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Working Paper

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GLO Discussion Paper, No. 1443

Provided in Cooperation with:

Global Labor Organization (GLO)

Suggested Citation: Wadho, Waqar; Chaudhry, Azam (2024) : Measuring process innovation outputs and understanding their implications for firms and workers: Evidence from Pakistan., GLO Discussion Paper, No. 1443, Global Labor Organization (GLO), Essen

This Version is available at:

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Measuring process innovation outputs and understanding their implications for firms and workers: Evidence from Pakistan.*

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Abstract

New processes significantly affect firms and workers; however, due to a lack of quantitative indicators, our understanding of the measures, determinants, and impacts of new processes remains limited. Drawing on unique data from Pakistan, we analyzed five different measures of process innovation output: cost reductions, defect rate reductions, reductions in production cycle time, increases in production capacity, and improvement in product quality. We find that the breadth and depth of innovative capabilities, level of competition, and availability of market sources of knowledge are important inducers of process innovation and that smaller firms are more likely to introduce new processes and are better able to transform them into higher output. All five process innovation outputs are associated with higher labor productivity and higher sales. We do not find that adopting new processes led to labor displacement; however, there is suggestive evidence that new processes led to the increased employment of skilled workers.

Keywords: Technology; Innovation; Process innovation; Cost-reduction; Labor productivity; Developing countries; Textiles & Apparel; Pakistan.

JEL Classification: O31, O32, O33, J23, J24.

* We thank the Bureaus of Statistics of Punjab and Sindh, Matthew McCartney, Sajid Rasool, Kazim Jaferi, Muhammad Waseem and the participants of workshop ‘Innovation in the Pakistani Textiles Sector’, Oxford University. The authors acknowledge financial support for the survey and data collection from the GCRF Research England Fund (KCD00140-M301.01).

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Introduction

Technological progress drives productivity growth, which is critical for firms to remain competitive and for economies to achieve sustained growth. While economic theory suggests that technical change stems from the ability of firms to introduce new products and processes, the empirical literature on technological innovation has largely focused on new products, relegating process innovation to second-order innovative activity (Rammer, 2023). The limited literature on process innovation has used a simple dichotomous measure of process innovation (whether a firm introduces process innovation), which does not consider its significance (Hall, 2011). In the absence of output measures, our understanding of the factors that induce process innovation, and the impact of process innovation on firms and workers remains limited.

We aim to fill this gap by collecting and drawing on unique data from a sample of textiles and apparel manufacturers in Pakistan. First, we propose five different measures of process innovation output encompassing the cost reduction, production capacity, and quality improvement dimensions of the new processes: cost reductions, defect rate reductions, reductions in production cycle time, increases in production capacity, and improvement in product quality. Second, we explore the factors affecting a firm's decision to engage in process innovation and its ability to successfully transform it into innovation outputs. Finally, we explore whether these immediate economic returns translate into greater firm productivity and analyze their impact on workers at the firm level.

Our study contributes to the literature on the determinants and impact of innovation in several ways. First, it contributes to the scant literature on measuring process innovation output. The theoretical literature frequently focused on cost reductions as an important output of engaging in R&D (see Cohen and Klepper, 1996; Kamien et al. 1992; Levin and Reiss, 1988), and process innovation (Mairesse and Mohnen, 2010). For example, the Oslo Manual, which provides guidelines for the collection and interpretation of innovation data in Europe, introduced cost reduction measures as an output of process innovation (OECD, 2018). Similarly, a number of process innovation output indicators measuring quality improvement dimensions have been proposed in the lean management literature (Shah and Ward, 2003). However, apart from some isolated national efforts such as the German innovation survey (Peters and Rammer, 2013), a very

few quantitative measures of process innovation have been collected in innovation surveys. We contribute to this strand of literature by providing measures of five different outcomes of process innovation that encompass the cost reduction, quality improvement, and production capacity dimensions of new processes.

Second, not only there is a limited literature on the measurement of process innovation output, the available output measures of process innovation are rarely used in academic and policy research (Rammer, 2023). Thus, unlike product innovation, our knowledge of the factors that induce process innovation at the firm level is limited. Knowledge of the sources and means that enable firms to engage in process innovations and successfully implement them in their operations is important for understanding how firms gain and sustain competitive advantage, and for productivity-led economic development. From a policy perspective, a better understanding of the factors that induce process innovation would enable governments to better design targeted innovation policies. We contribute to this strand of literature by providing new evidence on the factors affecting a firm's decision to engage in process innovation and on the factors that enable firms to translate these processes into economic outcomes. In particular, we model a firm's decision to introduce new processes and its ability to translate them into direct outcomes as a function of a firm's internal resources (including its size and accumulated experience), the breadth and depth of its innovative activities, the market environment it faces (comprising the intensity and type of competition in the market), and the sources of knowledge spillovers.

Third, we provide evidence on whether newly introduced processes translate into higher productivity and the implications of these new processes for labor demand and the composition of the labor force. Since process innovations lead to cost reductions, quality improvements, and increased production capacity, they are expected to increase firm productivity. Since most existing studies use a dichotomous measure of whether a firm introduced new processes, not much is known about the productivity effects of these outcomes. This is one of the few studies to report the impact of process innovation outputs on labor productivity. Peining and Slage (2015) and Rammer (2023) are some of the other related studies that use two output measures of process innovation: cost reductions and share of innovative sales. However, none of these studies examined the impact of process innovation output on productivity and labor market outcomes.

While a positive impact of process innovation on labor productivity is expected, its labor market implications are more controversial. Process innovations are often associated with automation replacing labor, which results in job losses. However, existing evidence also reports the existence of countervailing economic forces that can compensate for job losses, such as price advantages and productivity mechanisms (Vivarelli, 2014; Vivarelli, 2007). Acemoglu and Restrepo (2019) proposes a ‘tasks based’ framework to understand both these aspects in a single framework. At the center of this framework is the allocation of tasks between capital and labor – the task content of production. Automation reallocates some of the production tasks to capital that were previously performed by labor. Thus, even as new processes raise productivity, they may reduce labor demand due to the displacement effect. On the other hand, this negative impact of automation could be counterbalanced by the creation of new tasks in which labor has a comparative advantage—the reinstatement effect.

We contribute to this strand of literature by testing the employment implications of process innovations in a developing country context. We leverage the availability of data on multiple outcomes of process innovation to test whether any of the process outputs leads to lower employment at the firm level. Furthermore, we test for within-firm reinstatement effects by evaluating the skill composition of workers in firms that introduced new processes versus those that did not.

Finally, we contribute to the growing literature on innovation and productivity in developing countries and in labor-intensive, traditional manufacturing sectors. Our analysis is based on data from a unique innovation survey of Pakistani textile and apparel manufacturers. Pakistan is representative of a larger group of developing economies that are understudied in the literature on innovation and firm performance. Textile and apparel manufacturing is a traditional supplier-dominated sector, in which the main focus of technological activities is to reduce costs and expand the range of designs for a niche market. The main channel for technological change is the purchase of new machinery and materials. The textile sector is also the most important manufacturing sector in the Pakistani context, accounting for one-fourth of the industrial value added, employing about 40 percent of the industrial labor force, and constituting more than half of national exports.

Moreover, being very labor-intensive, textiles have the potential to contribute to wider social changes by providing employment opportunities for the growing labor force, including women and young workers. Results in this paper complement Wadho and Chaudhry (2018) who looked at product innovation and its impact on productivity, Wadho et al., (2019) who studied the role of innovation in firm growth, by providing the evidence that process innovation contributes significantly to the labor productivity in Pakistan.

We find that process innovation is the main source of technological progress in the Pakistani textile manufacturing sector and that firms achieve immediate economic returns in the form of reduced costs, improvements in product quality, lower defect rates, and enhanced production capacity. We also find that a firm's innovative capabilities in terms of its range of innovative activities and the amount of resources devoted to these activities are the main inducers of process innovation, along with the level of competition and the availability of market sources of knowledge. We also find that all five process innovation outputs lead to higher labor productivity; however, there is considerable heterogeneity in the size of these impacts. We did not find any labor displacement effects of the newly adopted processes, but they were associated with increased employment of skilled workers.

The remainder of this paper is organized as follows. In the next section, we review relevant literature. In section three, we discuss our innovation survey, provide summary statistics, and discuss our model and estimation techniques. In section four we discuss the results. Finally, we conclude in section five.

Literature Review

Measuring Process Innovation Output

Process innovation is broadly defined as the introduction of new or significantly improved methods of production, or new or significantly improved logistics, or new or significantly improved supporting activities for processes (OECD, 2018). While there is burgeoning theoretical literature on the importance of process innovation, empirical analyses of the sources and impact of process innovation have been significantly limited by the lack of data that specifically measures process

innovation output. Empirical research on process innovation has mainly focused on a simple binary indicator of whether a firm has introduced process innovation in a given period (Wadho and Chaudhry, 2022; Roper et al., 2008; Griffith et al., 2006; Mairesse et al., 2005).

The theoretical literature on technological progress has tended to take a dichotomous approach to the impacts of product and process innovations, where product innovations are associated with higher product quality, and process innovations are associated with cost reductions. Thus, process innovation is seen as a type of innovation that reduces costs per unit of output but leaves the product characteristics unchanged (Mantovani, 2006; Adner and Levinthal, 2001). In the product life cycle model (Cohen and Klepper, 1996), the initial stages of the technology life cycle are characterized by competition over innovative products. The number of new products, however, stabilizes after some time, and firms gain a competitive advantage by lowering costs through process innovation; hence, cost-reducing process innovation becomes the dominant mode of innovation. These cost-reduction outcomes of process innovation can be measured directly as the change in the costs per unit of output produced. The Oslo Manual (OECD, 2018), which provides guidelines for measuring innovation and conducting innovation surveys in Europe, proposes cost reduction as an outcome of process innovation. Innovation surveys in Germany (Peters and Rammer, 2013), and Switzerland (Bolli et al., 2018) use this metric as an outcome of process innovation.

In practice, there is no clear dichotomy between product and process innovations. Innovation in production methods has significant implications for product characteristics. New production methods can change product characteristics through production flexibility, enabling firms to quickly adjust product specifications to changing consumer demand (Robin and Schubert, 2013). For example, flexible production systems, such as automated tailoring machines, can create almost any design on demand in apparel manufacturing, which allows the production of customer-specific garments.

Several other metrics measuring the quality aspects of processes have been developed under the frameworks of ISO certification, lean management, and total quality management (Shah and Ward, 2003; Arnheiter and Maleyeff, 2005). These metrics quantify the impacts of processes for various

dimensions of product and process outcomes, such as the quality of process output (i.e., defect rates and accuracy rates), timeliness of a process (i.e., production cycle time and on-time delivery), and complexity of a process (i.e., number of steps).

Clearly, the outcomes resulting from process innovations go beyond simple cost reductions. At the same time, this multiplicity of outcomes may be one of the reasons for the lack of quantitative output measures and the limited use of the data collected on process innovation. For example, most of these metrics are well suited to the manufacturing sector but less so for the services sector. Some waves of the Community Innovation Surveys in Europe contained questions on process innovation output on a Likert scale for outcomes such as cost reduction, increase in flexibility, and increase in capacity (see Robin and Schubert, 2013), while others, such as the innovation survey in Germany, used the change in sales that could be attributed to quality improvements resulting from process innovation as a single measure for quantifying quality-related process innovation output (Rammer, 2023).

Determinants of Process Innovation

As researchers better understand the nature of process innovation, there is also a growing understanding of firm-level factors that foster process innovation. Many studies stress the importance of a firm's internal resources, including size and age, as important determinants of process innovation. Larger firms have greater resources, which may enable them to develop new processes in their existing production structures as well as invest in new technologies that require new processes. The product life cycle model (Klepper, 1996; 1997; Cohen and Klepper, 1996) proposes that while firms compete on new products in the initial stages, process innovation becomes the dominant form of innovation in the later stages of the industry life cycle when the market is highly concentrated. In many cases, this implies that larger, more developed firms engage in more process innovation. Empirical studies on the determinants of process innovation have reported a positive association between firm size and process innovation (Rammer, 2023; Griffith et al., 2006; Reichstein and Salter, 2006; Baldwin et al., 2002).

Firm-level heterogeneities in process innovation can also be the result of their distinctive capabilities, which allow certain firms to make better use of their resources. These dynamic

capabilities enable firms to improve their operational capabilities, such as logistics, marketing, and manufacturing, leading to improved firm outcomes (Helfat and Winter, 2011; Zahra et al., 2006). Accordingly, by engaging in a broad range of activities such as in-house R&D, external R&D, acquisition of external knowledge, training workers for innovative activities, and market research, firms develop innovative capabilities that increase the likelihood of innovating (Piening and Salge, 2015; Cohen and Levinthal, 1990). Heterogeneity may exist across firms not only in terms of the range of these types of activities but also in their intensities. Thus, the extent of the current investment in tangible and intangible assets can be important for leveraging innovative capabilities (Rammer, 2023). The nature and depth of firms' R&D activities are also important for inducing innovation in industrial organization literature (Pisano, 1994).

Empirical studies on process innovation have generally reported a positive relationship between innovation expenditure (Wadho and Chaudhry, 2022; Rammer, 2023), R&D intensity (Griffith et al., 2006; Reichstein and Salter, 2006; Mairesse and Mohnen, 2005; Baldwin et al., 2002), and process innovation. Rouvinen (2002), however, did not find a relationship between firm level R&D and process innovation. Regarding the breadth of innovative activities, Piening and Salge (2015) report a positive association with process innovation up to a certain level, after which further expansion in the variety of innovative activities has a negative impact on process innovation.

The traditional industrial organization literature as well as product life cycle models stress the importance of the industrial context in shaping the type (i.e., product vs. process innovation) and rate of innovation (Flach and Irlacher, 2018; Weiss, 2003; Klepper, 1997; Cohen and Klepper, 1996). Weiss (2003) proposes that the choice between product and process innovation depends on product differentiation and competition in an industry: firms would favor process innovation when products are less differentiated and there is less competition in the industry. Flach and Irlacher's (2018) theoretical model shows that firms in homogeneous industries obtain lower returns from investing in new products and higher returns from new processes. On the other hand, the technological life cycle model (Klepper, 1997; Cohen and Klepper, 1996) proposes that in the later stages of the industrial life cycle, competition is intense, and firms focus on process innovations.

The empirical work of Rammer (2023) shows that competition, proxied by the number of competitors, has a negative impact on the propensity to introduce cost-reducing process innovations and quality-improving process innovations as well as on the quantitative outcomes of cost reduction. However, firms facing competition from abroad are more likely to introduce new processes, quality-improving processes, and achieve higher cost reductions. Baldwin et al. (2002) report that in a sample of Canadian firms, competition at the intermediate level is most conducive to process innovation. However, Wadho and Chaudhry (2022) found no significant impact of local or foreign competition on a firm's propensity to introduce new processes.

Finally, an essential part of the innovation process involves searching for information and knowledge sources, and a firm's innovation performance critically depends on its ability to exploit external knowledge (Cohen and Levinthal, 1990). While broadly defined external sources of innovation have been found to be important for a firm's innovativeness, specific sources of external information for process innovation have not been studied carefully. While empirical studies have found that upstream knowledge sources such as suppliers are important for process innovation (Reichstein and Salter, 2006; Griffith et al., 2006; Rouvinen, 2002), the importance of customers as important sources of information has primarily focused on product innovation (see Wadho and Chaudhry, 2018; Griffith et al., 2006) and not on process innovation. Wadho and Chaudhry (2022) found that customers are an important source of new processes, and Reichstein and Salter (2006) found that using customers as a source of knowledge decreases the probability of being a process innovator. Griffith et al. (2006) also found competitors to be an important source of knowledge for process innovation in France and Spain. Overall, there seems to be little consensus on the importance of external sources of innovation in process innovation.

To sum up, we would expect a firm's internal resources, innovative capabilities, market environment, and external sources of knowledge to be important determinants of its decision to engage in process innovation as well as to translate these innovations into process outcomes.

Process Innovation and Productivity

New processes aimed at reducing costs and improving efficiency are expected to increase productivity. Besides their direct impact, new processes could also result in indirect positive

impacts when they result in improved product quality and/or substantial price reductions, which give rise to economies of scale and/or competitive advantages. For example, in the ‘tasks based’ framework of Acemoglu and Restrepo (2019), substituting labor with capital in the tasks where the capital is more efficient would improve efficiency and enhance productivity.

Existing empirical literature uses a binary variable construct for process innovation, and the reported impact varies significantly. Mairesse et al. (2005) find that firms engaging in process innovation in France experience higher productivity. These returns are even higher than those for product innovation. Similar findings were reported by Wadho and Chaudhry (2022) in the context of Pakistani manufacturers and by Parisi et al. (2006) in the case of Italy. On the other hand, in a cross-country comparison study, Griffith et al. (2006) found a positive impact of process innovation on labor productivity only in the case of France and not in the case of Germany, Spain, and the UK. Similarly, Roper et al. (2008) found no significant impact of process innovation in Ireland. In the case of the Netherlands, Polder et al. (2009) find no significant impact of process innovation, although they find a positive impact when process innovation is accompanied by organizational innovation. And in the case of Spain, Jaumandreu and Mairesse (2017) report process innovation resulting in a reduction in marginal cost and improved productivity in some of the specifications.

The existing empirical research on the impact of process innovation on productivity is greatly constrained by the lack of quantitative output measures of process innovation. For example, Hall (2011) concludes that in the case of product innovation, where quantitative measures such as innovative sales are used, the reported impacts of product innovation on productivity and firm performance are better aligned with theoretical predictions and are more homogenous across different studies. In summary, we expect that new processes (measured as quantitative outcomes) will have a positive and significant impact on labor productivity.

Process Innovation and Labor Outcomes

The implications of technological progress on the labor market have long been a subject of debate. While product innovation leads to the creation of new products that are generally associated with greater levels of employment (although new products may displace older products, making the

direction of the impact more ambiguous), process innovation is often associated with labor displacement. For example, the declining share of labor in the manufacturing sector has long been associated with technological changes.

While the direct impact of process innovation on employment can be negative, new processes often lead to lower average costs, improved production capacity, and product quality, which may trigger various compensating mechanisms. Cost savings in competitive industries could translate into lower prices, leading to higher demand, output, and employment. Cost savings, if not entirely passed through lower prices, could lead to extra profits, and if these extra profits are re-invested, can lead to new jobs (see Vivarelli (2007) for a survey). Similarly, when new processes lead to better-quality products and enhanced production capacity, firms can increase their production and employ more workers.

In the ‘tasks based’ framework of Acemoglu and Restrepo (2019), production requires completion of a range of tasks that could be performed by human labor or machines (capital). Process innovation enables machines to perform tasks previously performed by labor. For example, the production of a typical shirt involves several tasks ranging from design to spinning, weaving, knitting, dyeing, and processing. New processes may lead to labor displacement by introducing machines to perform some of the tasks that were performed by labor. However, the set of tasks involved in production is not static, and the creation of new tasks can be an important new source of employment, what they term as the ‘re-instatement effect.’ Acemoglu and Restrepo (2019) highlight computerized designs, new methods of market research, and various managerial activities for better targeting demand and cost-saving as some of the new tasks in the textile sector that could create new employment opportunities for labor. Moreover, even though these new tasks are labor-intensive in nature, they require a different and more often a higher set of skills.

The empirical evidence on the impact of process innovation on employment is also mixed: Calvino (2019), Lachenmaier and Rottmann (2011), Evangelista and Lauterbach (2008), Harrison et al. (2014) and Triguero et al. (2014) find a positive impact of process innovation on employment while Benavente and Lauterbach (2008) and Crespi et al. (2019) find no significant impact. In

contrast, Vivarelli et al. (1996) and Pellegrino et al. (2019) found that process innovation tends to displace labor.

Again, the lack of quantitative data on process innovation hinders quantification of its impact in these studies. We expect that process innovation outcomes may not lead to lower employment at the firm level because of the presence of various compensation mechanisms. Moreover, the presence of compensation mechanisms implies that process innovation leads to higher production (sales). In line with the ‘task based’ framework, we expect process innovation to be associated with greater employment of skilled workers.

Data and Model

Data and survey

In 2019, we surveyed a stratified random sample of 377 textile and apparel manufacturers from the Punjab and Sindh provinces of Pakistan.¹ The sample was based on an earlier project in 2015, which surveyed a stratified random sample of 614 manufacturers (Wadho et al. 2019). This frame included all firms with a minimum of 10 employees classified under Sections 13 and 14 of the Pakistan Standard Industrial Classification, PSIC 2010 (International Standard Industrial Classification (ISIC) 17 and 18). The sample was stratified based on the geographic location of firms and a stratified random sample representative was drawn, first at the provincial level and then at the district/regional level.² The survey was conducted in 2019 through face-to-face interviews with a knowledgeable person designated by firms at the managerial level or above. Interviews were conducted by well-trained officials of the Bureau of Statistics of the Punjab and Sindh Governments.

The survey instrument was designed based on the Oslo Manual (OECD 2018) and its recommendations for developing countries. While the core questions related to innovation were similar to those used in the European Community Innovation Surveys (CIS), we added additional

¹ The total population of manufacturers of textiles and apparel in Pakistan is approximately 4,380 units, of which 96 percent (4,205 units) are located in two provinces, Punjab and Sindh.

² Of the 377 old sample, 50 firms did not exist at the time of the survey. These firms were replaced with an additional 50 firms drawn from the original frame at their respective locations.

modules on process innovation outcomes and competition. The survey asked whether process innovation resulted in cost reductions, the types of costs reduced, and the magnitude of these cost reductions. Second, the survey asked whether process innovation led to improvements in product quality and what was the share of turnover due to these improved quality products. Third, the survey asked whether process innovations resulted in a reduction in defect rates and how much. Fourth, the survey asked whether process innovations led to a reduction in production cycle time and by how much. Fifth, the survey asked whether process innovations resulted in an increase in production capacity, and by how much.

The preliminary results from our survey show that firms engaged in process innovation and achieved a variety of process innovation-related outcomes. Table 1 reports the summary statistics for process innovation and its outcomes, firm size differences between small, medium, and large enterprises, and sectoral differences between the textile and apparel sectors. Overall, 41 percent of the sampled firms reported that they introduced process innovations during the three years 2016-18. Twenty-four percent of enterprises reported achieving cost reductions, 29 percent reported achieving reductions in defect rates, 26 percent reported reductions in the production cycle time, 34 percent reported increased production capacity, and 34 percent reported improvements in their product quality due to process innovation.

[Table.1 about here](#)

There are noticeable differences between small, medium, and large enterprises. On average, large firms have higher rates (more than three times that of small firms) of all types of process innovation, followed by medium-sized enterprises, which implies a positive association between firm size and the propensity to introduce new processes. There are also sectoral differences between the textile and apparel sectors: on average, more firms in the apparel sector engage in all types of process innovation.

The firms that achieved cost reductions as a result of process innovations were further asked about the types of cost reduction achieved and the size of the cost reductions in percentage terms. Figure 1 reports the average cost reduction for the sub-sample of firms that achieved cost reductions. On average, firms reporting cost reductions experienced about a 10 percent reduction in their total costs. On average, these firms reported a 6 percent reduction in labor, energy, materials, and

logistics costs due to process innovation, and about a 5 percent reduction in costs related to equipment.

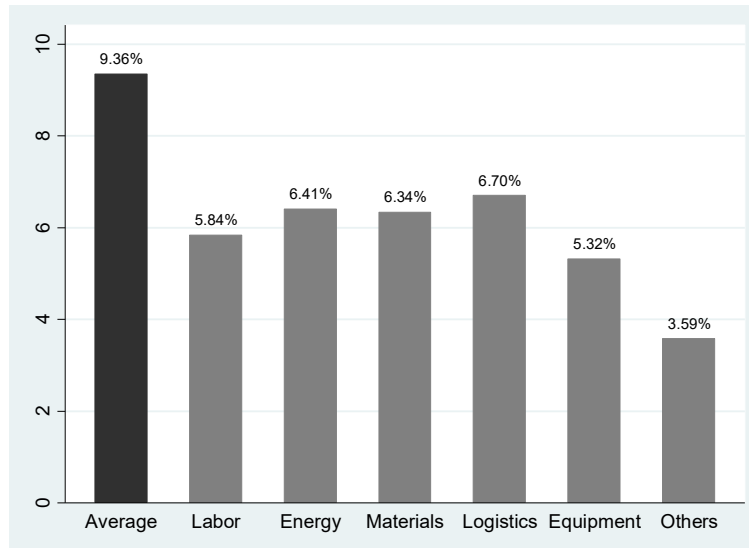


Figure 1. Percentage cost reduction, by type

Since process innovations are frequently associated with labor saving and labor displacement impacts, firms were asked about the implications of new processes for labor in terms of changes in labor and skill requirements due to process innovation. A significant proportion of firms (47 percent) reported no changes in labor requirements, and an almost equal number of firms reported a decrease and increase in labor requirements (27 and 26 percent, respectively). However, the majority of the firms reported increased skill requirements (55 percent) due to process innovation; 36 percent reported no changes in the skill requirement, whereas around 9 percent of the firms reported a decrease in the skill requirement.³

Model specification

We run three types of regressions⁴: (i) models on a firm's propensity to introduce new processes and product quality improving processes; (ii) models on the output of new processes: increases in sales due to quality improvement, percentage reductions in costs, percentage reductions in defect

³ The skill requirement is a subjective judgement of the respondent, and this should be viewed in that context.

⁴ The model is similar to the reduced form model proposed by Crépon et al., (1998).

rates, percentage reductions in production cycle time, and percentage increases in production capacity; and (iii) models on the impact of new processes on measures of firm performance: labor productivity, sales, and employment.

In order to examine a firm's propensity to introduce different types of processes and the resulting output of these new processes, we employ Heckman's two step selection model (Heckman, 1979), which explicitly corrects for selection bias.⁵ The basic structure of the model is as follows: Let g_i^* be an unobserved decision variable for a firm's process innovation and k_i^* the unobserved level of a firm's process innovation output, with g_i and k_i being their observable counterparts. The first stage comprising two equations can be defined as follows:

$$g_i = \beta_0 x_{0i} + \mu_{0i} \quad (1)$$

$$g_i = 1, \text{ if } g_i^* > 0, \text{ otherwise } g_i = 0$$

and

$$k_i | g_i > 0 = \beta_1 x_{1i} + \mu_{1i} \quad (2)$$

$$k_i = k_i, \text{ if } k_i^* > 0, \text{ otherwise } k_i = 0$$

where x_{0i} and x_{1i} are vectors of independent variables; β_0 and β_1 are vectors of unknown parameters to be estimated reflecting the impacts of various factors on the probability of introducing new processes and the output of these new processes, respectively; and μ_{0i} and μ_{1i} are random error terms with mean zero, constant variances and are uncorrelated with the explanatory variables but are correlated with each other. The first equation models the probability that a firm introduces new processes and is specified as a Probit model. The second equation describes the output of the process innovation, conditional on introducing new processes. We run two sets of models by changing the type of process innovation and its respective output. In the first set, the decision variable is process innovation and the output variable is (i) percentage reduction in total unit cost from process innovations or (ii) percentage reduction in defect rates from process innovations, or (iii) percentage reduction in production cycle time from process innovations, or (iv) percentage

⁵ Selection bias arises in innovation surveys since only a subset of firms engages in innovation activities, and many survey questions are directed to only this subset of firms.

increase in production capacity from process innovations. In the second set, the decision variable is product quality improving process innovation and the output variable is the share of sales due to improved quality products.

The third equation models firm performance, proxied by labor productivity⁶, as a function of the output of process innovation and a number of control variables that include other common productivity-enhancing factors, such as product innovation, innovation activities, human capital, and firm size:

$$q_i = \alpha_1 k_i + \beta_2 x_{2i} + \mu_{2i} \quad (3)$$

where q_i is labor productivity; k_i is the output of process innovation; x_{2i} is a vector of other explanatory variables and controls with β_2 their corresponding coefficient vector; and μ_{2i} is the random error term with mean zero and constant variance uncorrelated with the explanatory variables. This model was estimated using OLS only for the group of firms that introduced process innovation (Model 1). We ran five sets of estimations using five different outputs of process innovation. Alternatively, we use an instrumental variable (IV) approach in which predicted values of outputs from equation (2) are used as an instrument for process innovation output and estimate the OLS for the entire sample (Model 2). The use of the predicted values instead of actual values corrects for some of the endogeneity in the relationship between process innovation output and firm performance.

In the first stage (equations 1 and 2), we test four groups of process innovation-inducing factors that affect a firm's decision to introduce new processes and their intensity (output). Internal resources: Firm size and accumulated experience (age). Innovative capabilities: The breadth and depth of innovative activities. Innovative breadth represents the range of a firm's innovative activities, including in-house R&D; external R&D; acquisition of machinery, equipment, and software; acquisition of external knowledge; training workers for innovative activities; market introduction of innovations; and others (including design). Whereas innovative depth includes the amount of resources devoted to these activities. Market environment: comprising intensity

⁶ Unfortunately, we do not have a good proxy for physical capital. We did ask information about physical capital in our survey, but the number of responding firms to this question was small.

(extreme competition) and type (foreign competition) of competition in the market. Market sources of knowledge: comprising suppliers, clients, competitors, and their origin (foreign vs. local). To identify the Heckman model, we impose an exclusion restriction by including a lack of funds (i.e., whether a firm considers a lack of funds as a highly important factor constraining its decision to engage in technological innovation) in the selection equation and excluding it from the outcome equation. Additionally, we control for sector- and location-specific effects by including the sector and location dummies.

Table 2 provides an overview of the definitions of all variables used in the regressions and presents their summary statistics.

[Table. 2 about here](#)

Results

Propensity to introduce new processes and its output

Table 3 presents the results of the first stage of the regression, in which we explore the factors that affect a firm's decision to introduce new processes and their outcomes. Column 1 shows the results with the probability of introducing new processes (Process) as the selection equation and columns 4-7 show the outcomes estimated separately for each outcome. Column 2 shows the results with the probability of introducing product quality-improving processes (quality improvement), and column 3 shows the outcome of these quality-improving processes.

[Table. 3 about here](#)

The results in Table 3 show that smaller firms are more likely to introduce new processes, as well as product quality-improving processes. This contrasts with a general resource-based view, in which resource-rich larger firms tend to be more innovative. However, this is not counterintuitive given that the main channel through which resource-rich larger firms may outperform smaller firms is their superior innovative capabilities (Cohen and Klepper, 1996), which we explicitly accounted for in our estimations.⁷ Indeed, firms that engage in more innovative activities (higher breadth) and with a higher intensity of investment in these activities (higher depth) are more likely to introduce new processes as well as new quality-improving processes. This result shows the

⁷ We also ran a separate set of regressions by excluding the two innovative capabilities variables. The results confirm a positive firm size effect.

importance of innovative capabilities, both in terms of the range of activities and the resources devoted to these activities, as the key determinants of a firm's decision to introduce new processes.

The competition environment in which a firm operates shows differing results for intensity and type of competitor. Firms facing intensive competition are more likely to introduce new processes as well as new product quality-improving processes; however, firms facing competition from abroad are not more likely to introduce new processes or quality-improving processes. The latter result supports the product life cycle view, in which intense competition in product markets results in firms introducing new processes to gain and retain competitiveness.

Our results also support the notion that market sources of knowledge and information are important drivers of process innovation. However, there are some important differences that distinguish their effectiveness in process innovation versus quality-improving processes. We find that using foreign customers as a source of knowledge increases the probability of being process innovators and quality-improving process innovators. However, local customers have no significant impact on the probability of a firm being an innovator. Foreign customers are the only knowledge source that significantly increases a firm's probability of introducing new processes. In the local context of textiles and apparel manufacturers, foreign customers more often order in bulk, have better knowledge about the technologies and processes used in other supplier countries, and more often require a certain level of precision and quality standards that individually and/or collectively require local firms to improve and upgrade their processes. On the other hand, apart from foreign customers, having local suppliers and competitors as a source of knowledge increases a firm's probability of introducing quality improvement processes. This reflects the type of knowledge flow that firms receive from different market sources. Information about improved processes that enhance product quality seems to diffuse directly from its source, that is, the producer or through a local supplier who might be a supplier to multiple local producers.

However, as opposed to using local suppliers, we found that using foreign suppliers as a source of knowledge decreases the probability of being a quality-improving process innovator. This result does not necessarily mean that information from foreign suppliers reduces the ability of firms to innovate, but that this type of information might reduce incentives for firms to improve the quality

of their existing products. In fact, the results in Wadho and Chaudhry (2018) from the same sector show that having foreign suppliers as a source of knowledge increases a firm's probability of engaging in innovation activities, that is, investing resources in innovative activities.

The results in Table 3 also reveal a few differences between the propensity to be a process innovator and its intensity in terms of output as well as in terms of different types of outcomes. Smaller firms are not only more likely to introduce new processes but are also better at translating these processes into higher efficiency. Conditional on new processes, smaller firms achieve higher reductions in defect rates, higher reductions in the production cycle time, and a greater increase in production capacity. On the other hand, although larger firms are less likely to introduce quality improving processes, they are better at translating these improvements into higher sales volumes. Similarly, even though a firm's age has no significant impact on its propensity to introduce new processes, older firms are better at translating new processes into higher reductions in defect rate and translating quality-improving processes into higher sales volumes.

A greater breadth of innovative activities also translates into reduced production cycle times and increased production capacity, leading to higher sales volumes or lower costs and defect rates. On the other hand, firms with greater depth of innovative activities are better at translating quality-improving processes into higher sales volumes, but it has no significant implications for other outcomes. Regarding the competitive environment, the intensity of competition affects firms' propensity to innovate; however, firms with competition from abroad are better at translating new processes into higher reductions in costs and production cycle time, and higher production capacity and quality-improving processes into higher sales volumes.

Firms using customers as a source of knowledge are better at translating new processes into higher reductions in costs (local clients) and defect rates (foreign clients), and are better at translating quality improving processes into higher sales volumes (local clients). Local suppliers are not only important sources of knowledge for the introduction of new processes and quality improvement of new processes, but they also help firms translate these new processes into higher reductions in defect rates and production cycle times, and into higher sales volumes due to quality improvements. On the other hand, firms that use foreign suppliers as a source of knowledge are

not only less likely to introduce quality improving processes, but those that introduce these processes end up translating them into lower sales volumes.

Firm performance

Table 4 presents the results of the second stage of the regressions, where we explore whether process innovation outputs translate into improved firm performance. We do so by regressing labor productivity separately on each of the five indicators of process innovation output and other controls that are widely used as productivity inducers.⁸ We estimated two different sets of models. Model 1 is estimated using OLS only for the innovative sample, that is, the group of firms that introduced process innovation. In Model 2, we used an instrumental variable (IV) approach in which the predicted values of outputs from the outcome equations of the first stage were used as an instrument for process innovation output, and this was estimated using OLS for the entire sample.

[Table. 4 about here](#)

The results in Table 4 show that all outputs of process innovation lead to higher labor productivity, which holds true for both model specifications. However, the coefficients are relatively larger for the estimations using the predicted values (Model 2) of the outcome than for the actual values (Model 1). A 10 percent increase in innovative sales is associated with a 1 percent increase in labor productivity. This finding suggests that the quality improvement aspects of process innovation are important for enhancing firm productivity. Among the other outcomes, cost reduction has the strongest effect on labor productivity, followed by increase in production capacity. Each 1 percent reduction in costs is associated with a 6 percent increase in labor productivity, and a 1 percent increase in production capacity is associated with a 3 percent increase in labor productivity. Similarly, an additional 1 percent reduction in the production cycle time and defect rates is associated with a 2 percent and 1 percent increase in labor productivity, respectively.

⁸ Unfortunately, we could not test the impact of process innovation on firm profits because of data limitations. Thirty-seven firms in our sample did not respond to profit-related questions. Posterior data analyses showed that the non-responding firms were not a random sample but the firms located in the city of Karachi (35 out of 37) and firms that are medium- and large-sized. From the field, we suspect that respondents might hide or manipulate the profit number. Firms in Pakistan are often reluctant to reveal their profits due to tax considerations, as well as in some areas due to the fear of extortion.

New processes are often associated with higher efficiency in terms of producing the same amount of output with less input, that is, saving on labor. However, countervailing market compensation mechanisms may also exist, which can influence the labor-saving impact of new processes. For example, new processes lead to cost reduction, and in relatively competitive industries, this translates into lower prices, which in turn leads to higher demand, more output, and more employment. Similarly, when firms compete on relatively similar products, quality-improving processes can lead to higher demand, resulting in more output and employment.

In the following set of estimations, we explore the implications of new processes by regressing employment and turnover separately on process innovation outputs and other controls. Table 5 presents the results.

[Table. 5 about here](#)

The results in Table 5 show that process innovation leads to higher turnover, which is true for all process outcomes, suggesting the existence of market mechanisms that lead to higher output due to process innovation. Moreover, there is also suggestive evidence of counterbalancing the labor-saving impacts of new processes. We do not find a significant negative effect of new processes on employment levels; in fact, in the case of quality-improving processes and the production capacity increasing new processes, our results show a positive effect of process innovation on employment. These findings are in line with managers' assessment of the labor demand implications of the new processes, as reported in Section 2. Almost half of the process innovators did not report changes in the labor requirement, whereas from the other half, an almost equal number of innovators reported an increase and a decrease in labor demand.

We could also understand these implications of new processes through the lenses of 'tasks based' framework (Acemoglu and Restrepo, 2019) by looking at the displacement effect and the reinstatement effect of new processes. Our results in Table 5 do not support the presence of a net displacement effect (no significant negative effect of process innovation on employment), which may suggest that the displacement effect is counterbalanced by the creation of new labor-intensive tasks within the enterprise. However, the presence of the reinstatement effect requires evidence of the creation of new tasks within the enterprise. Since we do not have information about the total tasks and their distribution between labor and capital in our sample, we approach it indirectly by

looking at the share of skilled workers in total employment and its correlation with process innovation. In this case, the reinstatement effect implies that process innovators employ more skilled workers.

In Table 6, we regress the share of skilled workers on process innovation and control for new products as well as industry and location effects. The skill level of workers is proxied by whether they have a university degree or technical diploma certification. The share is defined as the percentage of employees with a university degree in 2018 in the first column and the percentage of employees with a technical diploma certification in 2018 in the second column.

[Table. 6 about here](#)

The results in Table 6 show that firms that introduced new processes between 2016-18 employed a higher share of employees with university degrees as well as a higher share of workers with technical diploma certifications in 2018. The coefficients are relatively larger for new quality-enhancing processes. This is again in line with managers' assessment of the skill requirements implications of new processes, as reported in Section 2. Many managers reported that new processes led to increased skill requirements.⁹ Combining this with the results in Tables 4 and 5, we find suggestive evidence of the reinstatement effect, that is, process innovation leads to higher productivity and higher sales with no significant negative effect on employment and more employment of skilled workers.

Conclusions

While the theory recognizes the importance of both product and process innovation as firms strive for productivity growth, the focus of the empirical literature has been on product innovation. This study contributes to the scant literature on process innovation output by analyzing the decision of firms to introduce new processes and the ability of the firm to translate newly introduced processes into direct outcomes. We also analyze how the newly introduced processes translate into higher productivity and impact labor demand and the composition of the labor force.

⁹ We are aware of the issue of reverse causation, in which a higher share of skilled workers could lead to higher innovation. However, we do see that this was not the case when we looked at the new products when skill was measured by university degree (columns 2 and 3). Nevertheless, this is suggestive evidence that should be interpreted as a positive correlation.

Our results show that process innovation is the main source of technological progress in the Pakistani textile manufacturing sector and that this innovation leads to reduced costs, improved product quality, lower defect rates, and enhanced production capacity. We also find that process innovation depends on the range of innovative activities pursued by firms, the level of resources devoted to these activities, the level of competition faced by firms, and the availability of market sources of knowledge.

We also examine how process innovation outcomes impact productivity and the amount of labor employed. Labor outcomes are important because process innovation has long been associated with increased use of technology, which is assumed to displace labor. More recently, the literature has developed a more nuanced approach, where process innovation may lead to labor displacement as some tasks are taken away from labor and performed by machines, but at the same time, innovation may lead to new tasks that require additional labor. Moreover, new tasks may require a higher set of skills.

We find that all five process innovation outcomes lead to higher labor productivity, although there is considerable heterogeneity in the size of these impacts. In terms of labor outcomes, we did not find any labor displacement effects of the newly adopted processes, but they were associated with increased employment of skilled workers. This implies that process innovation in the Pakistani textile sector does not change net employment but does lead to a shift towards more skilled labor.

This study extends the discussion on process innovation by examining a variety of new innovation outputs and analyzing the determinants and impacts of these outputs. The study also adds to the limited literature on innovation in developing countries, and its results are important for both academics and policymakers as they develop initiatives to promote innovation and foster technological growth.

Finally, we are aware of the limitations of the study, which are largely related to the cross-sectional nature of the data, limiting our ability to establish strong causal relations. Nevertheless, we believe that the sample is unique in two ways: first, in terms of homogeneity of firms and second, in terms

of the development of the data set, which was the result of a significant collection effort involving a wide range of stakeholders. Although this study focuses on one country, we feel that many of its conclusions are applicable to other countries because it analyzes a sector characterized by low technology and greater labor intensity, which are common characteristics of many developing country firms.

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Table 1: Descriptive statistics

	<i>Sample</i>	<i>Process Innovation</i>	<i>Costs reduction</i>	<i>Defect rate reduction</i>	<i>Production cycle time</i>	<i>Production Capacity</i>	<i>Quality Improvement</i>
Total	377	41%	24%	29%	26%	34%	34%
Small	178	23%	10%	15%	15%	17%	18%
Medium	116	48%	29%	31%	30%	39%	37%
Large	83	69%	46%	54%	46%	61%	65%
Textiles	313	38%	21%	25%	23%	30%	31%
Apparel	64	55%	36%	48%	44%	53%	52%

Table 2. Description and summary statistics of the variables

Variable	Definition	Obs	Mean (St. Dev.)	Min/ Max
Process innovation	1 if firm introduced new/significantly improved methods of manufacturing, or new/significantly improved logistics, delivery or distribution methods, or new/significantly improved supporting activities for processes in 2016-18, 0 otherwise	377	0.41 (0.49)	0/1
Quality improvement	1 if firm introduced product quality improving process innovation in 2016-18, 0 otherwise.	377	0.34 (0.48)	0/1
Innovative sales	Total turnover of innovative sales in 2018 due to products resulting from quality improvements in process innovation of three years, 2016-18, log	a. 377 b. 129	5.61 (8.01) 16.39 (3.26)	0/22.79 0/22.79
Cost reduction	Percentage reduction in total unit cost from process innovations of three years, 2016-18.	a. 377 b. 154	2.23 (6.21) 5.47 (8.78)	0/50 0/50
Defect rate reduction	Percentage reduction in defect rates from process innovations of three years, 2016-18.	a. 377 b. 154	6.63 (19.6) 16.23 (28.06)	0/95 0/95
Production cycle time	Percentage reduction in production cycle time from process innovations of three years, 2016-18.	a. 377 b. 154	3.24 (19.6) 7.92 (12.92)	0/60 0/60
Production capacity	Percentage increase in production capacity from process innovations of three years, 2016-18.	a. 377 b. 154	4.19 (9.90) 12.25 (13.35)	0/80 0/80
Labor productivity	Turnover per worker in 2018, log	377	13.50 (2.10)	0/18.42

Employment	Total employees in 2018, log	377	4.21 (1.57)	1.09/9.9
Turnover	Total turnover in 2018, log	377	17.65 (3.02)	0/23.02
Firm size	Total employees in 2016, log	377	4.20 (1.56)	0.69/9.9
Age	Firm age in years, log	377	2.82 (0.87)	0/4.23
Inn. Activity Breadth	Innovative breadth measured as a linear sum of 7 binary variables (1 if firm engages in that activity, 0 otherwise) representing a firm's innovative activities including: In-house R&D, External R&D, Acquisition of machinery, equipment and software, Acquisition of external knowledge, Training for innovative activities, Market introduction of innovations, and Others (including design).	a. 377 b. 154	1.80 (2.45) 4.06 (2.15)	0/7 0/7
Inn. Activity Depth	Total spending in 2018 on six innovative activities including: In-house R&D, External R&D, Acquisition of machinery, equipment and software, Acquisition of external knowledge, Training for innovative activities, and Market introduction of innovations, log	a. 377 b. 154	6.33 (8.17) 14.06 (6.35)	0/21.08 0/21.08
Extreme competition	1 if firm reported facing extreme competition, 0 otherwise.	377	0.73	0/1
Foreign competition	1 if firm reported facing competition from a foreign firm in its main market where it sales its main product, 0 otherwise.	377	0.39 (0.45)	0/1
Foreign suppliers	1 if a firm considered foreign suppliers as highly important source of information and cooperation for technological innovation during the three years 2016-18. 0 otherwise	377	0.12 (0.33)	0/1
Local suppliers	1 if a firm considered local suppliers as highly important source of information and cooperation for technological innovation during the three years 2016-18. 0 otherwise	377	0.12 (0.32)	0/1
Foreign clients	1 if a firm considered foreign clients as highly important source of information and cooperation for technological innovation during the three years 2016-18. 0 otherwise	377	0.11 (0.32)	0/1

Local clients	1 if a firm considered local clients as highly important source of information and cooperation for technological innovation during the three years 2016-18. 0 otherwise	377	0.13 (0.34)	0/1
Competitor	1 if a firm considered its competitors as highly important source of information and cooperation for technological innovation during the three years 2016-18. 0 otherwise	377	0.15 (0.36)	0/1
Lack of funds	1 if a firm considered lack of funds as highly important factor constraining its decision to engage in technological innovation during the three years 2016-18. 0 otherwise	377	0.38 (0.49)	0/1
Product innovation	1 if a firm introduced new or significantly improved products during the three years 2016-18, 0 otherwise	377	0.26 (0.44)	0/1
Human capital	Percentage of employees in 2018 with university degree.	377	7.97 (14.41)	0/100

Table 3. Propensity to introduce new processes and its output

Variables	Propensity to innovate		Innovation intensity				
	Process	Quality improvement	Innovative sales	Cost reduction	Defect rate reduction	Production cycle time	Production capacity
Firm size	-0.288*** (0.101)	-0.202** (0.0921)	0.531*** (0.189)	-0.640 (0.565)	-3.498** (1.674)	-1.847** (0.787)	-2.123** (0.888)
Age	-0.0970 (0.133)	0.0471 (0.141)	0.696** (0.297)	1.083 (0.926)	5.595** (2.714)	0.660 (1.289)	-0.310 (1.461)
Inn. Activity Breadth	0.398*** (0.0838)	0.352*** (0.0729)	-0.0584 (0.170)	0.00307 (0.465)	2.235 (1.374)	1.199* (0.647)	1.604** (0.730)
Inn. Activity Depth	0.0981*** (0.0204)	0.0762*** (0.0196)	0.319*** (0.0610)	-0.193 (0.185)	0.698 (0.546)	0.286 (0.257)	0.302 (0.291)
Extreme competition	0.623** (0.280)	0.671** (0.275)	-0.0265 (0.574)	-0.608 (1.717)	5.779 (5.062)	3.845 (2.390)	-1.167 (2.702)
Foreign competition	0.467 (0.296)	-0.140 (0.285)	0.899* (0.507)	3.692** (1.620)	5.309 (4.792)	4.518** (2.256)	6.262** (2.546)
Foreign suppliers	-0.519 (0.565)	-1.204** (0.492)	-1.265* (0.741)	-1.200 (2.164)	-4.939 (6.449)	-0.273 (3.012)	-4.635 (3.391)
Local suppliers	0.863 (0.641)	1.109** (0.511)	1.810*** (0.664)	3.248 (1.990)	15.12** (5.944)	7.947*** (2.769)	3.626 (3.114)
Foreign clients	0.850* (0.476)	1.266*** (0.419)	0.282 (0.681)	-0.676 (1.937)	10.81* (5.757)	-0.480 (2.697)	1.469 (3.039)
Local clients	0.122 (0.423)	0.207 (0.372)	1.148** (0.568)	3.410* (1.770)	-0.233 (5.265)	0.229 (2.464)	2.944 (2.775)
Competitors	0.521 (0.394)	0.719** (0.356)	0.113 (0.540)	3.683** (1.691)	16.95*** (5.019)	3.091 (2.353)	2.856 (2.653)
Lack of funds	-0.601** (0.249)	-0.744*** (0.261)					
Location (Sindh = 1)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sectoral dummies (3 digits)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lambda			2.069**	-3.167	14.47**	4.243	3.089
Wald chi-square			140.24***	50.00***	88.68***	70.33***	34.19***
Observations	377	377	377	377	377	377	377

This stage is estimated in a Heckman two-step sample selection model. The parentheses contain standard errors. *** p<0.01, ** p<0.05, * p<0.1

Table 4. Labor productivity

	^a Innovative sales		^a Cost reduction		^a Defect rate reduction		^a Production cycle time		^a Production capacity	
Variables	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Process innovation (a)	0.110*** (0.0393)	0.426*** (0.127)	0.0609*** (0.0181)	0.0910*** (0.0344)	0.0133** (0.0062)	0.0171* (0.00985)	0.0240** (0.0117)	0.0511** (0.0221)	0.0317*** (0.0104)	0.0791*** (0.0313)
Controls										
Size	-0.269* (0.161)	-0.203 (0.137)	-0.184 (0.166)	0.0971 (0.104)	-0.190 (0.168)	0.122 (0.0988)	-0.183 (0.171)	0.149 (0.103)	-0.183 (0.167)	0.185* (0.109)
Age	0.464*** (0.147)	0.0108 (0.163)	0.454*** (0.153)	0.210 (0.144)	0.440*** (0.155)	0.233* (0.139)	0.502*** (0.151)	0.285** (0.134)	0.540*** (0.152)	0.334** (0.140)
Product innovation	-0.259 (0.313)	-0.503* (0.278)	-0.471 (0.294)	-0.497* (0.280)	-0.201 (0.330)	-0.451 (0.287)	-0.275 (0.316)	-0.470 (0.287)	-0.345 (0.309)	-0.525* (0.281)
Inn. Activity Breadth	-0.272** (0.120)	-0.277** (0.109)	-0.241** (0.108)	-0.296*** (0.110)	-0.245** (0.115)	-0.33*** (0.109)	-0.236** (0.114)	-0.349*** (0.116)	-0.249** (0.111)	-0.41*** (0.129)
Inn. Activity Depth	0.189*** (0.0516)	-0.0135 (0.0444)	0.217*** (0.0596)	0.139*** (0.0294)	0.210*** (0.0593)	0.110*** (0.0301)	0.208*** (0.0594)	0.107*** (0.0293)	0.205*** (0.0585)	0.101*** (0.0288)
Human capital	0.0115 (0.00751)	0.0131** (0.00644)	0.0166** (0.00757)	0.0135** (0.00641)	0.0193** (0.00805)	0.0138** (0.00625)	0.0170** (0.00734)	0.0135** (0.00623)	0.0194** (0.00775)	0.0141** (0.00638)
Location (Sindh = 1)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sectoral dummies (3 digits)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	154	377	154	377	154	377	154	377	154	377
R-squared	0.346	0.151	0.315	0.143	0.286	0.136	0.281	0.139	0.295	0.143

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 5. Employment and Turnover

Variables	^a Innovative sales		^a Cost reduction		^a Defect rate reduction		^a Production cycle time		^a Production capacity	
	Employment	Turnover	Employment	Turnover	Employment	Turnover	Employment	Turnover	Employment	Turnover
Process innovation (a)	0.00336 (0.00640)	0.120** (0.0472)	-0.00495 (0.00439)	0.0583*** (0.0192)	-0.000348 (0.000972)	0.0138** (0.00683)	-0.00175 (0.00280)	0.0232* (0.0125)	0.000867 (0.00175)	0.0338*** (0.0112)
Controls										
Size	0.965*** (0.0321)	0.702*** (0.176)	0.964*** (0.0325)	0.791*** (0.179)	0.966*** (0.0322)	0.787*** (0.181)	0.964*** (0.0315)	0.792*** (0.184)	0.967*** (0.0313)	0.796*** (0.179)
Age	0.0800 (0.0564)	0.552*** (0.154)	0.0898 (0.0572)	0.554*** (0.162)	0.0852 (0.0581)	0.532*** (0.160)	0.0855 (0.0560)	0.599*** (0.162)	0.0823 (0.0548)	0.636*** (0.162)
Product innovation	-0.0255 (0.0653)	-0.248 (0.344)	-0.0103 (0.0563)	-0.453 (0.318)	-0.0281 (0.0679)	-0.188 (0.365)	-0.0262 (0.0647)	-0.266 (0.346)	-0.0279 (0.0656)	-0.340 (0.336)
Inn. Activity Breadth	-0.0189 (0.0258)	-0.307** (0.136)	-0.0132 (0.0246)	-0.268** (0.121)	-0.0155 (0.0246)	-0.276** (0.130)	-0.0140 (0.0255)	-0.264** (0.127)	-0.0180 (0.0227)	-0.281** (0.124)
Inn. Activity Depth	0.0102 (0.0103)	0.209*** (0.0629)	0.0101 (0.0117)	0.239*** (0.0735)	0.0108 (0.0114)	0.232*** (0.0727)	0.0109 (0.0113)	0.230*** (0.0729)	0.0107 (0.0113)	0.227*** (0.0717)
Human capital	0.000438 (0.00368)	0.0112 (0.00749)	0.000354 (0.00357)	0.0165** (0.00731)	0.000399 (0.00356)	0.0196** (0.00807)	0.000343 (0.00364)	0.0169** (0.00768)	0.000665 (0.00377)	0.0198** (0.00778)
Location (Sindh = 1)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sectoral dummies (3 digits)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	154	154	154	154	154	154	154	154	154	154
R-squared	0.930	0.575	0.931	0.549	0.930	0.538	0.930	0.534	0.930	0.543

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 6. Share of skilled labor

	% Employees with university degree		% Employees with technical diploma	
	^a <i>Process</i>	^a <i>Quality improvement</i>	^a <i>Process</i>	^a <i>Quality improvement</i>
Process innovation ^a	5.212*** (1.709)	6.188*** (1.730)	4.002*** (1.195)	5.325*** (1.261)
Product innovation	1.973 (2.066)	1.840 (1.969)	3.472** (1.711)	3.058* (1.576)
Location (Sindh = 1)	Yes	Yes	Yes	Yes
Sectoral dummies (3 digits)	Yes	Yes	Yes	Yes
Observations	377	377	377	377
R-squared	0.127	0.135	0.191	0.210

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1