the amount of sales to customers located abroad and total sales. This information is collected annually in the MIP. The profit margin is defined as pre-tax profits as a percentage of total sales and is collected as a categorical variable in the MIP, distinguishing seven categories (<0%, 0 to <2%, 2 to <4%, 4 to <7%, 7 to <10%, 10 to <15%, 15% and more).

The export model contains control variables for a firm's cost structure (share of material input, unit labour costs), its productivity level relative to the sector average, capital intensity and stock of brands (valid trade marks) as well as indicators on how close the firm's location is to an international border and whether the firm is part of an international group (see Arnold and Hussinger 2010, Beise-Zee and Rammer 2006, Cassiman et al. 2010, Becker and Egger 2013 for discussions on export performance models including innovation data). The profit margin model includes control variables on the intensity of competition as well as for capital intensity and whether a firm is part of a domestic or international group (see also Czarnitzki and Kraft 2010 and Rexhäuser and Rammer 2014 for more details on the profit margin model).

For each model, two variants are estimated, one with qualitative (yes/no) variables on process and product innovation output, and another one using quantitative indicators of innovation output. For the export model, we also estimate model variants for a one year and a two year lag between innovation output (and other controls) and export performance. For the profit margin model, we only use a one year time lag since too many things that affect the level of profitability may have changed within a two year time period and would need to be controlled for.

The export model shows not significant impact of quality improvements on the export share of firms, neither for the qualitative nor the quantitative indicator. For cost reduction, we find no effect for whether firms have introduced such innovation, but we do find a positive result for the share of cost reduction which only holds for non-lagged exports and the export share with a two year lag. The positive impact of the share of cost reduction on exports indicates that cost advantages gained from process innovation can be transferred into a stronger expansion of exports than total sales. This is plausible in case of the German economy since the majority of German exports goes to countries with a lower income level, meaning that products from Germany tend to be more expensive than domestic products and a decrease in price elasticity of demand is higher than for the same product in Germany. The insignificant result for quality improvement suggests that quality characteristics as such are not decisive for export success – in contrast to innovative features of products which clearly raise exportability.

Table 4: Impact of process and product innovation output on export success: marginal effects of random effects panel OLS models

	Export share in t		Export share in t+1		Export share in t+2	
Part 1: introduction yes/no						
Age	0.004	**	0.002	*	0.004	**
Size	0.026	**	0.025	**	0.024	**
New-to-market product innovation (yes/no)	0.012	**	0.009	**	0.008	**
New-to-firm product innovation (yes/no)	0.005	**	0.006	**	0.003	**
Cost reducing process innovation (yes/no)	0.002		0.002		0.002	
Quality improving process innovation (yes/no)	0.000		0.001		0.002	
Other process innovation	0.002		0.000		0.001	
Productivity level	0.001	**	0.001	**	0.001	**
Material input	0.035	**	0.027	**	0.017	**
International group	0.005	**	0.006	**	0.005	**
Stock of brands	0.007	**	0.008	**	0.008	**
Capital intensity	0.001		0.002		-0.004	
Unit labour costs	-0.010	**	-0.008	**	-0.005	
Border region	0.033	**	0.037	**	0.041	**
Next to border region	0.005		0.008	*	0.007	
No. of observations	71,711		56,932		45,098	
No. of firms	15,129		13,263		10,477	
R^2 adjusted	0.29		0.30		0.30	
Part 2: quantitative measure[1)]						
Sales share of new-to-market product innovations	0.059	**	0.054	**	0.038	**
Sales share of new -to-firm product innovations	0.024	**	0.021	**	0.013	**
Share of cost reduction resulting from process inn.	0.040	**	0.022		0.029	*
Increase in sales due to quality improvements	-0.017		-0.003		0.012	
No. of observations	51,425		38,027		31,130	
No. of firms	14,558		10,717		9,184	
R^2 adjusted	0.30		0.31		0.31	

1) These models include the same control variables as part 1.
All models include 12 year dummies and 45 sector dummies.
* / **: significant at the 0.05 / 0.01 level.
Source: Mannheim Innovation Panel

The results for the profit margin models are quite different. First, sales increase due to quality improvement clearly raises profit margins, both in the short run and if a one year time lag is considered. Secondly, a higher share of cost reduction does not result in significantly higher profitability. But we do find a positive impact of cost reduction on profit margins when a one year time lag is used, though only for the qualitative (yes/no) indicator. Thirdly, product innovation output has only limited impact on profitability. Firms with new-to-market innovation yield higher profit margins in the short run, but no statistically significant effect is found for the sales share of these innovations. In contrast, the sales share of new-to-firm innovations has a positive impact on profitability with a one year lag.

Table 5: Impact of process and product innovation output (yes/no) on profitability: marginal effects of random effects panel interval regression models

	Profit margin in t		Profit margin in t+1	
Part 1: introduction yes/no				
Age	0.112	*	0.087	
Size	-0.293	**	-0.437	**
New-to-market product innovation (yes/no)	0.386	**	0.130	
New-to-firm product innovation (yes/no)	0.068		0.089	
Cost reducing process innovation (yes/no)	0.144		0.322	**
Quality improving process innovation (yes/no)	0.232	**	0.103	
Other process innovation	-0.140		-0.070	
Domestic group	0.166		0.153	
International group	-0.061		0.070	
Few competitors	0.293	**	0.296	**
Many competitors	-0.029		-0.021	
Hard competition	-0.159	**	-0.151	**
Capital intensity	-0.380		-0.165	
Constant	7.278	**	8.162	**
No. of observations	41,092		33,275	
No. of firms	10,344		9,484	
Log likelihood	-70,758		-57,549	
Wald Chi^2	1,697	**	1,509	**
Part 2: quantitative measure[1)]				
Sales share of new-to-market product innovations	0.584		-0.114	
Sales share of new -to-firm product innovations	0.096		0.940	**
Share of cost reduction resulting from process innovations	1.077		0.912	
Increase in sales due to quality improvements from process inn.	4.095	**	1.850	**
No. of observations	32,152		22,502	
No. of firms	9,971		7,206	
Log likelihood	-56,501		-39,002	
Wald Chi^2	1,551	**	1,056	**

1) These models include the same control variables as part 1.
All models include 12 year dummies and 45 sector dummies.
* / **: significant at the 0.05 / 0.01 level.
Source: Mannheim Innovation Panel

The positive impact of quality improvements on profitability suggests that better product quality is valued by customers to a higher extent than a firm has to increase its costs for supplying a better quality. This may partly reflect a lower degree of competition for quality differentiated products.

6 Conclusions

The paper reported findings on two measures of process innovation output that have been used in the German innovation survey for many years, the share of cost reduction and the increase in sales due to quality improvement. The main aim of the paper was explorative in nature by looking at the response behaviour of firms, examining the determinants of process innovation output, exploring likely impacts on firm performance and comparing process innovation output with established measures of product innovation output (sales share of product innovations).

The two process innovation output measures used in the German innovation survey do work quite well. The vast majority of firms are able to report at least the qualitative part of the questions, whether their process innovation resulted in cost reduction or quality improvement. The share of item non-response on theses yes/no-questions falls to about 5-6 percent when firms participated at least 5 times in the survey, suggesting learning effects at the side of respondents. But falling item non-response shares are only found for the qualitative part of the question. For the quantitative part (share of cost reduction, increase in sales due to quality improvement), item non-response remains more or less the same for cost reduction regardless how many times a firm responded to the question in the past. The share of item non-response is higher for the increase in sales (25-30 percent) than for the share of cost reduction (15-20) percent. Both are higher than item non-response rates of measures for product innovation output (around 10 percent for firms with frequent survey participation).

Responses to the quantitative part of the two process innovation output measures are mainly categorical in nature. The vast majority of responses concentrate on a few full percentage values, suggesting that firms rather provide (rough) estimates than calculating the actual values of cost reduction and sales increase from their accounts. One could hence provide response categories instead of asking the exact percentage value in order to reduce item non-response on the quantitative part of the output measures. This would reduce the use of these indicators both for statistical and econometric applications, however, since it complicates the calculation of total values for cost reduction or sales increases, or average impacts of these measures on other variables.

Weighted data of the two indicators for the German enterprise sector provides intuitively meaningful results. Cost reduction is higher in manufacturing than in services while quality improvement plays a more important role in services than in manufacturing. For both dimensions, process innovation output increases by firm size, though the relation between size and output is much stronger for cost reduction. The determinants of a firm's propensity to realise cost reduction or quality improvement through process innovation are very similar, and they are also similar to those found for product innovation output. For the quantitative part of the measures, only a small fraction of the variance in cost reduction shares and sales increases can be explained by the variables at hand, including innovation expenditure, characteristics of the innovation process and investment in intangibles. This result may imply that the figures provided by firms on cost reductions and sales increase are too rough estimates and deviate too much from the real values so that systematic economic relations that one would expect between inputs in innovation and innovation output cannot be found. But it may also mean that the input variables are too general to identify output impacts, and more specific input variables in terms of expenditure, the way innovation processes are organised, and likely complementary activities are needed. Finally, there may be a much longer time lag between inputs and process innovation output than the one year time lag analysed in this paper.

Process innovation output is positively associated with firm performance. While cost reduction seems to facilitate exporting, quality improvement is beneficial to profitability. Both results do make sense, though the links are rather weak and not fully consistent. But weak and not fully consistent results are also found for product innovation output. For better understanding the performance contribution of process innovation, additional analysis focussing on productivity effects (e.g. following Griffith et al. 2006) and on employment effects (e.g. following Harrison et al. 2014) would be needed but were beyond the scope of this paper.

The main conclusion drawn from this investigation is twofold: First, it is possible to collect quantitative measures of process innovation output in innovation surveys that provide reliable and useful results and are comparable across sectors and types of firms. The relatively high item non-response which most likely results from the fact that firms only rarely keep an own record on process innovation outcome based on the measures used in the German innovation survey may be reduced by providing response categories. Secondly, process innovation output data does add information that helps to better understand the impacts of innovation on firm performance. Using just two measures that can be applied across industries and types of firms is likely to restrict the explanatory power of the data since these measures only crudely capture the results of process innovation activity in different sectors. While a more differentiated approach could be useful to better address sector and firm specificities, it clearly restricts comparison across firms and sectors.

7 References

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8 Appendix

Table 6: Indicators for process innovation output in Germany by NACE division (average for 2006 to 2014, %)

NACE	Share of firms with cost reduction	Share of firms with quality improvement	Share of cost reduction	Increase in sales due to quality improvement	NACE	Share of firms with cost reduction	Share of firms with quality improvement	Share of cost reduction	Increase in sales due to quality improvement
5-9	13	11	3.6	1.0	38	11	12	3.1	1.6
10	12	15	3.0	2.1	39	15	18	1.2	1.8
11	14	15	2.0	0.9	46	8	11	1.8	1.1
12	33	24	5.6	2.1	49	6	6	1.5	1.5
13	16	18	2.2	1.7	50	5	8	1.7	0.8
14	12	13	2.1	1.3	51	17	23	3.3	2.3
15	10	13	3.1	2.3	52	10	14	2.5	2.5
16	12	16	2.0	2.3	53	10	11	3.6	2.0
17	19	20	2.0	1.8	58	12	17	2.5	1.5
18	15	22	3.3	1.8	59	10	23	0.9	1.6
19	32	28	4.0	2.3	60	12	19	2.3	1.6
20	25	27	3.6	2.6	61	30	41	5.7	3.3
21	25	30	3.9	3.0	62	12	31	4.2	3.8
22	23	21	3.2	2.2	63	20	27	3.5	2.9
23	13	16	3.0	2.3	64	25	27	5.6	2.4
24	23	24	3.9	2.3	65	33	38	4.5	1.7
25	15	18	2.7	1.9	66	10	15	2.9	2.8
26	22	31	6.9	3.9	69	7	16	1.2	2.0
27	23	29	4.5	2.8	70	13	21	1.9	2.9
28	22	27	3.7	2.5	71	10	19	1.7	2.8
29	24	26	5.7	3.2	72	22	34	4.5	5.3
30	24	30	5.7	7.2	73	12	19	2.6	3.0
31	13	17	2.0	1.4	74	12	21	2.1	2.4
32	14	17	3.3	3.1	78	8	15	1.4	1.8
33	9	19	2.8	2.6	79	9	14	2.4	2.2
35	10	11	3.2	1.4	80	9	19	1.0	1.5
36	6	8	1.4	0.7	81	5	11	0.9	1.4
37	10	14	1.2	0.9	82	17	22	2.5	2.2

Weighted results.
Source: Mannheim Innovation Panel

Table 7: Descriptive statistics of model variables

Variable	Definition		# obs.	Mean	St.dev.	Min.	Max.
Cost reduction	1 if firm introduced cost reducing process innovation in previous three years, 0 otherwise		59,981	0.145	0.352	0	1
Quality improvement	1 if firm introduced quality improving process innovation in previous three years, 0 otherwise		59,364	0.177	0.382	0	1
New-to-market product inn.	1 if firm introduced new-to-market product innovation in previous three years, 0 otherwise		59,189	0.160	0.367	0	1
New-to-firm product inn.	1 if firm introduced new-to-firm product innovation in previous three years, 0 otherwise		55,868	0.307	0.461	0	1
Share of cost reduction	Share of average unit cost reduction from process innovations of previous three years	a	44,610	0.012	0.046	0.000	0.900
		b	4,781	0.094	0.091	0.000	0.900
Increase in sales	Increase in sales due to quality improvements from process innovations of previous three years	a	43,214	0.011	0.051	0.000	1.380
		b	5,124	0.084	0.116	0.000	1.380
Sales share new-to-market	Share of sales with new-to-market product innovations of previous three	a	42,848	0.022	0.091	0.000	1.000
		b	5,499	0.151	0.197	0.000	1.000
Sales share new-to-firm	Share of sales with new-to-firm product innovations of previous three	a	42,665	0.063	0.153	0.000	1.000
		b	10,488	0.223	0.217	0.000	1.000
Age	No. of years since foundation, log		59,981	3.018	0.980	-0.693	6.521
Size	No. of FTE employees, log		59,981	3.449	1.639	-3.178	12.947
Human capital	Share of graduated employees		59,981	0.202	0.250	0.000	1.333
Training expenditure	In-house and external expenditure for own employees per FTE employee (1,000 €)		59,981	0.432	0.637	0.000	4.995
Marketing expenditure	Marketing expenditure for advertising, branding, reputation buildung and market research per sales		59,981	0.007	0.016	0.000	0.134
Capital expenditure	Capital expenditure for tangible assets and software per sales		59,981	0.047	0.084	0.000	0.755
Organisational innovation	1 if organisational innovation has been introduced in previous three years, 0 otherwise		59,981	0.420	0.494	0	1
Uncertainty: competitors	1 if firm assessed that behaviour of competitors as difficult to foresee, 0 otherwise		59,981	0.426	0.494	0	1
Threat from new entrants	1 if firm assessed that new entrants threaten the own market position, 0 otherwise		59,981	0.385	0.487	0	1
Uncertainty: technology	1 if firm assessed that technological change is difficult to foresee, 0 otherwise		59,981	0.230	0.421	0	1
Rapid aging of products	1 if firm assessed that own products are aging rapidly, 0 otherwise		59,981	0.172	0.378	0	1
Easy substitutability	1 if firm assessed that competitors can easily substitute own products, 0 otherwise		59,981	0.535	0.499	0	1
Uncertainty: demand	1 if firm assessed that development of demand is difficult to foresee, 0 otherwise		59,981	0.577	0.494	0	1
Competition from abroad	1 if firm assessed that it faces strong competition by competitors from abroad, 0 otherwise		59,981	0.353	0.478	0	1
Few competitors	1 if no. of main competitors is below 6, 0 otherwise		59,981	0.484	0.500	0	1
Many competitors	1 if no. of main competitors is larger than 15, 0 otherwise		59,981	0.657	0.475	0	1
Innovation expenditure	Expenditure for product or process innovation per sales, log		21,879	-6.631	3.053	-13.82	0.405
Continuous R&D	1 if R&D was conducted on a continuous base in previous three years, 0 otherwise		21,879	0.420	0.494	0	1
Occasional R&D	1 if R&D was conducted on an occasional base in previous three years, 0 otherwise		21,879	0.211	0.408	0	1

Table 7: Ctd.

Variable	Definition	# obs.	Mean	St.dev.	Min.	Max.
Co-operation	1 if firm cooperated with partners on own innovation in previous three years, 0 otherwise	21,879	0.327	0.469	0	1
Public funding	1 if firm received financial support from government for innovation in previous three years, 0 otherwise	21,879	0.302	0.459	0	1
Export share	Sales to customers abroad per total sales	71,711	0.133	0.229	0.000	1.000
Other process innovation	1 if a firm reports process innovation but neither cost reduction nor quality improvement, 0 otherwise	71,711	0.065	0.247	0	1
International group	1 if firm is part of a group with locations abroad (either headquarters or subsidiaries), 0 otherwise	71,711	0.211	0.408	0	1
Productivity level	Sales per no. of FTE employees, divided by average productivity of the firms 3-digit sector	71,711	0.932	2.022	0.000	220.3
Material input	Purchases of material and service input per sales	71,711	0.400	0.225	0.029	1.000
Stock of brands	No. of valid trade marks at German and European trade mark offices	71,711	-4.532	3.742	-6.908	7.493
Capital intensity	Book value of tangible assets per no. of FTE employees	71,711	0.078	0.230	0.000	2.414
Unit labour costs	Labour costs per gross value added	71,711	0.343	0.364	0.000	2.822
Border region	1 if firm is located in a district that borders to another country, 0 otherwise	71,711	0.117	0.322	0	1
Next to border region	1 if firm is located in a district that borders to border region but does not border directly to another country, 0 otherwise	71,711	0.164	0.370	0	1
Profit margin	Pre-tax profits per sales, measured as categorical variable (<0%, 0 to <2%, 2 to <4%, 4 to <7%, 7 to <10%, 10 to <15%, 15% and more)	41,092	3.729	1.901	1	7
Domestic group	1 if firm is part of a group which has no locations abroad, 0 otherwise	41,092	0.077	0.267	0	1
Hard competition	Sum of 4-point Likert-scale assessment (0-3) on seven characteristics of competition (uncertainty of competitors, threat from new entrants, uncertainty of technology, rapid aging of products, easy substitutability, uncertainty of demand)	41,092	9.459	3.348	0	21

Table 8: Determinants of process and product innovation output (yes/no) with one year lag: marginal effects of random effects panel probit models

	Cost reduction in t+1		Quality improvement in t+1		New-to-market product innovat. in t+1		New-to-firm product innovat. in t+1	
Part 1: all firms								
Age	-0.067	**	-0.062	**	-0.099	**	-0.038	**
Size	0.293	**	0.200	**	0.281	**	0.207	**
Human capital	0.114		0.297	**	1.147	**	0.478	**
Training expenditure	0.167	**	0.159	**	0.233	**	0.160	**
Marketing expenditure	1.604		2.294	**	7.592	**	6.252	**
Capital expenditure	1.149	**	1.087	**	0.552	**	0.839	**
Organisational innovation	0.679	**	0.671	**	0.365	**	0.384	**
Uncertainty: competitors	0.059		0.000		-0.006		-0.010	
Threat from new entrants	0.026		0.021		-0.059		-0.027	
Uncertainty: technology	0.120	**	0.152	**	0.131	**	0.137	**
Rapid aging of products	0.031		0.105	**	0.260	**	0.159	**
Easy substitutability	0.017		-0.017		-0.178	**	-0.025	
Uncertainty: demand	-0.101	**	-0.074	*	-0.012		0.033	
Competition from abroad	0.047		-0.018		0.058		0.085	**
Few competitors	0.044		0.030		0.312	**	0.021	
Many competitors	0.051		0.034		0.055		-0.013	
Constant	-3.395	**	-2.867	**	-3.263	**	-2.153	**
No. of observations	53,612		53,563		53,802		51,407	
No. of firms	12,760		12,764		12,814		12,728	
Log likelihood	-15,367		-18,464		-14,260		-23,090	
Wald Chi^2	2,355	**	2,509	**	2,499	**	3,683	**
Part 2: innovative firms[1)]								
Innovation expenditure	0.081	**	0.067	**	0.096	**	0.074	**
Continuous R&D	0.225	**	0.243	**	0.634	**	0.464	**
Occasional R&D	0.149	**	0.096	*	0.276	**	0.241	**
Co-operation	0.216	**	0.190	**	0.338	**	0.220	**
Public funding	0.073		0.133	**	0.229	**	0.240	**
No. of observations	19,090		19,045		19,050		18,014	
No. of firms	7,808		7,794		7,799		7,566	
Log likelihood	-7,925		-9,203		-7,540		-9,948	
Wald Chi^2	1,231	**	1,132	**	1,634	**	2,042	**

1) These models include all variables of part 1.
All models include 12 year dummies and 45 sector dummies.
* / **: significant at the 0.05 / 0.01 level.
Source: Mannheim Innovation Panel

Table 9: Determinants of quantitative process and product innovation output with one year lag: marginal effects of pooled tobit models

	Share of cost reduction in t+1		Increase in sales due to quality improvement in t+1		Sales share of new-to-market product innovat. in t+1		Sales share of new -to-firm product innovat. in t+1	
Part 1: all firms								
Age	-0.009	**	-0.013	**	-0.018	**	-0.010	**
Size	0.023	**	0.011	**	0.026	**	0.031	**
Human capital	0.015		0.020	*	0.231	**	0.176	**
Training expenditure	0.025	**	0.033	**	0.047	**	0.039	**
Marketing expenditure	0.308	**	0.442	**	1.904	**	1.809	**
Capital expenditure	0.174	**	0.209	**	0.174	**	0.253	**
Organisational innovation	0.107	**	0.130	**	0.099	**	0.123	**
Uncertainty: competitors	0.009	**	0.012	**	0.001		0.010	*
Threat from new entrants	0.002		-0.005		-0.004		-0.002	
Uncertainty: technology	0.011	**	0.018	**	0.022	**	0.023	**
Rapid aging of products	0.003		0.023	**	0.050	**	0.083	**
Easy substitutability	0.005		-0.009	*	-0.044	**	-0.008	
Uncertainty: demand	-0.010	**	-0.007		-0.001		-0.001	
Competition from abroad	0.012	**	0.000		0.015	**	0.018	**
Few competitors	0.004		-0.003		0.058	**	0.001	
Many competitors	-0.009	*	0.001		-0.019	**	-0.033	**
Constant	-0.375	**	-0.427	**	-0.431	**	-0.425	**
No. of observations	43,198		42,273		43,491		43,283	
Log likelihood	-6,694		-7,251		-8,745		-15,213	
Wald Chi^2	4,530		3,418		7,624		9,194	
Part 2: innovative firms[1)]								
Innovation expenditure	0.012	**	0.010	**	0.022	**	0.020	**
Continuous R&D	0.031	**	0.037	**	0.120	**	0.109	**
Occasional R&D	0.018	**	0.013		0.048	**	0.055	**
Co-operation	0.015	**	0.014	*	0.029	**	0.038	**
Public funding	0.005		0.029	**	0.030	**	0.028	**
No. of observations	14,923		14,396		15,015		14,958	
Log likelihood	-2,520		-2,831		-3,592		-5,413	
Wald Chi^2	1,672		1,181		3,397		3,748	

1) These models include all variables of part 1.
All models include 12 year dummies and 45 sector dummies.
* / **: significant at the 0.05 / 0.01 level.
Source: Mannheim Innovation Panel

Table 10: Determinants of quantitative process and product innovation output with one year lag: marginal effects of random effects panel OLS models (firms with respective innovation only)

	Share of cost reduction in t+1		Increase in sales due to quality improvement in t+1		Sales share of new-to-market product innovat. in t+1		Sales share of new -to-firm product innovat. in t+1	
Age	-0.004	**	-0.006	**	-0.013	**	-0.009	**
Size	-0.002	*	-0.005	**	-0.011	**	-0.001	
Innovation expenditure	0.003	**	0.001	*	0.008	**	0.007	**
Continuous R&D	0.012	**	0.007		0.017		0.033	**
Occasional R&D	0.005		0.003		0.003		0.008	
Co-operation	-0.001		-0.003		-0.004		0.009	
Public funding	0.006		0.009	**	0.002		0.009	
Human capital	0.000		-0.011		0.070	**	0.057	**
Training expenditure	-0.002		0.002		0.003		-0.001	
Marketing expenditure	0.068		0.046		-0.168		0.325	*
Capital expenditure	0.065	**	0.034	*	0.098	**	0.022	
Organisational innovation	0.002		0.011	**	0.006		0.013	**
Uncertainty: competitors	-0.002		0.002		-0.003		-0.004	
Threat from new entrants	0.007	*	-0.001		0.000		0.004	
Uncertainty: technology	0.003		-0.001		0.004		-0.002	
Rapid aging of products	-0.003		0.004		0.010		0.044	**
Easy substitutability	-0.002		-0.007	**	-0.021	**	-0.009	
Uncertainty: demand	-0.005		-0.002		-0.012	*	-0.013	**
Competition from abroad	0.000		-0.001		0.004		0.011	*
Few competitors	0.008	**	-0.001		0.033	**	-0.003	
Many competitors	0.003		0.005		0.015	*	0.003	
Constant	0.106	**	0.059	**	0.200	**	0.142	**
No. of observations	4,084		4,570		4,526		8,413	
No. of firms	2,207		2,621		2,191		4,125	
Log likelihood	0.08		0.05		0.16		0.15	
Wald Chi^2	318	**	259	**	565	**	1,181	**

1) These models include all variables of part 1.
All models include 12 year dummies and 45 sector dummies.
* / **: significant at the 0.05 / 0.01 level.
Source: Mannheim Innovation Panel