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DISCUSSION PAPER

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Measuring Process Innovation Output: Results From Firm-Level 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 part of the Community Innovation Survey (CIS) over the past 25 years. Distinguishing between cost reduction and 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 with questionnaire experience of firms. 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.

Key Words: Process innovation, innovation output, panel data, Community Innovation Survey

JEL: O31, O32, O33

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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 2016, 206.7 thousand firms in Europe introduced one or more product innovation (26 percent of all firms) while 198.9 thousand firms (25 percent) introduced one or more process innovation.[1] In 21 out of 34 countries covered by the CIS 2016, the number of process innovators exceeded the number of product innovators. This relation has shifted towards process innovation with the introduction of an extended definition of business process innovation in the fourth edition of the Oslo Manual (OECD and Eurostat 2018). The new definition also considers new or improved organisational and marketing methods as process innovations. Results from the CIS 2018 based on the new definition show that in 2018, there were 299.1 thousand firms in Europe with process innovation (41 percent of all firms), compared to 217.4 thousand with product innovation (30 percent).

Firms invest a significant amount of financial resources into process innovation. Data from the German Innovation Survey show that in 2014, 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 (see Rammer et al. 2016: 59ff). These results are in line with similar findings from the German R&D survey which reports a share of 53 percent of R&D expenditures that were at least partially devoted to develop new or advanced processes (Eckl et al. 2017: 20).

For product innovation, 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, Hollanders et al. 2020) and academic research (see Laursen and Salter 2006, Leiponen and Helfat 2010, 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.

[1] See https://ec.europa.eu/eurostat/databrowser/view/inn_cis10_type/default/table?lang=en

Despite the significance of process innovation, no established quantitative measure for measuring the output of process innovation has been developed yet (see the review of Dziallas and Blind 2019). Most empirical works that examine the drivers and impacts of innovation output of firms either restrict to product innovation and do not consider process innovation output at all (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 they 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; Arundel et al. 2007, Antonucci and Pianta 2002, Classen et al. 2014, Diéguez-Soto et al. 2018, Fernández-Sastre 2015, Haneda and Ito 2018, Van Beveren and Vandenbussche 2010). Another approach to measure the output of process innovation is to rely on patent data (see Cohen and Klepper 1996, Bena et al. 2021, Ganglmair and Reimers 2019, Schwartz et al. 2012). However, identifying patents related to process innovation is difficult (see Banholzer et al. 2019), and patents are rather an output indicator for the R&D process, than an indicator of the results obtained from introducing process innovations (see Griliches 1990, Janger et al. 2017).

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, Spence 1984). Cost reduction from process innovation has been also been stressed as an important output dimension of innovation (see Mairesse and Mohnen 2010).

The aim of this paper is to discuss ways to measure process innovation output of firms based on quantitative indicators. The paper presents results of a respective effort in the German part of the Community Innovation Survey (CIS). This survey has developed two measures, one related to cost savings from process innovation, the other capturing quality improvements. As the German part of the CIS is an annual panel survey, it allows to empirical analyse the reliability of these measures in more detail than other surveys would allow. We examine item non-response and response behaviour over time, investigate the determinants of both types of process innovation output, and analyse the impact of process innovation output on firm performance.

The paper consists of four main parts. The first part (section 2) 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 innovating firm. Section 3 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 incidence of different types of process innovation outcome. Section 4 analyses the drivers of process innovation output while section 5 aims at identifying performance impacts of process innovation output as compared to product innovation output for two performance measures, the export share and the profit margin. Section 6 discusses the

2 Measuring Process Innovation Output

Types of 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 Oslo Manual (OECD and Eurostat 2018), which provides guidelines for the collection and interpretation of innovation data, frequently mentions cost reduction as an important dimension of innovation output and less frequently quality improvement. It also proposes to use the amount of cost reduction as a quantitative output measure for process innovation (§ 8.40). 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 the frequent use of quantitative measures of product innovation output.

Qualitative measures of process innovation output

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).

Other studies tried measure qualify this binary measure by measuring the degree of novelty of process innovation. One approach used bei Simms et al. (2021) relates to 'radical process innovation' which is the introduction of processes that fall outside the firm's existing production technologies. Another approach is to identify process innovations that were entirely new to the industry (Reichstein and Salter 2006, Möldner et al. 2020). The latter measure was also used in several CIS waves (2008 to 2014), but not much used in empirical research yet.

Another way to measure process innovation output is to ask firms to what extent process innovation led to certain effects. Some waves of the Community Innovation Surveys (CIS) contained such a question with effects closely related to process innovation (cost reduction, increase in flexibility, increase in capacity) that had to be evaluated on a 4-point Likert scale. 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.

Quantitative measures of process innovation output

The different dimensions of output potentially produced by process innovation complicate output measurement by a single quantitative indicator. With respect to cost reduction several national innovation surveys took up the proposal of the Oslo Manual (OECD and Eurostat 2018) and included, at least from time to time, a question on the change in the costs of one unit of output or in the costs of providing a certain type of service resulting from the introduction of a new or improved process technology. The innovation surveys in Germany (see Peters and Rammer 2013), Flanders (Czarnitzki and Wastyn 2009) and Switzerland (Wörter et al. 2010, Bolli et al. 2018) applied this metrics already, typically by asking for the average change in unit costs or cost per operation.

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 (see Möldner et al. 2020). 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).

Studies using quantitative measures of process innovation output are rather 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 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), also using German innovation data, 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 output is market turbulence (uncertain demand, competitors' action difficult to foresee). They also found a positive impact of process innovation output on profit margins. Rammer et al. (2021) used German innovation data to analyse the role of artificial intelligence (AI) for innovation output, showing that the use of AI has a strong, significant impact on cost reduction from process innovation. Bolli et al. (2018) used data from the Swiss innovation survey to investigate the role of educational diversity in a firm on innovation output, finding no significant impact on process innovation output measured through cost savings over sales. Czarnitzki and Wastyn (2009) used the Flemish innovation survey to investigate the role of knowledge management for innovation output, finding that cost savings from process innovation are higher when firms provide incentives for employees to share knowledge and implement a codified knowledge management policy.

3 Process Innovation Output Measures in the German Innovation Survey

Survey measure for process innovation output

In order to measure process innovation output in innovation surveys that cover a wide variety of manufacturing and service firms, metrics are required that can be applied to all sectors and all types of firms. In the German part of the Community Innovation Survey (CIS), an attempt was made to implement such metrics. Immediately after the first CIS conducted in 1993, the German innovation survey included a measure on cost savings from process innovation, following the measure proposed by the Oslo Manual (average share of reduction in costs per unit of output). After having observed that only a relatively small share of process innovators reported cost saving results, research was carried out into other outputs of process innovation and how they could be measured. This research suggested, in line with the literature described in the previous section, to develop measures on quality aspects of process technology. Based on expert interviews, discussion among a scientific advisory board and cognitive testing in firms, it turned out that the best single measure for quantifying quality-related process innovation output would be 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 questions on process innovation output were placed subsequently to the standard CIS questions on process innovation. A first question collects information on whether process innovations did reduce the average costs per unit or operation, while a second question captures improvements in the quality of goods or services resulting from process innovation (see Figure 1). If firms answered ‘yes’, they were asked to provide an estimate of the reduction in average unit costs, and the increase in sales due to quality improvements. Note that both questions were used in surveys that employed the definition of process innovation prior to the 4th edition of the Oslo Manual, i.e. process innovation did not include new or improved methods of organisation and marketing, but referred to 'technological' process innovation.

Figure 1: Questions on product innovation output in the German innovation survey 2017

Did the process innovations introduced by your enterprise during 2014 to 2016 reduce the average costs (per unit / operation)**?**

Yes .... ☐ ➔ What was the reduction in average unit costs due to these process innovations in 2016 .... ca. ☐ %

No .... ☐

Did the process innovations introduced by your enterprise during 2014 to 2016 lead to improvements in the quality of your goods or services?

Yes .... ☐ ➔ What was the increase in turnover due to these quality improvements in 2016 .... ca. ☐ %

No .... ☐

The question on cost reduction was for the first time included in the German innovation survey in the year 1994 for manufacturing. For the service sector, this question was part of the questionnaire from the survey year 1997 onwards. The question on quality improvement was included in the survey years 2003 to 2018.

In contrast to most other national CIS, 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 consists of about 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).

Reliability of process innovation output measures: item non-response

A key indicator of the reliability of a measures is the share of firms that are not able or willing to provide data on the measure. This item non-response for the binary (yes/no) part of the question on cost reduction is 17.1 percent for firms in the first year they respond to this question (Table 1). This falls almost continuously to 4.9 percent for firms that have responded to the question for 13 times. Firms with more frequent participations do not show a consistent pattern. Their item non-response rate is between 6 and 7 percent. For the question on quality improvement, item non-response of firms that responded the first time to that question is 19.4 percent. From the 7th time a firm responded to the quality improvement question, the share of item non-response is below 10 percent and falls to 7.1 percent in case of 10 responses.

The item non-response results on the binary 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 stays the same irrespective of the number of times a firm responded to the questions. Item non-response is significantly higher than for the binary part. For the amount of cost reduction, 15 to 20 percent of firms that stated to have obtained 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 increase 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 17.3 percent of all firms with quality improvements).

Table 1: Share of item non-response (in %) for questions on cost reduction and quality improvement due to process innovation, differentiated by the number of questionnaire responses per firm

	Number of responses in the panel survey																
	1	2	3	4	5	6	7	8	9	10*	11	12*	13	14*	15	16	17*
CR	17.1	13.7	12.3	9.9	9.2	8.9	8.6	6.8	7.5	6.5	5.8	6.7	4.9	5.9	6.3	5.5	7.3
QI	19.4	16.6	14.3	12.0	12.5	10.4	9.2	9.4	7.5	7.1	10.7	8.0					
CRs	18.0	17.4	19.3	19.2	16.9	19.6	16.3	17.3	18.5	18.5	14.2	19.1	16.0	24.9			
QIs	26.3	26.2	25.5	25.5	27.3	26.4	26.8	27.6	25.6	31.0							
PIs	*20.9*	*19.0*	*17.3*	*14.3*	*14.8*	*13.0*	*13.2*	*12.3*	*10.5*	*11.9*	*12.1*	*10.6*	*9.4*	*9.6*			

CR: cost reduction (y/n); QI: quality improvement (y/n); CRs: share of cost reduction (%); QIs: increase in sales due to quality improvement (%); PIs: sales share of product innovations (%).
* for QIs: 10 or more responses; for QI: 12 or more responses; for CRs and PIs: 14 or more responses; for CR: 17 or more responses.
Based on 44,624 observations for CR, 23,265 observations for QI, 30,438 observations for CRs, 18,347 observations for QIs, and 56,520 observations for PIs.
Source: Mannheim Innovation Panel

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 20.9 percent for first-time respondents to 9.4 percent for firms that responded to that question 13 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. For process innovation, however, 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 binary 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 (Table 2). 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.

Table 2: Item non-response for questions on cost reduction and quality improvement due to process innovation, differentiated by sector groups and size classes

	CR	QI	CRs	Qis	*PIs*
Sector group					
Material processing manufacturing (NACE 5 to 24)	10.3	13.3	19.0	24.9	*15.7*
Manufacturing of 'complex goods' (NACE 25 to 33)	9.9	13.0	17.4	25.2	*12.8*
Utilities, construction, trade, logistics (NACE 35 to 53)	14.7	17.1	19.9	27.8	*24.4*
Other services (NACE 55 to 93)	14.5	17.0	17.7	27.9	*17.5*
Size class					
5 to 9 employees	15.8	16.6	9.4	19.1	*14.5*
10 to 19 employees	14.5	15.9	10.4	19.4	*14.9*
20 to 49 employees	12.3	14.6	13.4	21.0	*14.2*
50 to 99 employees	11.0	12.5	13.5	21.3	*13.8*
100 to 249 employees	10.6	13.9	15.8	26.2	*14.1*
250 to 499 employees	8.5	12.6	20.1	31.2	*14.8*
500 to 999 employees	8.4	13.8	22.6	37.6	*16.8*
1,000+ employees	11.4	16.3	36.8	52.4	*25.2*
No. of observations	44,625	30,438	23,265	18,347	*56,536*

CR: cost reduction (y/n); QI: quality improvement (y/n); CRs: share of cost reduction (%); QIs: increase in sales due to quality improvement (%); PIs: sales share of product innovations (%).
Based on 44,625 observations for CR, 30,438 observations for QI, 23,265 observations for CRs 18,348 observations for increase in sales due to quality improvement; and 56,533 observations for sales share of product innovations.
Source: Mannheim Innovation Panel

Reliability of process innovation output measures: variance of reported values

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 71.3 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, 92.7 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, 95.5 percent of all responses include such values. The five most frequently reported values represent 71.0 percent of all responses This result indicates that firms rather estimate and rarely actually calculate the quantitative measures of process innovation output. It is in line with findings on the response to the quantitative measure for product innovation output, the sales share of product innovations. 90.0 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 57.0 percent of all responses. Figure 2 in the Appendix 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 79 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 (Table 3). From about 6 responses on, the variety does not increase systematically anymore. 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.

Table 3: Number of different values for quantitative measures of process innovation and product innovation output per responding firm, differentiated by number of responses in the panel survey

	Number of responses in the panel survey													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14*
CRs	1.00	1.79	2.27	2.51	2.57	2.78	2.74	2.62	2.86	2.88	2.89	3.93	2.84	2.70
QIs	1.00	1.76	2.19	2.39	2.40	2.69	2.41	2.40	2.56	2.85	2.69	2.25	2.17	
PIs	*1.00*	*1.83*	*2.39*	*2.73*	*2.92*	*3.01*	*3.06*	*3.41*	*3.53*	*3.57*	*3.50*	*3.68*	*3.55*	*4.03*

CRs: share of cost reduction (%); QIs: increase in sales due to quality improvement (%); PIs: sales share of product innovations (%)
* for CRs and PIs: 14 or more responses.
Based on 19,043 observations for CRs; 13,526 observations for QIs; and 48,045 observations for PIs.
Source: Mannheim Innovation Panel

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.

Weighted results for process innovation output

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 (Table 4). The difference is less pronounced in manufacturing (3.3 percentage points in average) but bigger in the service sectors (5.7 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.

Table 4: Share of firms in Germany with process innovation by type of process innovation outcome, 2002-2017

	Reporting year																
	'02	'03	'04	'05	'06*	'06*	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17
Manufacturing																	
CR	21.1	24.4	21.2	25.3	21.7	16.5	17.9	20.0	19.4	15.2	16.1	14.8	12.3	14.6	13.1	12.1	13.3
QI	22.3	26.6	24.4	27.3	26.0	24.0	21.9	25.9	23.2	17.9	20.7	17.4	13.6	16.6	15.7	16.0	16.1
PC	30.6	34.6	35.9	37.4	36.5	33.2	31.5	36.3	32.7	27.4	27.7	27.2	24.9	25.4	26.3	28.2	27.8
CRs	4.9	4.4	5.1	4.8	5.0	4.8	4.7	4.5	4.1	4.2	3.6	3.7	3.5	3.4	3.8	3.1	3.5
QIs	4.2	3.2	2.8	3.7	4.4	3.8	3.0	3.1	2.4	2.5	2.9	2.1	2.6	1.8	2.2	1.9	2.5
Services																	
CR	11.4	15.4	10.0	13.4	10.9	10.3	12.3	12.4	10.9	9.6	9.4	8.5	6.6	6.3	8.0	6.0	8.6
QI	19.4	21.8	16.7	20.0	16.3	15.2	18.8	20.2	17.2	14.9	16.2	12.7	11.7	11.5	11.5	10.3	12.3
PC	25.7	30.2	25.2	28.3	25.4	24.2	26.1	28.1	23.8	21.4	22.6	19.5	21.4	18.0	19.6	19.4	22.2
CRs	4.1	3.4	2.9	3.5	3.0	3.3	3.6	3.5	3.8	3.4	3.5	3.2	2.8	2.3	3.1	3.2	2.8
QIs	4.7	3.0	2.5	2.5	1.9	1.8	2.1	2.0	1.9	1.3	2.3	1.4	1.9	1.3	1.5	1.8	1.6

CR: cost reduction (y/n); QI: quality improvement (y/n); PC: process innovation (y/n) CRs: share of cost reduction (%); QIs: increase in sales due to quality improvement (%).
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

Secondly, a significant share of process innovators do not yield cost reductions. The share of process innovators that did not report cost reductions is between 29 and 57 percent in manufacturing, and between 49 and 69 percent in services. The share of process innovators with no cost reduction tends to increase over time in both sectors, with a strong increase reported for manufacturing. 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.

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, about one out of four firms reported cost reduction owing to process innovation in the first half of the 2000s, compared to less than 15 percent from 2012 onwards (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 15 percent in the early 2000s to just 6 percent in 2016. We do not know the reasons for this decline. One hypothesis is that the impact of new information and communication technologies (ICT) for realising both unit cost reduction and higher output quality is diminishing over time as ICT is diffusing across firms.

The weighted results for the quantitative indicators confirm this declining trend (see Table 4). The average reduction in unit costs obtained in manufacturing was about 5 percent in the early 2000s and fell to 3.1 percent in 2016. 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).

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 (60 and 55 percent, respectively, for the 2006-2017 period) and at the same time generate the highest output values among all size classes (5.7 percent average cost reduction and 2.7 percent average increase in sales for the 2006-2017 period) (Table 5).

Small and medium-sized firms do only rarely realise 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 costs and economies of scale for cost reducing process innovation and less so for quality improvements.

Table 5: Indicators of process innovation output in Germany by size class (average for 2006 to 2017, %)

	CR	QI	CRs	QIs
5-9 employees	7	11	0.6	1.2
10-19 employees	9	13	1.2	1.1
20-49 employees	11	16	1.1	1.1
50-99 employees	15	19	1.8	1.1
100-249 employees	21	23	2.6	1.2
250-499 employees	29	29	3.0	1.2
500-999 employees	36	35	4.9	1.6
1,000+ employees	60	55	5.7	2.7

CR: cost reduction (y/n); QI: quality improvement (y/n); CRs: share of cost reduction (%); QIs: increase in sales due to quality improvement (%).
Weighted results.
Source: Mannheim Innovation Panel

The process innovation output indicators also vary significantly by sector (see Table 11 in the Appendix). 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 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

Empirical model of process innovation output determinants

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 (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, high price elasticity of demand).

- *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[2], 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.

Definitions of model variables and descriptive statistics are shown in Table 12 in the Appendix. 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 16 year period (2002 to 2017) since data on quality improvement is available for this period only. 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. In order to compare the findings for process innovation with product innovation determinants, we run the same models for product innovation that were new to the firm's market or only new to the firm.

Results for binary measures

The estimation results for the qualitative (yes/no) process innovation 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 6). While age effects are larger for quality improvements, size effects are similar for both types. Expenditures in intangible assets (human capital, brand value) and tangible assets are also positively associated with both 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 only-new-to-firm innovations. Marginal effects of investment in training and tangible assets 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 (share of graduates among all employees) is positively linked to quality improving but not to cost reducing process innovation. In this respect, the determinants of quality improvement are more similar to those of product innovation output as the latter is also positively driven by a firm’s human capital resources.

[2] 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.

Table 6: Determinants of process and product innovation output (yes/no): results of random effects panel probit models

	Cost reducing process innovation		Quality improving process innovation		New-to-market product innovation		Only-new-to-firm product innovation	
	m.E.	St.D.	m.E.	St.D.	m.E.	St.D.	m.E.	St.D.
M1: All firms								
Age	-0.007	0.001 **	-0.012	0.002 **	-0.010	0.002 **	-0.005	0.002 *
Size	0.035	0.001 **	0.032	0.001 **	0.031	0.001 **	0.043	0.001 **
Human capital	0.012	0.006	0.056	0.007 **	0.132	0.006 **	0.146	0.008 **
Training expenditure[a)]	23.20	2.07 **	31.20	2.37 **	24.90	2.17 **	34.30	2.94 **
Marketing expenditure[a)]	1.88	0.591 **	1.60	0.662 *	8.55	0.609 **	9.49	0.841 **
Capital expenditure[a)]	0.573	0.101 **	0.665	0.115 **	0.211	0.112	0.334	0.139 *
Organisational innovat.	0.101	0.003 **	0.126	0.003 **	0.043	0.003 **	0.090	0.004 **
Rapid aging of products	0.003	0.004	0.015	0.004 **	0.024	0.003 **	0.041	0.005 **
Technological uncert.	0.011	0.003 **	0.024	0.004 **	0.014	0.003 **	0.019	0.004 **
Easy substitutability	0.004	0.003	-0.008	0.003 *	-0.031	0.003 **	-0.007	0.004
Threat from entrants	-0.008	0.003 **	-0.007	0.003 *	-0.013	0.003 **	-0.012	0.004 **
Uncert. ab. competitors	0.004	0.003	0.005	0.003	0.005	0.003	0.004	0.004
Uncert. about demand	-0.008	0.003 *	-0.012	0.003 **	-0.001	0.003	-0.003	0.004
Competition fr. abroad	0.012	0.003 **	0.005	0.004	0.015	0.003 **	0.002	0.004
High price elasticity	0.002	0.003	-0.003	0.004	-0.009	0.004 **	-0.002	0.004
No. of observations	89,028		89,220		89,554		88,309	
No. of firms	28,569		28,612		28,724		28,508	
Log likelihood	-28,535		-34,250		-27,171		-40,642	
Wald Chi^2	4,623 **		5,205 **		4,821 **		7,151 **	
M2: Innovative firms[1)]								
Innovation expenditure[a)]	0.282	0.075 **	0.211	0.081 **	0.505	0.100 **	-0.077	0.091
Continuous R&D	0.071	0.006 **	0.086	0.006 **	0.179	0.006 **	0.121	0.006 **
Occasional R&D	0.030	0.006 **	0.029	0.006 **	0.080	0.006 **	0.034	0.006 **
Innovation co-operation	0.018	0.006 **	0.035	0.007 **	0.057	0.006 **	0.056	0.008 **
Public funding of innov.	0.023	0.007 **	0.024	0.007 **	0.040	0.006 **	0.023	0.008 **
No. of observations	48,300		48,477		48,861		47,812	
No. of firms	19,901		19,953		20,212		19,979	
Log likelihood	-23,527		-27,262		-22,245 **		-28,856	
Wald Chi^2	2,617 **		2,450 **		4,127		3,258 **	

1) These models include the same control variables as M1. - a) per employee (FTE)
All models include 15 year dummies, 23 sector dummies and a constant.
m.E.: marginal effect at means; St.D.: standard deviation; * / **: significant at the 0.05 / 0.01 level.
Source: Mannheim Innovation Panel

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, a strong competition by competitors from abroad stimulates cost reducing process innovation (reflecting that foreign competition usually has a cost advantage over firms in Germany) but has no effect on quality improvement. In case a firm's products are easy to substitute by competitor products is negatively linked to quality improvement (and new-to-market products), indicating that for these firms, there in the firm's market little room for quality-based product differentiation.

For three other market characteristics, we find similar results for both types of process innovation: High technological uncertainty is positively associated with cost reduction and quality improvement (as well as both types of product innovation), while threat from new entrants and uncertainty about the development of demand are negatively linked to both types. Uncertainty about competitor actions and a high price elasticity are neither linked with cost reducing nor quality improving process innovation.

In firms with innovation activities, the amount of innovation expenditure per employee 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. Firms that conduct in-house R&D are also more likely to introduce both types of process innovation, with a stronger effect of continuous R&D activities on quality improvement. 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. This view is supported by the fact that firms that co-operate with others are two-times more likely to generate quality improving than cost reducing process innovation. 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 more likely to introduce either type of process innovation. For almost all innovation variables, we find stronger effects on product innovation than on process innovation, except for innovation intensity and public funding on only-new-to-firm product innovation.

Results for quantitative measures (all firms)

The results for the propensity to introduce cost reducing and quality improving process innovation 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. Results of tobit estimations show only a very few differences (Table 7). For quality improving process innovation, uncertainty about competitor actions becomes significant, suggesting that more non-transparent markets provide a better environment to yield higher additional sales when increasing quality features of products. At the same time, uncertainty about demand development becomes insignificant for quality improvements. With regard to innovation indicators, the positive impact of co-operation disappears when looking at the extent of cost reduction and the increase in sales owing from quality improvements. Co-operation is hence important for realising such types of process innovation, but cannot help for obtaining higher economic returns from the innovations.

Table 7: Determinants of quantitative process and product innovation output: results 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 only-new-to-firm product innovat.	
	m.E.	St.D.	m.E.	St.D.	m.E.	St.D.	m.E.	St.D.
M1: All firms								
Age	-0.010	0.001 **	-0.022	0.002 **	-0.026	0.002 **	-0.015	0.002 **
Size	0.025	0.001 **	0.011	0.001 **	0.033	0.002 **	0.033	0.001 **
Human capital	0.011	0.006	0.034	0.009 **	0.212	0.009 **	0.180	0.009 **
Training expenditure[a)]	23.07	2.01 **	32.18	2.77 **	32.47	2.97 **	32.34	2.96 **
Marketing expenditure[a)]	2.057	0.563 **	2.691	0.736 **	12.626	0.817 **	8.913	0.817 **
Capital expenditure[a)]	0.618	0.098 **	0.853	0.143 **	0.391	0.170 *	0.447	0.155 **
Organisational innovat.	0.091	0.003 **	0.129	0.004 **	0.063	0.004 **	0.093	0.004 **
Rapid aging of products	0.005	0.003	0.025	0.005 **	0.041	0.005 **	0.060	0.005 **
Technological uncert.	0.011	0.003 **	0.025	0.005 **	0.020	0.005 **	0.018	0.005 **
Easy substitutability	0.004	0.003	-0.018	0.004 **	-0.057	0.005 **	-0.010	0.004 *
Threat from entrants	-0.007	0.003 *	-0.005	0.004	-0.020	0.005 **	-0.014	0.004 **
Uncert. ab. competitors	0.005	0.003	0.011	0.004 *	0.005	0.005	0.002	0.004
Uncert. about demand	-0.007	0.003 *	-0.003	0.004	-0.002	0.005	-0.001	0.004
Competition fr. abroad	0.012	0.003 **	0.000	0.005	0.024	0.005 **	0.004	0.005
High price elasticity	0.004	0.003	0.002	0.005	-0.012	0.005 *	-0.003	0.005
No. of observations	87,528		58,957		88,723		87,346	
No. of firms	11,030		6,610		12,949		24,282	
Log likelihood	-12,712		-9,568		-16,709		-28,818	
Wald Chi²	3,600 **		2,396 **		5,092 **		7,630 **	
M2: Innovative firms[1)]								
Innovation expenditure[a)]	0.175	0.041 **	0.178	0.051 **	0.588	0.059 **	0.187	0.064 **
Continuous R&D	0.041	0.003 **	0.062	0.004 **	0.165	0.005 **	0.081	0.005 **
Occasional R&D	0.016	0.003 **	0.027	0.004 **	0.075	0.005 **	0.025	0.005 **
Innovation co-operation	0.006	0.003	0.006	0.005	0.035	0.005 **	0.023	0.005 **
Public funding of innov.	0.014	0.004 **	0.022	0.005 **	0.035	0.005 **	0.023	0.005 **
No. of observations	46,829		44,729		48,058		46,764	
No. of firms	10,894		9,898		12,741		23,780	
Log likelihood	-8,282		-10,385		-12,205		-17,816	
Wald Chi²	2,005 **		1,772 **		4,614 **		3,868 **	

1) These models include the same control variables as M1. - a) per employee (FTE)
All models include 15 year dummies, 23 sector dummies and a constant.
m.E.: marginal effect at means; St.D.: standard deviation; * / **: significant at the 0.05 / 0.01 level.
Source: Mannheim Innovation Panel

The results shown in Table 6 and Table 7 mainly remain the same if a one year time lag between determinants and process innovation output is considered (see Table 13 and Table 14 in the Appendix). The threat from entrants becomes insignificant for both types of process innovation, suggesting that new firm entries disencourage process innovation only in the short run. For quality improvements, innovation intensity is not significant anymore, indicating that projects to improve the quality of processes are rather short duration. With respect to the amount of cost reduction, human capital (share of graduates) exerts a positive and significant effect in the lagged model.

Results for quantitative measures (process innovators only)

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 type of innovation. The results, shown in Table 8, differ quite substantially from those found in Table 7. Many determinants become significant both when looking at the introduction of cost reducing or quality improving process innovation, and for the extent of the achieved output. This means that the results in Table 7 are mainly driven by the dichotomous part of the variable, i.e. whether a firm decides to develop and introduce a certain type of process innovation. The explanatory variables at hand do explain only a small part of the variation in the share of cost reduction and the increase in sales due to quality improvement for firms with such innovations, which is revealed by the low adjusted R^2 of 0.10 and 0.08. Interestingly, the amount of investment in intangible and tangible assets is not correlated with the increase in sales due to quality improvements, while marketing and capital expenditure are positively linked to the share of cost reduction. Firms with highly qualified staff are more likely to yield higher cost savings form process innovation, but do not affect the economic returns from quality improvement. Introducing organisational innovations is not linked to the amount of cost savings in firms that did introduce cost saving process innovation, but is positively correlated with the increase in sales from quality improvements in firms with such type of process innovation.

The innovation-related variables are all insignificant except for continuous in-house R&D (for both types of process innovation output) and public funding of innovation activities (only for increase in sales due to quality improvements). The findings change, however, if a one year time lag between innovation input and process innovation output is considered (see Table 15 in the Appendix). In this case, innovation expenditure becomes significant for both cost reduction and increase in sales, and public funding also becomes significant for cost savings. This result suggests that it takes time to transfer financial investment in process innovation into economic returns.

Table 8: Determinants of quantitative process and product innovation output: results 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 only-new-to-firm product innovat.	
	Coeff.	St.D.	Coeff.	St.D.	Coeff.	St.D.	Coeff.	St.D.
Age	-0.007	0.001 **	-0.014	0.002 **	-0.025	0.002 **	-0.015	0.002 **
Size	-0.011	0.001 **	-0.015	0.001 **	-0.022	0.001 **	-0.019	0.001 **
Human capital	0.026	0.007 **	0.009	0.008	0.073	0.011 **	0.050	0.008 **
Training expenditure[a)]	-0.755	1.844	0.741	2.176	-2.092	2.869	-4.565	2.552
Marketing expenditure[a)]	0.925	0.409 *	1.117	0.695	1.432	0.820	0.410	0.707
Capital expenditure[a)]	0.203	0.093 *	0.120	0.133	0.285	0.213	0.018	0.146
Organisational innovat.	-0.002	0.003	0.008	0.003 *	0.006	0.004	0.009	0.003 **
Rapid aging of products	0.003	0.003	0.001	0.003	0.017	0.005 **	0.042	0.004 **
Technological uncertainty	0.003	0.002	0.009	0.003 **	0.005	0.004	-0.003	0.004
Easy substitutability	-0.007	0.002 **	-0.013	0.003 **	-0.030	0.004 **	-0.008	0.003 *
Threat from entrants	0.008	0.002 **	0.002	0.003	0.000	0.004	0.003	0.004
Uncert. ab. competitors	-0.002	0.002	0.002	0.003	-0.002	0.004	-0.005	0.003
Uncert. about demand	0.000	0.002	-0.002	0.003	-0.005	0.004	0.004	0.003
Competition fr. abroad	0.004	0.002	0.001	0.003	0.008	0.004	0.009	0.004 *
High price elasticity	0.000	0.002	0.002	0.003	-0.007	0.005	-0.004	0.004
Innovation expenditure[a)]	0.107	0.065	0.163	0.100	0.415	0.200 *	0.577	0.090 **
Continuous R&D	0.007	0.003 **	0.012	0.003 **	0.014	0.005 *	0.010	0.004 *
Occasional R&D	-0.004	0.002	0.002	0.003	-0.009	0.005	-0.005	0.004
Innovation co-operation	0.001	0.003	-0.007	0.003	-0.007	0.005	-0.004	0.004
Public funding of innov.	0.005	0.003	0.008	0.003 *	0.006	0.005	0.011	0.005 *
No. of observations		10,941		11,965		12,944		24,176
No. of firms		6,488		7,372		6,694		12,029
R^2 adjusted		0.104		0.079		0.166		0.107
Wald Chi^2		749.0 **		691.9 **		1046.6 **		1765.8 **

a) per employee (FTE)
All models include 15 year dummies, 23 sector dummies and a constant.
Coeff.: estimated coefficient; St.D.: standard deviation; * / **: significant at the 0.05 / 0.01 level.
Source: Mannheim Innovation Panel

5 Performance Impacts of Process Innovation Output

This section analyses the contribution of process innovation output on two measures of firm performance, the export share and the profit margin. The export share is a performance measure particularly relevant to SMEs as the ability of SMEs to expand sales beyond their home market is a key performance criterion and most often a pre-condition to growth. The profit margin is a standard measure for a firm's ability to successfully 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).

Process innovation and export performance

The export model is based on the model used by Freel et al. (2019) who also use MIP data. It 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 is based on the model used by Czarnitzki and Kraft (2010) and Rexhäuser and Rammer (2014) who also use MIP data. It 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 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 export performance. For the profit margin model, we only use a one year time lag.

The export model shows no significant impact of quality improving process innovation on the export share of firms, neither for the qualitative nor the quantitative indicator, except for the qualitative indicator and when a two-year lag of export performance is used. For cost reduction, we find positive effects for both the qualitative and the quantitative indicator for the non-lagged model and the one-year lag. These results clearly indicate that 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 tends to be higher than for the same product in Germany. Cost savings are hence important to gain competitive advantages on foreign markets. This is particularly true for SMEs that may suffer from a liability of smallness and a lack of reputation when serving customers abroad (Stoian et al. 2018). Note that the MIP sample mainly includes SMEs, with a mean 43 for the number of employees.

The insignificant result for quality improvement suggests that quality characteristics that can be altered through process innovation - e.g. a higher durability of prodcuts or a lower probability of product defects - as such are not decisive for export success – in contrast to innovative features of products which clearly raise exportability. This is particularly true for new-to-the-market product innovations, but also for product innovation that is only new to the innovating firm.

Table 9: Impact of process and product innovation output on export success: results of random effects panel OLS models

	Export share in t		Export share in t+1		Export share in t+2	
	Coeff.	St.D.	Coeff.	St.D.	Coeff.	St.D.
M1: introduction yes/no						
Cost reducing process innovation (yes/no)	0.005	0.002 **	0.005	0.002 *	0.003	0.002
Quality improving process innov. (yes/no)	0.000	0.002	0.000	0.002	0.006	0.002 **
Other process innovation	0.005	0.002 *	0.001	0.003	0.009	0.003 **
New-to-market product innov. (yes/no)	0.021	0.002 **	0.018	0.002 **	0.019	0.002 **
Only-new-to-firm product innov. (yes/no)	0.010	0.001 **	0.007	0.002 **	0.009	0.002 **
Age	0.002	0.001	0.003	0.001	0.003	0.002
Size	0.024	0.001 **	0.024	0.001 **	0.024	0.001 **
Productivity	0.001	0.000 **	0.003	0.000 **	0.003	0.000 **
Material/service input	0.032	0.004 **	0.019	0.005 **	0.020	0.005 **
Domestic group	0.011	0.002 **	0.011	0.002 **	0.011	0.003 **
International group	0.060	0.002 **	0.060	0.003 **	0.058	0.003 **
Marketing expend. per employee (FTE)	2.885	0.321 **	3.074	0.372 **	3.302	0.408 **
Capital intensity	-0.001	0.001	-0.001	0.001	-0.002	0.001
Unit labour costs	-0.026	0.003 **	-0.015	0.003 **	-0.017	0.003 **
Border region	0.019	0.004 **	0.024	0.005 **	0.009	0.011
Next to border region	0.006	0.003 *	0.007	0.004	0.018	0.005 **
No. of observations		68,597		42,469		38,319
No. of firms		23,431		13,500		12,218
R^2 adjusted		0.315		0.323		0.323
Wald		9,852 **		5,596 **		4,932 **
M2: quantitative measure[1)]						
Share of cost reduction from process inn.	0.048	0.012 **	0.042	0.014 **	0.025	0.015
Increase in sales due to quality improvem.	0.010	0.010	0.012	0.012	0.024	0.013
Sales share of new-to-market product inn.	0.093	0.006 **	0.071	0.008 **	0.075	0.009 **
Sales share of only-new-to-firm product in	0.031	0.004 **	0.028	0.005 **	0.027	0.005 **
No. of observations		65,167		40,460		36,554
No. of firms		22,774		13,120		11,899
R^2 adjusted		0.309		0.316		0.315
Wald		9,401 **		5,310 **		4,596 **

1) These models include the same control variables as M1.
All models include 15 year dummies, 23 sector dummies and a constant
Coeff.: estimated coefficient; St.D.: standard deviation; * / **: significant at the 0.05 / 0.01 level.
Source: Mannheim Innovation Panel

The control variables of export model show that larger firms, more productive firms, firms that rely on a higher share of material and service inputs, firms that belong to an enterprise group, higher marketing expenditure, and lower unit labour cost all contribute to a higher export share. We do not find a linear age effect nor an effect from a firm's capital intensity (fixed assets per employee). Firms located in a border region profit from a better access to foreign markets. The results of the control variables are consistent for all three model variants (no lag, 1-year lag, 2-year lag).

Process innovation and profitability

The results of the profit margin models are quite different. First, sales increase due to quality improvement clearly raises profit margins. The effect is stronger in the short run than for a one year time lag. In the non-lagged model, a sales increase of 10 percent due to quality improvement would translate into a 0.359 percentage points higher profit margin. For the 1-year lag model, this effect lowers to 0.164 percentage points. For the binary indicator, we find no statistically significant impact on profitability in the 1-year lag model.

Table 10: Impact of process and product innovation output (yes/no) on profitability: results of random effects panel interval regression models

	Profit margin in t		Profit margin in t+1	
	Coeff.	St.D.	Coeff.	St.D.
M1: introduction yes/no				
Cost reducing process innovation (yes/no)	0.198	0.083 *	0.241	0.103 *
Quality improving process innovation (yes/no)	0.258	0.076 **	0.092	0.094
Other process innovation	-0.016	0.115	-0.045	0.140
New-to-market product innovation (yes/no)	0.302	0.078 **	0.191	0.097 *
Only-new-to-firm product innovation (yes/no)	0.082	0.061	0.105	0.076
Age	0.033	0.043	0.090	0.058
Size	-0.286	0.029 **	-0.394	0.038 **
Domestic group	-0.256	0.091 **	0.036	0.114
International group	0.080	0.112	0.144	0.144
Hard competition	-1.204	0.075 **	-1.186	0.099 **
Capital intensity	-0.016	0.030	-0.040	0.029
No. of observations		49,889		31,580
No. of firms		19,089		10,813
Log likelihood		-89,536		-55,435
Wald Chi^2		1,912 **		1,111 **
M2: quantitative measure[1)]				
Share of cost reduction resulting from process innov.	1.212	0.575 *	1.810	0.733 *
Increase in sales due to quality improvements	3.590	0.479 **	1.644	0.611 **
Sales share of new-to-market product innovations	0.242	0.307	-0.021	0.398
Sales share of only-new-to-firm product innovations	-0.055	0.178	0.304	0.223
No. of observations		47,560		30,250
No. of firms		18,472		10,562
Log likelihood		-85,454		-53,157
Wald Chi^2		1,904 **		1,091 **

1) These models include the same control variables as M1.
All models include 15 year dummies, 23 sector dummies and a constant.
Coeff.: estimated coefficient; St.D.: standard deviation; * / **: significant at the 0.05 / 0.01 level.
Source: Mannheim Innovation Panel

Secondly, the share of cost reduction also positively affects profitability. The level of statistical significance is lower, however, suggesting a higher variation in the way cost savings transfer into higher profit margins. A 10 percent decrease in average unit cost would increase the profit margin by 0.121 percentage points. The short-run effect of cost savings on profitability is lower than the effect in the following year (0.181 percentage points). A higher marginal effect of cost saving process innovation in the 1-year lag model is also found for the binary indicator. Thirdly, we do not find a significant impact on profitability by process innovation that neither led to cost savings nor quality improvements. This result suggests that the two indicators on process innovation output cover quite well the different types of economic returns from process innovation.

The higher impact of quality improvements on profitability in the short run compared to cost savings 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.

The estimation results also show that product innovation output increases profitability only in case of new-to-market innovations, but not for products that are only new for the innovating firms (i.e. imitations of other firms' innovations). This positive effect is limited to the binary indicator. Firms with new-to-market innovation yield a 0.302 percentage points higher profit margin than firms with no such innovations. For the 1-year lag model, this effect diminishes to 0.191 percentage points and becomes statistically less significant. For the sales share of new-to-market innovations, no significant impact on profitability is found.

6 Conclusions

This paper reports findings on two measures of process innovation output that have been used in the German part of the Community Innovation Survey (CIS) 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 reliability of the measures through analysing the response behaviour of firms, examining the determinants of process innovation output, and exploring likely impacts on firm performance.

The two process innovation output measures used in the German innovation survey seem to 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 less than 10 percent when firms participated at least 6 times in the survey, suggesting learning effects at the side of respondents. For the practice of innovation surveys, this implies that it will take some time after newly introduced measures achieve an acceptably low item non-response. Falling item non-response shares are only found for the binary part of the question, however. For the quantitative part (share of cost reduction, increase in sales due to quality improvement), item non-response remains more or less the same 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 indicator (25-30 percent) than for the share of cost reduction (15-20 percent). Both are higher than item non-response rates of product innovation output measures (around 10 percent for firms with frequent survey participation).

Responses to the quantitative part of the two process innovation output measures turned out to be 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 show that cost reduction is more frequent process innovation output 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 the cost reduction share and percentage sales increase 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 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. Cost reduction, but not quality improvement, seems to facilitate exporting. Both types of process innovation output are beneficial to profitability, with a higher short-term impact from quality improvement. Profitability impacts of process innovation are stronger for a 1-year time lag. This result confirms the study of Adner and Levinthal (2001) on the critical role of quality improvement as an output of process innovation. 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 useful, 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, e.g. by using metrics for specific types of process technologies (e.g. Shah and Ward 2003 and Möldner et al. 2020 on lean management practices), this would clearly restrict comparability across firms and sectors.

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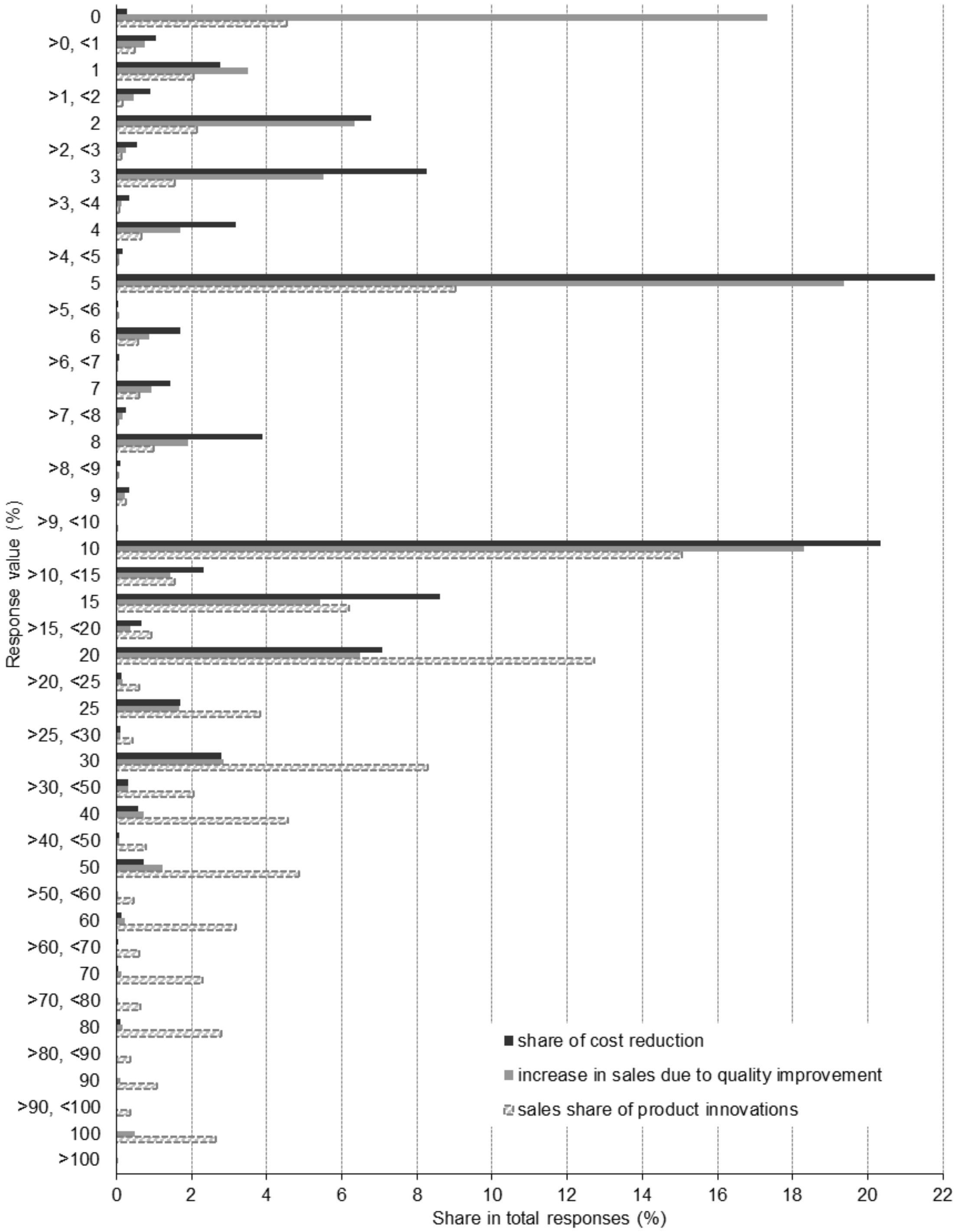
8 Appendix

Figure 2: Response values on quantitative measures process innovation and product innovation output



Based on 19,043 observations for share of cost reduction; 13,526 observations for increase in sales due to quality improvement; and 48,045 observations for sales share of product innovations.
Source: Mannheim Innovation Panel

Table 11: Indicators for process innovation output in Germany by NACE division (average for 2006 to 2017, %)

NACE	Share of firms with cost reduction	Share of firms with quality improve-ment	Share of cost reduction	Increase in sales due to quality improve-ment	NACE	Share of firms with cost reduction	Share of firms with quality improve-ment	Share of cost reduction	Increase in sales due to quality improve-ment
5 to 9	13	10	3.5	0.9	38	10	11	2.6	1.5
10	10	13	3.0	2.1	39	15	18	1.2	1.7
11	14	16	1.8	0.9	46	7	10	1.7	1.1
12	31	23	5.3	2.0	49	5	5	1.5	1.4
13	16	19	2.1	1.7	50	6	7	1.5	0.7
14	10	12	1.9	1.2	51	16	21	3.5	2.2
15	10	12	3.1	2.3	52	10	15	2.3	2.4
16	13	17	2.1	2.1	53	12	12	3.5	2.0
17	19	18	2.2	1.6	58	12	17	2.3	1.4
18	15	20	3.2	1.7	59	9	20	0.8	1.5
19	35	28	3.9	2.2	60	11	19	2.3	1.6
20	24	26	3.2	2.7	61	29	35	5.6	3.2
21	25	30	3.9	3.1	62	13	29	4.1	3.8
22	21	21	3.6	2.2	63	19	25	3.8	2.6
23	13	16	2.8	2.1	64	25	27	5.6	2.4
24	22	23	3.7	2.3	65	30	32	4.2	1.7
25	14	17	2.6	1.7	66	9	17	2.9	3.0
26	22	30	6.2	3.9	69	6	14	1.1	1.9
27	22	27	4.5	2.7	70.2	12	19	1.8	3.0
28	21	25	3.5	2.4	71	9	18	1.6	2.7
29	25	25	5.4	3.0	72	20	32	4.0	4.9
30	25	32	5.2	6.3	73	12	17	2.4	2.7
31	12	15	1.9	1.4	74	12	20	1.9	2.4
32	13	17	4.3	3.3	78	7	14	1.2	1.5
33	10	18	2.4	2.6	79	8	13	2.2	2.0
35	10	12	3.4	1.4	80	10	18	1.1	1.6
36	7	7	1.4	0.6	81	6	10	0.9	1.3
37	9	12	1.1	0.8	82	16	21	2.5	2.5

Weighted results.
Source: Mannheim Innovation Panel

Table 12: Definition and descriptive statistics of model variables

Variable	Definition		# obs.	Mean	St.D.	Min.	Max.
Cost reduction	1 if firm introduced a cost reducing process innovation in previous 3 years, 0 otherwise		89,028	0.141	0.348	0	1
Quality improvement	1 if firm introduced a quality improving process innovation in previous 3 years, 0 otherwise		88,328	0.172	0.378	0	1
New-to-market product inn.	1 if firm introduced a new-to-market product innovation in previous 3 years, 0 otherwise		85,883	0.154	0.361	0	1
Only-new-to-firm product inn.	1 if firm introduced an only-new-to-firm product innovation in previous 3 years, 0 otherwise		84,776	0.290	0.454	0	1
Share of cost reduction	Share of average unit cost reduction from process innovations of previous 3 years	a	87,528	0.012	0.047	0.000	1.000
		b	10,941	0.098	0.097	0.000	1.000
Increase in sales	Increase in sales due to quality improvements from process innovations of previous 3 years	a	84,399	0.013	0.057	0.000	2.500
		b	11,965	0.093	0.128	0.000	2.500
Sales share new-to-market	Share of sales with new-to-market product innovations of previous 3 years	a	83,947	0.023	0.094	0.000	1.000
		b	12,944	0.156	0.202	0.000	1.000
Sales share only-new-to-firm	Share of sales with only-new-to-firm product innovations of previous 3 years	a	82,859	0.063	0.155	0.000	1.000
		b	24,176	0.229	0.221	0.000	1.000
Age	No. of years since foundation, log		89,028	2.965	0.967	-0.693	6.520
Size	No. of FTE employees, log		89,028	3.489	1.641	0.000	13.071
Human capital	Share of graduated employees		89,028	0.221	0.268	0.000	1.000
Training expenditure	In-house and external training expenditure per FTE employee (million €)		89,028	0.000	0.001	0.000	0.005
Marketing expenditure	Advertising, reputation building and market research expenditure per FTE employee (million €)		89,028	0.001	0.003	0.000	0.021
Capital expenditure	Capital expenditure for tangible assets per FTE employee (million €)		89,028	0.007	0.015	0.000	0.131
Organisational innovation	1 if organisational innovation has been introduced in previous 3 years, 0 otherwise		89,028	0.400	0.490	0	1
Uncertainty: competitors	1 if firm assessed that behaviour of competitors as difficult to foresee, 0 otherwise		89,028	0.474	0.499	0	1
Threat from entrants	1 if firm assessed that new entrants threaten the own market position, 0 otherwise		89,028	0.442	0.497	0	1
Uncertainty: technology	1 if firm assessed that technological change is difficult to foresee, 0 otherwise		89,028	0.337	0.473	0	1
Rapid aging of products	1 if firm assessed that own products are aging rapidly, 0 otherwise		89,028	0.258	0.438	0	1
Easy substitutability	1 if firm assessed that competitors can easily substitute own products, 0 otherwise		89,028	0.566	0.496	0	1
Uncertainty: demand	1 if firm assessed that development of demand is difficult to foresee, 0 otherwise		89,028	0.596	0.491	0	1
Competition from abroad	1 if firm assessed that it faces strong competition by competitors from abroad, 0 otherwise		89,028	0.405	0.491	0	1
High price elasticity	1 if firm assessed that that a price increase immediately leads to a loss in sales , 0 otherwise		89,028	0.592	0.491	0	1
Innovation expenditure	Expenditure for product or process innovation per FTE employee (million €), log		48,300	0.010	0.027	0.000	2.000
Continuous R&D	1 if R&D was conducted on a continuous base in previous 3 years, 0 otherwise		48,300	0.415	0.493	0	1

Table 12: Ctd.

Variable	Definition	# obs.	Mean	St.D.	Min.	Max.
Occasional R&D	1 if R&D was conducted on an occasional base in previous 3 years, 0 otherwise	48,300	0.209	0.407	0	1
Co-operation	1 if firm cooperated with partners on own innovation in previous 3 years, 0 otherwise	48,300	0.289	0.453	0	1
Public funding	1 if firm received public financial support for innovation in previous 3 years, 0 otherwise	48,300	0.315	0.465	0	1
Export share	Sales to customers abroad per total sales	68,597	0.142	0.239	0.000	2.402
Other process innovation	1 if a firm reports process innovation but neither cost reduction nor quality improvement in previous 3 years, 0 otherwise	68,597	0.041	0.198	0	1
Domestic group	1 if firm is part of a group with locations only in Germany, 0 otherwise	68,597	0.153	0.360	0	1
International group	1 if firm is part of a group with locations abroad (either headquarters or subsidiaries), 0 otherwise	68,597	0.145	0.352	0	1
Productivity level	Sales per no. of FTE employees, divided by average productivity of the 3-digit sector a firm belongs to	68,597	0.984	2.320	-17.96	367.1
Material input	Purchases of material and service input per sales	68,597	0.396	0.224	0.032	1.000
Unit labour costs	Labour costs per gross value added	68,597	0.600	0.285	0.059	2.750
Border region	1 if firm is located in a district that borders to another country, 0 otherwise	68,597	0.120	0.325	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	68,597	0.168	0.374	0	1
Profit margin	Pre-tax profits per sales, measured as categorical variable (1-7: <0%, 0 to <2%, 2 to <4%, 4 to <7%, 7 to <10%, 10 to <15%, 15% and more)	49,889	3.774	1.917	1	7
Capital intensity	Stock of fixed capital per FTE employee (million €)	49,889	0.127	1.029	0.000	82.13
Hard competition	Average of 4-point Likert-scale assessment (0-3) on eight characteristics of competition (uncertainty of competitor behaviour, threat from new entrants, uncertainty of technology development, rapid aging of products, easy substitutability of products, uncertainty of demand, strong competition from abroad, high price elasticity of demand)	49,889	1.389	0.508	0	3

obs.: observations; St.D.: standard deviation; Min.: minimum value; Max.: maximum value.
a: all firms; b: firms with respective innovation only.
Source: Mannheim Innovation Panel

Table 13: Determinants of process and product innovation output (yes/no) with one year lag: results of random effects panel probit models

	Cost reducing process innovation		Quality improving process innovation		New-to-market product innovation		Only-new-to-firm product innovation	
	m.E.	St.D.	m.E.	St.D.	m.E.	St.D.	m.E.	St.D.
M1: All firms								
Age	-0.007	0.001 **	-0.013	0.002 **	-0.010	0.002 **	-0.006	0.002 **
Size	0.030	0.001 **	0.026	0.001 **	0.027	0.001 **	0.035	0.001 **
Human capital	0.009	0.007	0.040	0.007 **	0.120	0.006 **	0.114	0.008 **
Training expenditure[a)]	20.34	2.12 **	26.46	2.35 **	23.59	2.14 **	31.06	2.94 **
Marketing expenditure[a)]	2.193	0.554 **	1.55	0.637 *	7.52	0.583 **	9.30	0.840 **
Capital expenditure[a)]	0.493	0.100 **	0.656	0.110 **	0.035	0.109	0.395	0.140 **
Organisational innovat.	0.097	0.003 **	0.123	0.003 **	0.046	0.003 **	0.093	0.004 **
Rapid aging of products	0.007	0.004	0.013	0.004 **	0.026	0.004 **	0.032	0.005 **
Technological uncert.	0.009	0.003 **	0.020	0.004 **	0.012	0.003 **	0.014	0.004 **
Easy substitutability	0.005	0.003	-0.007	0.003 *	-0.032	0.003 **	-0.005	0.004
Threat from entrants	-0.006	0.003	-0.001	0.003	-0.008	0.003 *	-0.009	0.004 *
Uncert. ab. competitors	0.003	0.003	0.000	0.003	0.001	0.003	0.002	0.004
Uncert. about demand	-0.007	0.003 *	-0.009	0.003 *	-0.004	0.003	0.002	0.004
Competition fr. abroad	0.010	0.003 **	0.001	0.004	0.013	0.003 **	0.008	0.004
High price elasticity	0.000	0.003	0.000	0.004	-0.010	0.004 **	-0.003	0.004
No. of observations		75,989		74,499		76,216		75,228
No. of firms		24,646		24,446		24,771		24,560
Log likelihood		-22,196		-25,548		-21,159		-33,203
Wald Chi^2		3,960 **		4,632 **		3,846 **		6,163 **
M2: Innovative firms[1)]								
Innovation expenditure[a)]	0.261	0.074 **	0.167	0.094	0.460	0.094 **	0.201	0.098 *
Continuous R&D	0.050	0.006 **	0.064	0.007 **	0.135	0.006 **	0.146	0.007 **
Occasional R&D	0.034	0.006 **	0.039	0.006 **	0.074	0.007 **	0.078	0.007 **
Innovation co-operation	0.042	0.006 **	0.051	0.007 **	0.063	0.006 **	0.082	0.008 **
Public funding of innov.	0.047	0.007 **	0.080	0.007 **	0.081	0.007 **	0.118	0.008 **
No. of observations		33,558		32,529		33,225		32,635
No. of firms		14,000		13,753		13,996		13,863
Log likelihood		-13,202		-14,723		-12,751		-17,138
Wald Chi^2		2,168 **		2,327 **		2,867 **		3,889 **

1) These models include the same control variables as M1. - a) per employee (FTE)
All models include 15 year dummies, 23 sector dummies and a constant.
m.E.: marginal effect at means; St.D.: standard deviation; * / **: significant at the 0.05 / 0.01 level.
Source: Mannheim Innovation Panel

Table 14: Determinants of quantitative process and product innovation output with one year lag: results 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 only-new-to-firm product innovat.	
	m.E.	St.D.	m.E.	St.D.	m.E.	St.D.	m.E.	St.D.
M1: All firms								
Age	-0.011	0.002 **	-0.020	0.002 **	-0.026	0.003 **	-0.016	0.002 **
Size	0.022	0.001 **	0.009	0.002 **	0.029	0.002 **	0.027	0.002 **
Human capital	0.015	0.007 *	0.038	0.010 **	0.216	0.010 **	0.151	0.010 **
Training expenditure[a)]	20.07	2.16 **	33.51	3.01 **	34.22	3.23 **	32.73	3.24 **
Marketing expenditure[a)]	2.522	0.584 **	2.542	0.791 **	11.405	0.860 **	10.075	0.869 **
Capital expenditure[a)]	0.525	0.102 **	0.614	0.152 **	0.186	0.182	0.624	0.163 **
Organisational innovat.	0.095	0.003 **	0.131	0.004 **	0.072	0.004 **	0.104	0.004 **
Rapid aging of products	0.007	0.004	0.026	0.006 **	0.047	0.006 **	0.055	0.006 **
Technological uncert.	0.011	0.004 **	0.019	0.005 **	0.021	0.006 **	0.013	0.005 *
Easy substitutability	0.004	0.003	-0.014	0.005 **	-0.062	0.005 **	-0.008	0.005
Threat from entrants	-0.004	0.003	-0.002	0.005	-0.014	0.006 *	-0.012	0.005 *
Uncert. ab. competitors	0.006	0.003	0.007	0.005	0.003	0.005	0.000	0.005
Uncert. about demand	-0.009	0.003 **	0.000	0.005	-0.003	0.005	0.005	0.005
Competition fr. abroad	0.008	0.003 *	-0.003	0.005	0.026	0.006 **	0.014	0.005 *
High price elasticity	0.002	0.004	0.003	0.005	-0.018	0.006 **	-0.004	0.005
No. of observations		74,848		53,366		75,565		74,466
No. of firms		8,304		5,235		9,726		18,922
Log likelihood		-9,964		-7,873		-12,941		-23,739
Wald Chi^2		3,266 **		2,087 **		4,249 **		6,820 **
M2: Innovative firms[1)]								
Innovation expenditure[a)]	0.169	0.051 **	0.138	0.086	0.460	0.072 **	0.352	0.081 **
Continuous R&D	0.037	0.004 **	0.051	0.006 **	0.145	0.007 **	0.123	0.006 **
Occasional R&D	0.023	0.004 **	0.033	0.006 **	0.079	0.007 **	0.073	0.006 **
Innovation co-operation	0.024	0.004 **	0.019	0.005 **	0.057	0.006 **	0.054	0.006 **
Public funding of innov.	0.034	0.004 **	0.064	0.006 **	0.078	0.006 **	0.096	0.006 **
No. of observations		32,787		30,746		32,784		32,180
No. of firms		5,645		4,743		7,056		12,626
Log likelihood		-4,916		-5,526		-6,836		-10,981
Wald Chi^2		1,778 **		1,498 **		3,110		4,518 **

1) These models include the same control variables as M1. - a) per employee (FTE)
All models include 15 year dummies, 23 sector dummies and a constant.
m.E.: marginal effect at means; St.D.: standard deviation; * / **: significant at the 0.05 / 0.01 level.
Source: Mannheim Innovation Panel

Table 15: Determinants of quantitative process and product innovation output with one year lag: results 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 innovation			Sales share of only-new-to-firm product innovation		
	Coeff.	St.D.		Coeff.	St.D.		Coeff.	St.D.		Coeff.	St.D.	
Age	-0.002	0.001		-0.004	0.001	**	-0.009	0.003	**	0.645	0.126	**
Size	-0.002	0.001	**	-0.004	0.001	**	-0.008	0.001	**	0.045	0.005	**
Human capital	0.001	0.008		-0.007	0.006		0.060	0.013	**	1.921	0.793	*
Training expenditure[a)]	-0.244	1.956		2.072	1.852		0.501	3.484		-0.181	0.165	
Marketing expenditure[a)]	0.537	0.466		0.702	0.482		2.162	0.776	**	0.015	0.004	**
Capital expenditure[a)]	0.070	0.086		0.024	0.098		0.309	0.189		0.043	0.006	**
Organisational innovat.	0.005	0.003		0.012	0.002	**	0.005	0.004		-0.003	0.005	
Rapid aging of products	0.001	0.003		0.005	0.003		0.018	0.006	**	-0.007	0.004	
Technological uncert.	0.001	0.003		0.002	0.002		0.004	0.005		0.003	0.004	
Easy substitutability	0.001	0.002		-0.005	0.002	*	-0.028	0.004	**	-0.008	0.005	
Threat from entrants	0.003	0.002		-0.002	0.002		-0.001	0.005		-0.001	0.004	
Uncert. ab. competitors	0.002	0.003		0.005	0.002	*	0.006	0.005		0.007	0.004	
Uncert. about demand	-0.002	0.003		-0.002	0.002		-0.009	0.005		-0.010	0.004	*
Competition fr. abroad	-0.002	0.003		-0.001	0.002		0.006	0.005		0.008	0.009	
High price elasticity	0.000	0.003		-0.001	0.002		-0.016	0.005	**	-0.017	0.007	*
Innovation expenditure[a)]	0.142	0.053	**	0.203	0.081	*	0.352	0.228		0.015	0.005	**
Continuous R&D	0.012	0.003	**	0.009	0.003	**	0.029	0.005	**	0.016	0.005	**
Occasional R&D	0.002	0.003		0.005	0.003		0.002	0.005		0.036	0.006	**
Innovation co-operation	0.004	0.003		0.000	0.003		0.004	0.006		0.033	0.010	**
Public funding of innov.	0.014	0.003	**	0.015	0.003	**	0.024	0.006	**	-3.187	3.266	
No. of observations		6,370			7,403			7,073			13,711	
No. of firms		3,863			4,698			3,716			7,078	
R^2 adjusted		0.061			0.051			0.135			0.152	
Wald Chi^2		379.3	**		487.8	**		465.7	**		1617.4	**

a) per employee (FTE)
All models include 15 year dummies, 23 sector dummies and a constant.
Coeff.: estimated coefficient; St.D.: standard deviation; * / **: significant at the 0.05 / 0.01 level.
Source: Mannheim Innovation Panel

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