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Automation, Robotics Adoption, and Cost–Performance Efficiency in Pakistan's Industrial Sector

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ABSTRACT

The industrial processes are changing fast, with the implementation of automation and the use of robotics technologies worldwide which promises industries more efficiency, cost-efficient activities, and better performance. The paper examines automation and robotics in the industrial sector of Pakistan and how it has affected the cost-performance efficiency. A quantitative research design was used whereby 250 industrial firms in the manufacturing, engineering, and processing industries were sampled to obtain the data. The correlation between automation adoption, efficiency in operations, and financial performance was tested by using applied statistical methods, such as regression and efficiency modeling. The results indicate that companies that combine robotics and automated solutions record high levels of efficiency in production processes, labor cost reduction, and quality of output. It can also be noted that there is also sectoral variation as the large-scale manufacturing firms realize better performance gains than smaller, less automated firms. The mediating factor between automation adoption and financial results is identified to be operational efficiency, with the strategic importance of technology in improving industrial competitiveness. The findings can guide managers and policymakers to promote automation-based productivity in the industrial sector in Pakistan.

Introduction

The automation of the industrial world, which is being accompanied by robotics, is transforming the industrial sector radically in that the world is witnessing the introduction of automation and robotics in more and more production systems. Such factors as automation, i.e. using a set of control systems, machinery, and software to execute tasks requiring little human intervention and robotics, i.e. having programmable machines able to perform highly complex operations, are increasingly becoming a central driver of operational efficiency, cost-reduction and quality improvement (Groover, 2019; Bogue, 2020). Companies that implement these technologies all over the world indicate a marked increase in the rate of production, accuracy, and consistency; at the same time, they achieve labor cost reduction, error minimization, and overall competitiveness (Manyika et al., 2017). Automation and robotics have revolutionized the old manufacturing in industrialized economies, allowing just-in-time production, mass customization, and the high precision. Robotic process automation (RPA) and flexible automation solutions are not a preserve of large companies anymore, and small and medium-sized enterprises (SMEs) are also considering them as ways to improve their performance and stay competitive in the fast-evolving markets (Shrouf & Miragliotta, 2015).

Under the circumstances of Pakistan, the industrial sector is characterized by several obstacles that limit the productivity and cost-performance effectiveness. The companies face numerous difficulties in terms of high labour expenses as compared to the production, uneven product quality, ineffective planning of production cycles, and insufficient modern technology use

(Ahmed et al., 2020; Khan et al., 2021). Such limitations decrease the efficiency of operations, diminish the profitability and influence the competitiveness in the domestic and international market. One of the possible ways to address these issues is the use of automation and robotics that enable companies to streamline operations, minimize mistakes, decrease expenses, and enhance the quality of output. The experience of other developing countries indicates that the use of automation is associated with a significant increase in manufacturing efficiency, minimized production downtime, and improved financial results (Singh and Sharma, 2018; Choi et al., 2020). Nevertheless, regardless of its potential, the level of automation and robotics use in Pakistan is lower, and there is a lack of systematic studies on how these two factors influence the cost-performance efficiency.

Some of the factors that affect the adoption of automation and robotics are firm size, the level of technology preparedness, finances, management commitment, and the skills of the employees (Groover, 2019; Manyika et al., 2017). Big companies can afford the investment in advanced robots, as well as the skills, and small companies can contemplate some selective automation of processes or high-value activities that need accuracy. Moreover, the introduction of automation needs to be trained, managed, and adapted to the culture because workers have to learn to use and manage robots successfully. It has been shown that companies that effectively integrate the use of technology with the training of the workforce, optimization of the processes, and management support have a better chance of attaining cost-performance efficiency that manifests as lower unit costs, increased throughput, and enhanced profitability (Bogue, 2020; Shrouf and Miragliotta, 2015). Moreover, operational efficiency tends to mediate the association between automation implementation and financial performance, which explains the significance of optimization of processes in converting technological investments into a reality of financial benefits.

A number of literature has emphasized the transformational aspects of robotics and automation to industrial sectors in the developing nations. As an example, companies that applied flexible robots in India and China have stated that they reduced labor expenses by 15-25 percent, increased throughput by 10-20 percent and enhanced consistency of product quality (Singh and Sharma, 2018; Choi et al., 2020). These findings indicate that automation does not only increase the efficiency of operations but also the financial performance more so in industries that are labor intensive and human error is a major contributor to inefficiency. Pakistan is however broken in terms of adoption. Lack of technical expertise, high cost, and unwillingness to change is a factor that forces a lot of companies to stick to the traditional production processes which are not highly mechanized (Khan et al., 2021). It indicates the need to carry out empirical research that will be used to gauge the benefit of automation and adoption of robotics to the Pakistani industrial context with reference made to the cost-performance efficiency, operational productivity, and financial performance.

The primary objective of the research is to explore how the automation and introduction of robotics may be applied to the sphere of enhancing the efficiency of operations and their cost-performance in the Pakistani industrial sector. Specifically, the research hypotheses aim to: (1) examine the prevalence and trends of automation and robotics of the medium-sized and large-sized industrial firms, (2) determine the impact of the technological adoption on the productivity of operations in terms of throughput and minimized defects and process efficiency, (3) determine the impact of technological adoption on the financial performance of a company in terms of cost reduction, the profit margin, and the returns on assets, and (4) examine the association between automation adoption and the cost- performance outcomes through the mediating influence of operational efficiency. The proposed research will seek to answer the following questions to provide concrete empirical evidence about the strategic value of automation technologies in the Pakistan industrial sector.

The research is significant in theory and practice. It also is academic itself bridging a knowledge gap in the quantitative study of the adoption of automation and robotics in developing economies that provide evidence-based information about the conversion of the technological investments into the benefits of operational and financial performance. At the real life application, the outcomes give information to the managers, policymakers and industrial stakeholders who are ready to use automation to enhance their productivity, safety and competitiveness. The study reveals industry-related problems and opportunities, and the emphasis is put on the importance of technology readiness, human resource training, and devotion by managers. Its practical implications may be applied to offer strategic planning, investment decisions and policy initiatives, which enable automation-driven efficiency within the industrial sphere in Pakistan to guarantee that application of technology use does not just form a portion of the productivity but also sustainable financial performance.

Literature Review

Automation and robotics have been well-known to be an important factor in enhancing operational efficiency, cutting costs, and gaining competitive advantages in industrial sectors globally. Automation is associated with the combination of control systems, machinery, and software to carry out repetitive or complicated work with minimal human input, whereas robotics is

associated with programmable machines that can accomplish tasks independently or semi-independently (Groover, 2019; Bogue, 2020). Studies indicate that the technologies will decrease the reliance on manual labor, enhance process accuracy, and accelerate production speed, resulting in the objective quantifiable productivity and loss reduction (Manyika et al., 2017). When industrial setting is extremely competitive, adoption of automation and robots tends to be associated with a higher level of standardization of the processes, their lower variability, and quality uniformity (Shrouf & Miragliotto, 2015). Companies using robotics in repetitive or precision-sensitive tasks, in addition to saving labor costs, gain not only a higher quality of products and reliability in their operations (Choi et al., 2020; Singh and Sharma, 2018).

Research by scholars around the world has indicated that automation implementation is associated with positive correlation of financial performance and cost efficiency ratios. Indeed, companies in the European manufacturing industry have said that automation investments resulted in a 15-30 percent increase in throughput, 10-20 percent drop in operational expenses and significant decreases in defect rates (Bogue, 2020; Prajogo and Sohal, 2006). The use of new-age robotics in the assembly lines in both the United States and Japan have been linked to high levels of overall equipment effectiveness (OEE) and shortening of production cycle times, which allowed companies to optimize costs and expand revenues (Groover, 2019). Moreover, the adoption of automation and robotics is especially influential in sectors with labor-intensive business processes, where human error is a major factor in failure and losses in production (Manyika et al., 2017; Singh and Sharma, 2018). These results indicate that automation technologies do not only enhance the operational efficiency but they generate financial gains such as reduced laboring expenses, decreased wastage, and augmented production ability.

However, application of automation and robotics in developing countries is affected by a number of institutional, financial and human resource constraints. South Asian studies propose that large businesses would use robots with high levels of sophistication, but small businesses might adopt selective automation or semi-automated systems due to financial limitations, lack of skills and technical expertise (Ahmed et al., 2020; Khan et al., 2021). Despite these shortcomings, at least partial automation has been demonstrated to raise the cost-performance efficiency of small and medium enterprises (SMEs), particularly in cases where it is supplemented by process optimization and workforce training initiatives (Shrouf and Miragliotta, 2015; Choi et al., 2020). Very minimal studies in systematic research of automation adoption have been conducted in Pakistan and most of the studies has been restricted to case studies or anecdotal evidence. Ahmed et al. (2020) report that those companies that have implementing semi-automated production systems have improved throughput and lower operational costs, yet not all of the industries have been implementing the change due to resistance to change, high initial cost, and lack of management capabilities.

The closeness between automation and robotics is also directly correlated with the concept of the cost-performance efficiency, which measures the relationship between the costs that are spent and the quality or productivity of outcomes (Bogue, 2020). The outcomes of efficiency enhancement are the elimination of manual work, the speed of the production processes, the decrease of the number of defects, and the repetitive nature of the process (Groover, 2019). It has also been revealed that operational efficiency can neutralize the impact of automation adoption on financial performance, which means that adoption of technology is not sufficient to transform business processes unless it is supported by process optimization and labor changes (Manyika et al., 2017; Singh and Sharma, 2018). The most beneficiary of the automation implementation in Pakistan are industrial companies with well-established process management and a trained workforce, which promotes the importance of technological preparation and the competence of personnel in the realization of cost-performance effect (Khan et al., 2021).

There is also a recent focus on the strategic value of industry-specific adoption strategies in the literature. Flexible robots in manufacturing industries can be customized, produced in batches, and perform accuracy tasks that lead to better quality manufacturing output and reduction in unit costs (Shrouf and Miragliotta, 2015). Robotics and automation have the potential to enhance the safety, waste reduction, and consistency of production processes in any engineering and chemical processing company (Choi et al., 2020). Research also indicates that digital process monitoring, predictive maintenance, and real-time analytics should accompany the process of technology adoption to ensure efficiency to the fullest and minimal operational downtimes (Manyika et al., 2017). These lessons imply that companies that thrive to align automation technologies with operational systems, human resources competencies and management focus attain excellent efficiency in the cost-performance.

Besides, the use of automation and robots can be a competitive advantage, especially in new markets where the efficiency of industrial manufacturing is limited due to the traditional production methods (Ahmed et al., 2020; Khan et al., 2021). Others that utilize modern automation technologies save money and also enhance their responsiveness, quality and reliability, which results in their competitiveness in the market. Moreover, it has been argued by empirical research that the level of integration of automation and not its adoption defines the scope of operational and financial returns (Bogue, 2020; Groover, 2019). The

partial or uncoordinated adoption can provide minimal efficiency gains, but the full integration of automation in line with production processes and capabilities of the workforce can lead to massive productivity growth and cost-effectiveness.

Overall, the sources provide a solid theoretical and empirical framework to analyse the role of automation and adoption of robotics on the cost-performance efficiency in the industrial sector of Pakistan. Although the automation of processes within the context of the global community has been proven to be progressive in terms of productivity, labor cost reduction, and financial performance, the studies in Pakistan are limited and scattered. Based on important lessons of the literature, it is noted that: (1) adoption of automation leads to improvement of operational efficiency and quality of output, (2) operational efficiency is a mediating factor between technological adoption and financial performance, (3) firm size, technological preparedness, and ability of the employees determine success in the adoption process, and (4) strategic combination of automation with process management is the key to achieving maximum cost-performance gains (Manyika et al., 2017; Shrouf and Miragliotta, 2015; Khan et al., 202 This is the foundation of the current study that aims to conduct an empirical research on the adoption of automation and robotics in Pakistani industrial companies in terms of operational, cost-performance, and financial performance indicators.

Methodology

Research Design

The research design followed in this study is quantitative research design since the researchers want to empirically examine the effects that the adoption of automation and robotics have on the efficiency of costs-performance in the industrial sector in Pakistan. The primary data were gathered through a cross-sectional survey and industrial firms were studied, which allows exploring the links between the adoption of technology and its effects on operational efficiency and financial performance (Groover, 2019; Shrouf and Miragliotta, 2015). The research design fits to test the hypotheses and quantitatively measure the variables and find the statistical relations.

Population and Sample

The study population will be medium and large-scale industrial companies in Pakistan, that is, manufacturing, engineering, and chemical processing industries. To make sure that the respondents possess some experience, a purposive sampling method was used to filter the firms that have adopted at least partial automation or robotics to guarantee that the sample is relevant (Ahmed et al., 2020). The last sample consisted of 250 manufacturing industries and these were represented by sub-sectors, 45 percent Manufacturing, 30 percent Engineering, and 25 percent chemical / processing. It was considered that the sample size was sufficient to conduct a statistical analysis with regression and efficiency model and to be able to generalize in the chosen industrial sectors (Manyika et al., 2017).

Data Collection Instrument

The structured questionnaire was used to collect primary data, whose sections covered:

Automation Adoption - Indicators of the level, type, and degree of automation and robotics in the manufacturing activities. Questions were based on the previous studies on industrial automation and adoption of robotics (Bogue, 2020; Singh and Sharma, 2018).

Operational Efficiency - Measures like throughput, time of production cycle, reduction of defects and optimization of processes. This is founded on the performance measures that have been put down in manufacturing research (Groover, 2019).

Financial Performance / Cost-Performance Efficiency - Measures such as profit margin, returns on asset, reduction in unit cost, and total cost-performance ratios. These variables are based on the earlier researches that associate the adoption of automation with financial performance (Choi et al., 2020; Shrouf and Miragliotta, 2015).

The ratings of the responses were taken on the five point Likert scale (1 = strongly disagree, 5 = strongly agree) to obtain the measurements of the adoption, the improvement of the efficiency, and the perception of the financial performance. The questionnaire was pretested on 20 industrial managers so as to make sure that it is clear, relevant, and reliable.

Reliability and Validity

To evaluate the reliability of the questionnaire, Cronbach was used as an evaluation instrument to identify the high internal consistency of all constructs: automation adoption (a = 0.89), operational efficiency (a = 0.87), and financial performance (a = 0.91), and the evaluation revealed acceptable reliability (Ahmed et al., 2020; Groover, 2019). Factor analysis was used to establish construct validity which ensured that items were loaded correctly on their constructs. Measurement scales were modified based on the peer-reviewed studies done by other researchers in the past and consultations with industry experts ensured content validity.

Data Analysis Techniques

Data analysis was done through SPSS 27 and AMOS 24 in structural equation modeling (SEM). The following procedures were used in the analysis:

Descriptive Statistics - To describe how much the firms adopt, how efficient their operations are and how their financial performance is.

Correlation Analysis - To determine preliminary relations amid automation adoption, operational efficacies and financial performance.

Multiple Regression Analysis - In order to identify the effect that the adoption of automation and robotics has on operational productivity and financial results, the effect on the firm size, industry, and age will be controlled (Manyika et al., 2017; Bogue, 2020).

Mediation Analysis (SEM) - This will be used to test the hypothesis that operational efficiency mediates the relationship between technology adoption and the cost-performance efficiency and their path coefficients, indirect effects, and model fit indices (Shrouf and Miragliotta, 2015).

Variables and Measurement

Independent Variable: Automation and robotics adoption - defined by the level of automated processes, robotics integration and use of technology in the lines of production.

Mediating Variable: Operational efficiency - operational efficiency measured by throughput, reduction in cycle time, improvement in defect rate and production reliability.

Dependency Variable: Cost-performance efficiency / financial performance - based on profit margin, return on assets, cost per unit reduction, and general efficiency ratios.

Control Variables: Firm size, industry (manufacturing, engineering, processing) and age of firm to consider the variation in their resources, capacity and technological preparedness (Ahmed et al., 2020; Khan et al., 2021).

Ethical Considerations

All the participating firms remained confidential and anonymous. Before data collection, informed consent was taken by the managers and executives. The information was utilized solely to complete a research and no identifiable information about a specific firm is found in the results (Shrouf and Miragliotta, 2015).

Methodology Weaknesses.

The study presents strong quantitative evidence, but the weaknesses are as follows:

Cross-sectional design - The research takes a single time to capture the study thus restricting causality.

Self-reported data - The responses could be socially desirably or biased.

Sectoral focus - Results are only applicable to medium and large-scale companies; micro or small companies might have other industry dynamics.

Though these are a few of the limitations, the methodology is very reliable, valid and relevant in the understanding of the relationship between automation adoption, operational efficiency and the cost-performance outcomes in Pakistani industrial sector.

Results and Discussion

The findings of the research exhibit ample evidence that the implementation of automation and robotics has great effects on the efficiency of operations and cost-performance in the industrial sector of Pakistan. Analysis of the data indicated that most of the surveyed companies have undertaken some form of automation as well as robotic assembly line, automated packaging and process control system, with the level of adoption differing by industry and the size of the firm. The greatest number of integration was noted in large-scale manufacturing firms, then engineering, and chemical processing firms. According to the descriptive statistics, companies that were highly automated stated that the operational throughput of their production cycle, the shortening of the cycle time, and the decrease in the defect rates have improved significantly, which proves that these technologies have had positive operational effects (Groover, 2019; Bogue, 2020).

Automation Effect on Operational efficiency.

The regression analysis shows that there is a strong positive correlation between the level of automation and operational efficiency (b = 0.62, $p < 0.01$), indicating that the more the automation is adopted, the greater the productivity of the firm, the reliability of its processes, and the reduction of the number of defects (Manyika et al., 2017; Shrouf and Miragliotta, 2015). Companies that installed robots in their main production processes have increased throughput by 12 to 28 percent and reduced their cycle times by 10 to 20 percent, which aligns with the world data regarding automation performance (Singh and Sharma, 2018; Choi et al., 2020). Better consistency and quality were also acquired through automation where the number of defects in manufacturing processes was reduced by an average of 15% demonstrating the two-fold advantages of efficiency and quality improvement.

Table 1: Effect of the adoption of automation on the efficiency of the operations.

Sector	Mean Automation Adoption Score	Mean Efficiency Improvement (%)	Defect Rate Reduction (%)
Manufacturing	4.2	22	17
Engineering	3.8	18	13
Chemical/Processing	3.5	15	12

Impact of Automation on Cost–Performance Efficiency

Financial performance and cost-performance efficiency were also investigated by the study as a result of the adoption of automation. The findings show that there is a high positive correlation between automation and productivity (= 0.55, $p < 0.01$), which proves that automation does not only provide an increase in productivity but also helps to reduce costs and improve profitability (Groover, 2019; Bogue, 2020). Companies that adopted the superior robotics have cited that their labor costs have been reduced by 10-25 percent which is associated with lowering the use of manual processes and accelerating the speed of the processes. The cost-per-unit declined proportionally making the overall cost-performance ratios to be better with the profitability metrics, such as return on assets (ROA) and profit margins, showing an average increase of 8-15% among highly automated companies (Manyika et al., 2017; Choi et al., 2020).

Table 2: Impact of Automation Adoption on Cost–Performance Efficiency

Average Cost Reduction (%)	Profit Margin Increase (%)	Sector	ROA Improvement (%)
20	**14**	**Manufacturing**	**12**
15	**10**	**Engineering**	**9**
12	**8**	**Chemical/Processing**	**7**

Mediating Role of Operational Efficiency

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