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TECH FOR COMPETITION AND GROWTH

Edited by Nadeem Javed & Faheem Jehangir Khan

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TECH FOR COMPETITION AND GROWTH

(Volume XXI)

Edited by Nadeem Javaid & Faheem Jehangir Khan

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Tel. +92 (51) 9248144, 9248026

Email: rasta@pide.org.pk

URL: rasta.pide.org.pk

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PART I

TECH FOR COMPETITION AND GROWTH

Research Papers

EFFECT OF FIRM'S BIG DATA ANALYTICS CAPABILITY ON COMPETITIVE ADVANTAGE: MEDIATING EFFECT OF BUSINESS MODEL INNOVATION AND MODERATING EFFECT OF ENVIRONMENTAL UNCERTAINTY

Chaudry Bilal Ahmad Khan[1], Fizza Khan[2], Mehwish Iftikhar[3], and Muhammad Imran Qureshi[4]

ABSTRACT

The purpose of this research was to investigate the effect of big data analytics capabilities on competitive advantage, the mediating role of business model innovation, and the moderating effect of environmental uncertainties. Survey questionnaires were randomly distributed using a multistage sampling technique, yielding 304 usable responses. The data were analysed using PLS-SEM. In parallel, interviews were conducted with eight middle- and senior-level managers to enable triangulation and provide in-depth insights. The results revealed that big data analytics capabilities significantly influenced competitive advantage, with business model innovation playing a significant mediating role in this relationship. Environmental uncertainties—such as market turbulence, technological turbulence, and competitive intensity—negatively moderate the effect of big data analytics capabilities on competitive advantage. The interviews indicated that telecommunications firms leveraged big data analytics capabilities for decision-making and product improvement, which enhanced their competitive advantage. Business model innovation, particularly through the introduction of new customer services, further strengthened this advantage by enabling market differentiation. However, uncertainties such as technological turbulence, market turbulence, and competitive intensity weakened the link between big data analytics capabilities and competitive

[1] Assistant Professor, Institute of Space Technology, Islamabad.

[2] Assistant Professor, National University of Science & Technology (NUST), Islamabad.

[3] Assistant Professor, National University of Science & Technology (NUST), Islamabad.

[4] Senior Lecturer, Teesside University, UK.

advantage. Moreover, given the rapidly changing customer requirements and evolving technologies, the telecommunications industry was unable to enhance its infrastructure and retain skilled human resources. The in-depth analysis identified additional barriers, including restrictive government policies, an unstable local currency, insufficient government support, and heavy taxation. We would like to give our special thanks to Jazz Digital, PTCL, Ufone, Nayatel, Cybernet, and Zong for their support in data collection.

1. INTRODUCTION

Information technology has transformed activities and processes in all fields across the world. Due to the changing dynamics of the business world and ever-increasing data, analysing the scientific analysis of data facilitates decision-making and also helps in improving the production process and, eventually, the quality of goods or services (Gao et al., 2020). Business analytics plays a positive role in improving business processes by providing a better understanding of changing business dynamics and consumer behaviours, preferences, and then devising strategies accordingly (Min, 2016).

At the same time, big data also plays a very pivotal role in the success of the business through targeted marketing and customised service provision. Big data has been the focus of research interests in recent times because of its ability to analyse a large amount of data and transform it into valuable information, which eventually enables the business to make better and informed business decisions, leading to improved goods and services and also cost reductions (Zhong et al., 2016).

Big data analytics (BDA) combines big data and business analytics. Therefore, the use of BDA by collecting, processing, and analysing large amounts of data provides better insights. It helps businesses to make informed decisions, which eventually enables the businesses to improve customer relationships, increase customer satisfaction, and, finally, gives them a competitive advantage (Dahiya et al., 2022).

The success of any business depends upon the business model it has adopted, as based on their business model, firms materialise the available opportunities to improve their turnover and earn profits (Yunus et al., 2010). A business model provides the base for firms to implement their innovative ideas through the use of technology and, thus, achieve a competitive advantage (Chesbrough, 2007). However, considering the rapidly changing external environment, even a successful business model adopted by any firm cannot be used permanently. Therefore, to cope with the changing dynamics of the business, firms should innovate their business models (Schneider & Spieth, 2013).

The focus of a business model is limited to the firm level, while business model innovation focuses on the customer value proposition and structural redesigning of the firm (Spieth et al., 2014). Therefore, through business model innovation, firms can address the changing dynamics and environmental uncertainty and achieve a competitive advantage while maintaining their market share. Research shows that the firms with big data capabilities perform better when it comes to innovation (Zheng et al., 2022).

Purpose and scope of the study

Competitiveness plays an important role in the growth and development of organisations (Sohail et al., 2024). Globally, competitive organisations tend to outperform others based on profitability, innovation, efficiency, and overall market share. Competitiveness is therefore a multi-faceted concept that allows organisations to flourish in the market. Businesses compete with their competitors to gain more profit and market share. During the past few years, businesses in Pakistan have faced issues due to the challenging economic environment (Akhuand & Abbas, 2023). For example, the telecommunications sector once demonstrated enormous growth and competitiveness, but the recent exit of a major mobile operator has raised concerns. It signals not only the intensity of competition in the sector (Ahmed, 2024) but also questions the capacity of organisations to innovate their business models and sustain a competitive edge. In this technology-driven era, where organisations depend on knowledge-based decisions, it is important for organisations to develop their capabilities to handle data appropriately and make decisions based on the information.

Pakistan has witnessed enormous digital penetration, with 77.7% of the total population having mobile connections. A country producing an enormous amount of data has a huge scope for the utilisation of big data (Nasir, 2021). Therefore, telecommunications organisations can keep themselves competitive if they develop capabilities to handle big data (Sony & Naik, 2020). Mubarak et al., (2019) suggest that industries in Pakistan have been facing various challenges, including a lack of business information infrastructure, financial resources, and human resources (Mubarak et al., 2019). As the efforts to digitise Pakistan have remained tentative (Warf, 2017), the policies for industries are required to encourage the capacity building of experts and the upgrade of industries to promote the use of big data (Latif et al., 2018).

Therefore, organisations must develop their BDA capabilities to make well-informed decisions to compete and sustain in the market. Pakistan's digital policy also emphasises the development of infrastructure that can facilitate cloud and big data capacity building to attract the local and international markets for industrial competitiveness (MoIT, 2018).

Considering the importance of digitisation of industries for the modern era, this study focuses on the competitive advantage of telecommunications firms in Pakistan, the effect of big data capabilities on their competitive advantage, internal/external factors affecting the big data capabilities, and organisations' competitive advantage.

2. LITERATURE REVIEW

The importance of big data has increased exponentially in the last few years. BDA has a strategic importance in making businesses operating in different industries successful (Jha et al., 2020; Persaud, 2021; Pizło et al., 2023). Organisations using big data are crucial components of the economic growth and development in developed economies as they have the ability, knowledge, and skills that enable them to innovate (Duval-Couetil et al., 2016).

BDA capabilities are the ability of an organisation to capture, examine, and analyse data and give meaningful insights by arranging and coordinating unstructured and semi-structured data (Mikalef et al., 2018). There are three main dimensions of big data capabilities, i.e., management, infrastructure, and personnel capabilities. BDA has revolutionised business practices. Several noticeable advantages of BDA in various industries have increased the interest of companies in benefiting from its potential. The interest of researchers and practitioners has significantly increased in BDA given its visible benefits to businesses (Jha et al., 2020; Persaud, 2021).

Many other aspects of BDA, apart from data and its analysis, contribute to making big data projects successful. Through the use of BDA, organisations of different sizes are exploring ways of increasing their business value through innovation (Mikalef et al., 2019; Shinwari & Sharma, 2018). The use of big data can contribute positively to economic growth and development by increasing the innovative capabilities of the organisations using it (Shahzad et al., 2017). It may also increase the competitive advantage of the firm in the long run.

Therefore, this research project analyses the effect of BDA capabilities on competitive advantage, focusing on the mediating effect of business model innovation and the moderating effect of environmental uncertainty in the relationship between BDA capabilities and competitive advantage.

Big Data Analytics Capabilities in Relation to Competitive Advantage

Big data capabilities are defined as, “it includes resources, techniques, tools, and processes that enable an organization to process, analyze, and visualize big data in such a way that the resulting insights make data-driven planning, decision-making and implementation possible, and ultimately lead to the organization’s competitive advantage” (Dubey et al., 2019; Srinivasan & Swink, 2018).

Previous research has shown that advancements in BDA have the potential to improve the operations of businesses that provide goods and services (Zhong et al., 2016). Embracing BDA can aid the service sector, particularly the telecommunications sector, in improving its services as BDA helps the firms to solve the problems they encounter while providing services to the customers. It can also enable the telecommunications sector to provide custom-made services to each customer using data analysis (Muharam et al., 2021).

According to Fortune Business Insights' latest report (FortuneBusinessInsights, 2021), the global BDA market has a value of USD 271.83 billion, and it is forecasted to reach a value of USD 745.15 billion by 2030, showing a compound annual growth of 13.5%. Considering the importance of BDA, it is also important to identify the factors that create a competitive advantage for firms. Therefore, this research study investigates whether BDA capabilities affect the competitive advantage of the firms in the telecommunications sector.

Previous studies have shown that the greatest achievement of the BDA capabilities is creating valuable insights to understand the changes in the market and the business environment, and creating a competitive advantage for a firm (Wamba et al., 2017). Another research has also emphasised that BDA may provide valuable information, which can enhance competitive advantage (Morabito, 2015).

BDA capabilities help firms transform their operations through innovative business models and procedures and enterprise-oriented practices (Côrte-Real et al., 2017). It enables the firms to have a competitive advantage. Firms that use BDA effectively perform better compared to their competitors. BDA facilitates the firms understanding customer choices and developing the products and services accordingly, which gives them a competitive advantage.

BDA capabilities, along with the right organisational and technological resources, provide valuable and instrumental insights and competitive advantage (Agarwal & Dhar, 2014; Côrte-Real et al., 2017).

The majority of the organisations that invest in enhancing BDA capabilities are motivated by gaining important insights into customer behaviour, market dynamics, and emerging trends, which enables them to adapt, innovate, and excel in the market, and may provide them with a competitive edge (Mikalef et al., 2018). Recent studies in the telecommunications sector also confirm that BDA has a positive effect on the competitive advantage (Alshawawreh et al., 2024). Bag et al., (2023) show that adopting BDA enables the management of firms to concentrate on organisational resources, capabilities, and competencies, which leads to a competitive advantage.

Although some studies have been done on the telecommunications sector, limited studies have examined the relationship between BDA capabilities and competitive advantage. Therefore, further investigation into this aspect can be quite useful for managers as well as employees who work with big data technologies (Nikolić, 2017). Therefore, BDA, by designing unique business strategies, is considered to have a vital impact on the company's competitive advantage.

However, a few studies have shown that most of the companies are unable to gain a competitive advantage despite taking BDA initiatives (Côrte-Real et al., 2019). This research has also highlighted the need to research further for a better understanding of whether organisations can gain a competitive advantage from BDA capabilities. Therefore, to analyse whether or not whether BDA capabilities give an organisation a competitive advantage, the current study's first hypothesis is that:

H1: Big data analytics capabilities have a positive impact on creating competitive advantage.

Big Data Analytics Capabilities' Effect on Business Model Innovation

The existing research has focused on new venture creation regarding technology use, but not enough consideration is given to the exploration of the dynamic process of interaction between resources (internal and external) of technology-based enterprises to promote business model innovation (Koka & Prescott, 2008). The existing research has established that the organisations that rely on BDA report better innovation-related performance (Khan & Tao, 2022; Zheng et al., 2022). However, the impact of BDA Capabilities on a firm's innovation performance needs further research to be fully understood. Innovation is fundamental to achieving business value. Nonetheless, there is scarce research on what changes organisations should make to grasp innovation (Munir et al., 2022). The use of BDA capabilities for implementing innovative strategies (Ciampi et al., 2021; Munir et al., 2022) is transforming the way many businesses operate (Santoro et al., 2018).

Business models used by businesses all over the world were badly affected after the COVID-19 pandemic (Clark et al., 2020). This made it essential for businesses to devise effective mechanisms to recover from the challenges they faced after the COVID-19 pandemic (Breier et al., 2021). To recover from the effects of this global crisis, new opportunities need to be created, which can be done by bringing innovation to the existing business models (Breier et al., 2021). This indicates the requirement of conducting research to understand the factors affecting business model innovation. Existing research indicates that business innovation is significantly dependent on technology (Mostaghel et al., 2022). Existing research has also established the positive impact of BDA capabilities on business model innovation (Ciampi et al., 2021). However, this area needs to be explored as only a handful of studies have been done in this area. To explore this relationship further, this study has proposed the following hypothesis:

H2: Big data analytics capabilities have a positive impact on business model innovation.

Business Model Innovation and Competitive Advantage

Most of the authors share the viewpoint that continuous business model innovation can be a sustainable source of competitive advantage, where firms constantly change business model components based on new technology development and try to satisfy the changing needs in the emerging market. Chesbrough & Rosenbloom (2002) initiated the idea that business model innovation may capture value and can be a source of creating competitive advantage. Later on, multiple authors followed this principle (McGrath, 2013; Osterwalder, 2004; Teece, 2010).

Saqib & Satar (2021) did a study on an Indian online transport service, OLA, which provides ride-sharing services. According to the study, OLA was able to gain a competitive advantage through its innovative business model that included customised customer services, a collaborative ecosystem, consumption-based pricing, and competitive expansion strategies. This supports the idea that competitive advantage can be achieved through business model innovation. However, this has not been studied in the context of other sectors, such as the telecommunications sector. Therefore, it is hypothesised for the telecommunications sector of Pakistan that:

H3: Business model innovation has a positive impact on creating competitive advantage.

Based on H2 and H3, it can also be hypothesised that:

H4: Business model innovation mediates the relationship between big data analytics capabilities and competitive advantage.

Environmental Uncertainty as a Moderator

Uncertainty is defined as "the inability to assign an objective probability to each potential outcome or the inability to predict the likelihood of an event occurring" (Knight, 1921). Environmental uncertainty is defined as the likelihood of unexpected changes in the environment in which firms operate. This includes the unexpected economic, technological, and political changes (Eroglu & Hofer, 2014; Sharfman & Dean, 1991).

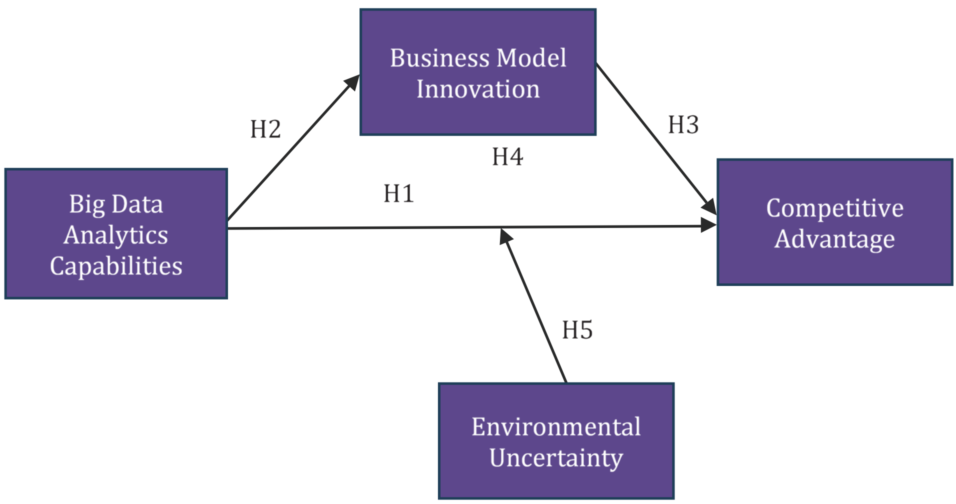
Companies have to deal with environmental uncertainties so that they remain competitive by continuing their business activities (Aldrich, 2008). Environmental uncertainty can be considered both a threat and an opportunity for firms to innovate their business processes and operations. It can be explained as firms spending most of their resources to cope with the changes in external factors rather than focusing on innovation that leads to competitive advantage (Zhou et al., 2007). On the other hand, firms facing high levels of environmental uncertainties might divert most of their resources to innovation, which helps them achieve a competitive advantage as compared to those with lower levels of uncertainties.

The ability of the company to achieve its goals and objectives is dependent upon the environment in which the firm operates. Therefore, firms operating in a dynamic environment need to respond quickly to maintain their competitive advantage (Koka & Prescott, 2008). Therefore, apart from posing a threat to the firms, environmental uncertainty has a lot to offer. As environmental uncertainty acts both as an opportunity and a threat for the firms, companies that can combat the threat and avail the related opportunities by making the right investment decisions and implementing innovative ideas can achieve a competitive advantage (Dreyer & Grønhaug, 2004). Therefore, apart from creating the risk for firms, environmental uncertainty also presents many opportunities (Lee et al., 2015). The direct effect of environmental uncertainty on competitive advantage has been studied in various studies (Koç et al., 2022). Similarly, the moderating role of environmental uncertainty in the digital platform capability and competitive advantage relationship in manufacturing companies has also been studied (Liao et al., 2024). However, there is apparently no study available on the moderating role of environmental uncertainty in the BDA capabilities and competitive advantage nexus. Thus, the current study proposes the following hypothesis:

H5: Environmental uncertainty acts as a moderator between big data analytical capabilities and competitive advantage.

The research model is given in Figure 1.

Figure 1: Theoretical Framework



Source: Authors' compilations.

3. THEORETICAL FRAMEWORK

Although the literature on the business potential of BDA is expanding, the empirical work that applies the established theories is still quite limited in the IT-business value domain (Gupta & George, 2016). The current study used a deductive approach based on the resource-based view (RBV) as well as the emerging dynamic capabilities view (DCV) of the firm.

The RBV provides the basis for identifying and evaluating all the relevant resources in terms of their importance. It is widely used in the information technology context, especially in measuring IT-related capabilities (Bharadwaj, 2000). According to the RBV, an organisation consists of a bundle of tangible and intangible resources that provide the basis for creating competitive performance gains (Mikalef et al., 2016). Resources are defined as assets, knowledge, capabilities, and processes. Thus, BDA capabilities are an organisation's intangible resource that may create a competitive advantage for it. The RBV suggests that organisations may attain competitive advantage based on various resources and capabilities (BDA capabilities in the current research) that are in their control, and based on these capabilities, organisations can innovate by introducing new concepts and models.

The DCV tries to explain how organisations sustain a competitive advantage in changing environments (Eisenhardt & Martin, 2000). Thus, both the internal and external environmental factors should be considered to take the actions required to perform operations according to changing demands. Therefore, in the current research, environmental uncertainty is defined as a changing environment, which is a moderating variable that indirectly affects competitive advantage.

The theoretical framework of the study is developed based on the above conceptual background. The framework explains how BDA capabilities create a competitive advantage for the companies that use big data. The BDA capabilities-comparative advantage relationship is mediated by business model innovation and moderated by environmental uncertainty.

4. MATERIALS AND METHODS

Most of the telecommunications firms use big data in their daily operations and require financial and human resources to take advantage of big data. Financial resources are required for deploying databases on servers, while human resources are required to maintain the databases and extract information from the data through analytics. Therefore, to analyse BDA capabilities and their effects, the target population for this study was the telecommunications sector of Pakistan.

Sampling and Research Design

For the selection of a sample from the telecommunications sector, the multistage sampling technique was used. In the first stage, random sampling was adopted to select the sample, i.e., nine telecommunications companies from the population of a total of 18 telecommunications companies in Pakistan. Letters and/or emails to all the randomly selected companies were sent to request their participation in this research study. In response, seven companies agreed to participate in the study. In the second stage, the focal persons from the middle and high organisational tiers were contacted. These focal persons were also requested to randomly select the branches of their respective firms for data collection. In the third stage, a random selection of the respondents/participants was made by the firms from the lower, middle, and higher tiers based on the criterion that employees are directly or indirectly involved in using BDA in the firm's operations. In total, 304 responses from all the telecommunications firms were collected based on random sampling.

The adequacy of the sample size was verified based on multiple methods. First, the suggestion provided by Hair et al. (2021) was taken into consideration. According to them, the minimum sample should be equal to 10 times the largest number of structural paths directed at a particular construct in the structural model. In this study, there are three paths directed towards the endogenous variable (including the moderator). Therefore, according to this principle, a minimum sample size of 30 was adequate. Second, the inverse square root method suggested by Kock & Hadaya (2018) was used for the minimum sample size. Keeping in view the 5% significance level and the minimum path coefficient of 0.3, the minimum sample size came out to be 68.66. Third, Cohen(1992) suggested calculating the sample size using the maximum number of arrows pointing towards the construct and R2. Keeping in view the model, three arrows point towards the construct (including the moderator variable), and if the minimum achievable R2 is 0.50 (medium effect size), the minimum sample size comes out to be 38.

The sample size calculator available on the web (Soper, 2024) was also used for sample size calculation. Soper (2024) is supported by the suggestions of Cohen (1992) and Westland (2010). According to Soper (2024), for the anticipated medium effect size of 0.3, desired statistical power of 0.8, 8 latent variables, and 45 observed variables, the minimum sample size is 177. Since a sample of 304 exceeds all the minimum sample size selection criteria discussed above, it was deemed sufficient for the analysis using PLS-SEM. Also, as PLS-SEM is a non-parametric technique, some researchers argue that it is robust even for a smaller sample size.

To fulfil the objectives of the study, a quantitative study was conducted. The choice of conducting the quantitative study is supported by the view of various authors (Watson, 2015). In the past, however, the qualitative approach has remained common (see, for example, Bhatti et al., 2022; Sabharwal & Miah, 2021). Also, quantitative research employs standardised procedures, measurement instruments, and statistical methods that lead to more reliable and valid results. This also helps promote evidence-based decision-making in domains like psychology and organisational behaviour (Saunders et al., 2019).

Quantitative research was performed using the survey questionnaire distributed among respondents. To validate the data collected through the survey, the responses were triangulated with semi-structured interviews with the top and middle management. Interviews provided us with in-depth opinions and views regarding the BDA capabilities of the telecom firms, innovation techniques, and models the firms are using, the level at which firms can create competitive advantage, and the uncertainties due to dynamically changing market and external forces involved in it. The interviews were used to validate the findings from the quantitative responses and to identify the reasoning. A total of eight individuals from the high-level and middle-level management were interviewed.

Measurements

The measurements proposed by Sun & Liu (2021) and Ashaari et al., (2021) were used to measure BDA capabilities. These measures comprise three dimensions:

1. Infrastructure capabilities, which was measured using the question, "Our organisation gathers data from multiple sources for data analysis."

2. Human resource capabilities, which was measured using the question, "Our analytic staff are very knowledgeable about the role of business analytics."

3. Management capability, which was measured using the question, "Our organisation performs big analytics planning processes in systematic ways."

The questionnaire contained questions on business model innovation, which is measured using a six-item scale adapted from Asemokha et al., (2019). The question on business model innovation was, "We leverage big data insights to optimise our internal operations for better opportunities."

Environmental uncertainty was measured using three dimensions, namely, market/demand turbulence (four items), technology turbulence (four items), and competitive intensity (six items). Market/demand turbulence and technology turbulence had four items each, while competitive intensity had six items. The measures were adopted from previous studies (Grewal & Tansuhaj, 2001; Jaworski & Kohli, 1993; Uzkurt et al., 2012). The question on environmental uncertainty was, 'The demand of our customers varies a lot'. Finally, competitive advantage was measured with the six-item scale adopted from Singh et al. 2019). The question used to measure competitive advantage was, "Our organisation's products/services are better than its competitors." The responses of all the constructs were measured using a 5-point Likert scale, with 1 = Strongly Disagree and 5 = Strongly Agree.

Analysis Tools

The data was analysed using SPSS. The hypotheses were tested using PLS-SEM. PLS-SEM has high statistical power (Hair et al., 2023) and is widely accepted and preferred in business research fields, such as information systems, consumer behaviour, and marketing (Peng & Lai, 2012). SmartPLS version 4.0, which is a scientifically grounded software (Memon et al., 2021), was used for data analysis. This software has proven to be very useful in helping researchers analyse complex relationships between latent variables, i.e., moderation and mediation (Cheah et al., 2024).

5. RESULTS

The demographic information of the respondents in the telecommunications sector in Pakistan is illustrated in Table 1. Key findings shed light on various aspects, including gender, education, organisational representation, and the distribution of roles within these organisations.

The sample was predominantly male, with 76.6% of respondents identifying as male, indicating a notable gender imbalance. Most respondents were between 25 and 40 years old (82.9%), suggesting the study largely reflected individuals in the early to mid-stages of their careers. The sample was also highly educated, with 75% holding a bachelor's degree or equivalent, highlighting the presence of strong academic backgrounds among participants. Furthermore, the sample was distributed across higher, middle, and lower management tiers within their organisations. This distribution allowed for a comparison of perspectives and experiences across different levels of management responsibility and authority. The sample also exhibited a wide range of experience levels, but the majority (66.5%) had between 1 and 15 years of experience. Overall, the sample population was characterised by a young, well-educated, predominantly male workforce employed in the private sector. This demographic profile provided valuable insights into the characteristics and experiences of the individuals who participated in the study.

Table 1: Frequency Distribution of Industry Characteristics

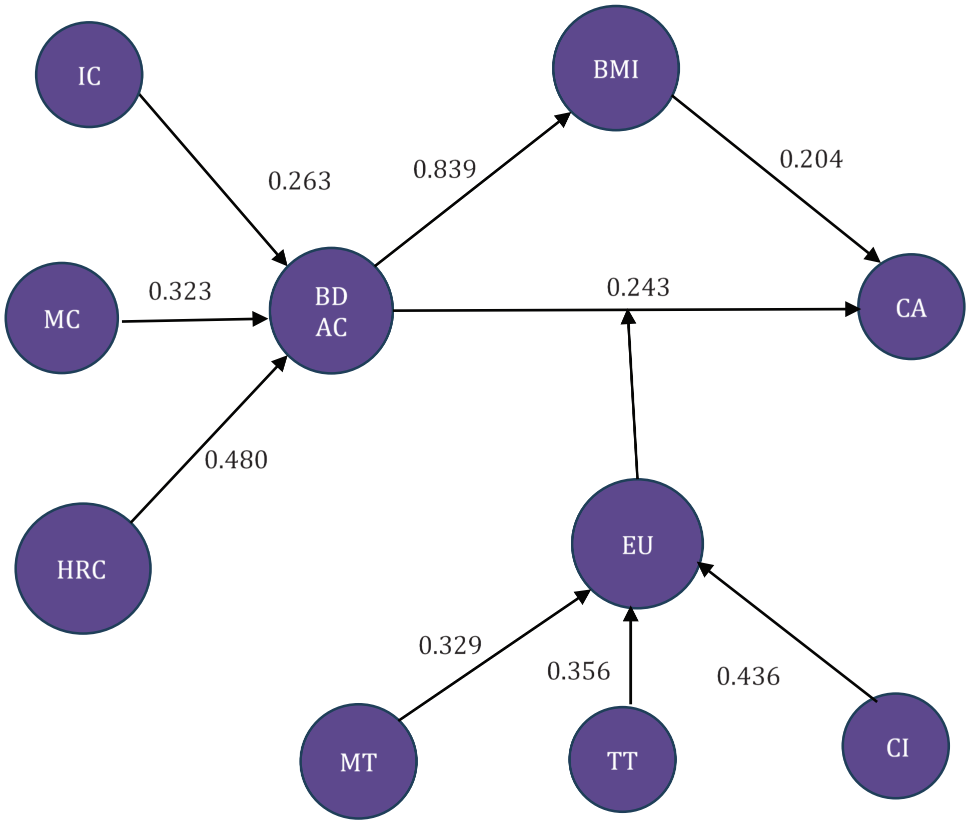
Demographic	Frequency	Percent	Cumulative Percent
Gender			
Male	223	76.6	76.6
Female	71	23.4	100
Total	164	100	
Age			
Below 25	52	17.1	17.1
25-30	117	38.5	38.5
31-40	83	27.3	27.3
41-50	48	15.8	15.8
Above 50	4	1.3	1.3
Total	304	100.0	100.0
Education			
BS or equivalent	228	75.0	75.0
MS or equivalent	69	22.7	97.7
PhD	3	1.0	98.7

Demographic	Frequency	Percent	Cumulative Percent
Other	4	1.3	100.0
Total	304	100.0	
Org Tier			
Higher Management	48	15.8	15.8
Middle Management	113	37.2	53.0
Lower Management	143	47.0	100.0
Total	304	100.0	
Age			
Below 25	52	17.1	17.1
25-30	117	38.5	55.6
31-40	83	27.3	82.9
41-50	48	15.8	98.7
Above 50	4	1.3	100.0
Total	304	100.0	
Experience			
1-5 years	68	22.4	22.4
6-10 years	80	26.3	48.7
11-15 years	54	17.8	66.4
16-20 years	29	9.5	76.0
21-25 years	34	11.2	87.2
26-30 years	14	4.6	91.8
31-35 years	18	5.9	97.7
36-40 years	7	2.3	100.0
Total	304	100.0	

Source: Authors' compilations.

The measurement model was assessed to check the reliability and validity of the constructs. The results are displayed in Figure 2. Reflective measurement techniques, which rely on the influence of the measures on each other, were used for the assessment. To ensure that the measures accurately captured the intended concepts (construct validity), the focus was on three key aspects, namely, internal consistency reliability, convergent validity, and discriminant validity (Hair et al., 2023).

Figure 2: Measurement Model



Source: Authors' illustration.

Construct validity essentially refers to how well a test measures the intended constructs. Hair et al. (2023) identify two main approaches to assess this validity, i.e., convergent validity and discriminant validity. Convergent validity examines how closely the measures of the same construct are related. High correlations between these measures (indicated by standardised outer loadings above 0.700) suggest they capture the same concept effectively (Hair et al., 2023). However, even if some loadings fall below this threshold, the measure can still be acceptable if the average variance extracted (AVE) for the construct surpasses 0.50 (Hair et al., 2023). A high AVE indicates that, on average, the construct explains more than half of the variation in its measures, suggesting a good fit. Table 2 presents the results of this measurement model evaluation.

Table 2: Measurement Model

Construct		Item	Factor Loading	Composite Reliability	AVE
Business Model innovation		BMI1	0.853	0.926	0.730
		BMI2	0.868		
		BMI3	0.847		
		BMI4	0.887		
		BMI5	0.845		
		BMI6	0.823		
Competitive Advantage		CA1	0.857	0.918	0.706
		CA2	0.833		
		CA3	0.831		
		CA4	0.813		
		CA5	0.848		
		CA6	0.856		
Big Data Analytics Capabilities	Human Resource Capabilities	HRC1	0.862	0.960	0.756
		HRC2	0.861		
		HRC3	0.879		
		HRC4	0.859		
		HRC5	0.841		
		HRC6	0.895		
		HRC7	0.868		
		HRC8	0.891		
		HRC9	0.870		
	Infrastructure Capabilities	IC1	0.866	0.928	0.776
		IC2	0.878		
		IC3	0.896		
		IC4	0.896		
		IC5	0.869		
	Management Capabilities	MC1	0.878	0.938	0.761
		MC2	0.900		
		MC3	0.865		
		MC4	0.868		
		MC5	0.854		
		MC6	0.871		

Construct		Item	Factor Loading	Composite Reliability	AVE
Environmental Uncertainty	Technological Turbulence	TT1	0.867	0.859	0.697
		TT2	0.844		
		TT3	0.735		
		TT4	0.885		
	Market Turbulence	MT1	0.827	0.876	0.729
		MT2	0.882		
		MT3	0.867		
		MT4	0.838		
	Competitive Intensity	CI1	0.891	0.904	0.721
		CI2	0.853		
		CI3	0.848		
		CI4	0.845		

Source: Authors' compilations.

The measurement model assessment utilising PLS-SEM revealed strong psychometric properties across all constructs. Business model innovation (BMI) exhibited excellent internal consistency and convergent validity, as evidenced by composite reliability (CR) of 0.926 and an AVE of 0.730. Similarly, competitive advantage (CA) demonstrated exceptional reliability and validity, with a CR of 0.918 and an AVE of 0.706. The BDA construct had three dimensions, namely, the human resource capabilities, infrastructure capabilities (IC), and management capabilities (MC). The HRC had a CR of 0.960 and an AVE of 0.756, showcasing remarkable internal consistency and convergent validity. The IC had a CR of 0.928 and an AVE of 0.776, which also meet the convergent validity criteria. Similarly, MCs were also found to be internally consistent with a CR of 0.938 and an AVE of 0.761. Environmental uncertainty (EU) was also measured using three dimensions. Technological turbulence (TT) exhibited good internal consistency with a CR of 0.859 and an AVE of 0.697. Similarly, other dimensions, market turbulence (MT) and competitive intensity (CI) were also found to be consistent with CRs of 0.876 and 0.904 and AVEs of 0.729 and 0.721, respectively.

After assessing the internal consistency and convergent validity of the constructs, discriminant validity was assessed. Hair et al. (2023) define discriminant validity as a measurement instrument's ability to distinctively represent a concept, affirming its uniqueness in a model. This validity is confirmed when the square root of the AVE exceeds inter-construct correlations. Three criteria, including cross-loadings, the Fornell-Larcker criterion, and HTMT, were used to assess discriminant validity following Hair et al. (2023) and Henseler et al., (2009). The Fornell-Larcker criterion states that each construct's square root of the AVE should surpass its inter-construct correlations.

Table 3 shows that all AVE values surpassed the corresponding squared correlations, confirming the distinctiveness of each construct. For instance, CA had an AVE of 0.840, significantly higher than its highest squared correlation of 0.689 with other constructs. This indicates that CA is a unique concept, separate from others in the model. Similar patterns were observed for all other constructs, with AVE values consistently exceeding squared correlations, underscoring the model's strong discriminant validity. These results demonstrated that the constructs were distinct and well-defined, allowing for clear interpretation and analysis of their relationships. The model's robust discriminant validity further solidified its foundation for further investigation, ensuring that any observed relationships between constructs were not due to overlap or measurement error, but rather reflected true differences in the underlying concepts.

Table 3: Fornell-Larcker Criterion

	BMI	CA	CI	MT	HRC	IC	MC	IT
BMI	0.854							
CA	0.688	0.840						
CI	0.622	0.633	0.849					
MT	0.602	0.534	0.575	0.854				
HRC	0.779	0.708	0.628	0.617	0.870			
IC	0.768	0.554	0.599	0.549	0.795	0.881		
MC	0.815	0.658	0.551	0.529	0.826	0.824	0.873	
IT	0.701	0.657	0.784	0.710	0.687	0.629	0.601	0.835

Source: Authors' compilations.

The discriminant validity was assessed using the Heterotrait-Monotrait (HTMT) ratio, following the recommendations of Hair et al. (2023). The results of this analysis are presented in Table 4. When the HTMT value exceeds 0.85, it indicates a potential issue with discriminant validity. Conversely, values below 0.85 are indicative of good discriminant validity (Hair et al., 2023). As demonstrated in Table 4, all HTMT values were below 0.85, signifying robust discriminant validity. Thus, the evaluations of convergent and discriminant validity affirmed the reliability and validity of the measurement items, allowing hypothesis testing.

Table 4: Heterotrait-Monotrait (HTMT) ratio

	BMI	CA	CI	MT	HRC	IC	MC	TT	EU x BDA
BMI									
CA	0.744								
CI	0.680	0.690							
MT	0.667	0.595	0.647						
HRC	0.826	0.752	0.674	0.673					
IC	0.828	0.596	0.654	0.609	0.842				
MC	0.875	0.704	0.597	0.583	0.868	0.882			
TT	0.786	0.741	0.891	0.825	0.759	0.706	0.671		
EU x BDAC	0.682	0.634	0.613	0.623	0.672	0.640	0.623	0.724	

Source: Authors' compilations.

The quality of the structural model was evaluated using various indicators, including R^2 and Q^2 values. According to Hair et al. (2021), R^2 values fall within a range of 0 to 1, with values of 0.75, 0.50, and 0.25 representing substantial, moderate, or weak levels of variation in endogenous constructs, respectively.

Table 5 illustrates the assessment of structural model quality in the PLS-SEM analysis. The model demonstrated strong explanatory and predictive power. For each construct, a substantial portion of the variance was explained, as indicated by the high R^2 values. Specifically, the model explained 70% of the variance in BMI and 57% in CA. HRC, IC, and MC had even higher explanatory power at 91%, 82%, and 87%, respectively. Similarly, TT, DT, and CI showed explanatory power of 86%, 69%, and 81%, respectively. Overall, the R^2 values indicate that the constructs explained medium to high levels of variation. The model's predictive relevance was further supported by the Q^2 predict values, all of which are above 0.67, suggesting its ability to forecast omitted data for each construct and indicating a good fit between the observed and predicted values.

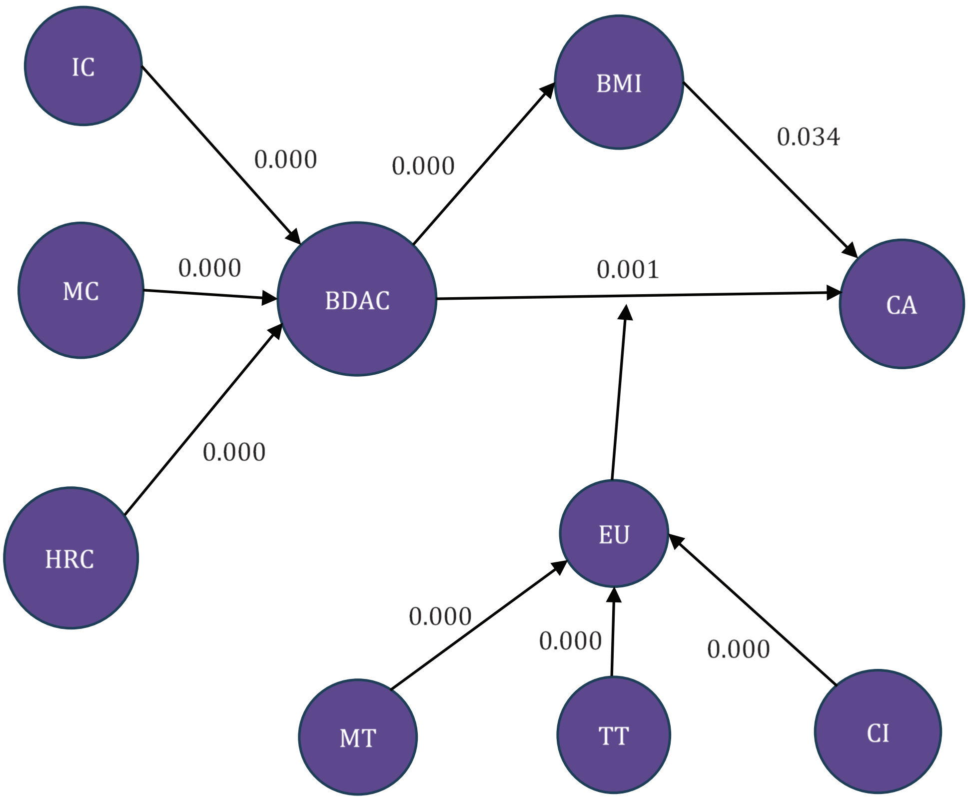
Table 5: Quality of Structural Model

Constructs	R^2	R^2 Adjusted	Q^2predict
BDAC	0.705	0.704	0.704
BMI	0.579	0.574	0.561

Source: Authors' compilations.

The Q2 statistics were computed in SmartPLS software using a PLSPredict procedure. This method is employed to assess the quality of both the path model and data fit. When the Q2 value exceeds zero, it suggests that the conceptual model possesses the capability to measure endogenous latent constructs (Henseler et al., 2016). Table 5 illustrates that the results of the Q2 statistics demonstrated the model's capacity to forecast the endogenous latent constructs effectively. All the Q2 values surpassed the predefined threshold values, indicating that the conceptual model had sufficient predictive relevance.

Figure 3: Structural Model



Source: Authors' illustration.

Table 6 provides the results of hypothesis testing. The results revealed intricate relationships between the constructs, shedding light on the dynamics of the model. The first hypothesis (H1), examining the impact of BDA on CA, was accepted, with a statistically significant relationship (p-value = 0.000; β = 0.415; t-value = 6.330), reinforcing the notion that BDA offered a competitive advantage.

The second hypothesis (H2), proposing a positive effect of BDA capabilities on BMI, was strongly supported by the data. It is evident from the statistically significant relationship between BDA and BMI (p-value = 0.000; β = 0.839; t-value = 33.252) that BDA played a substantial role in driving BMI. This suggests that firms leveraged big data to innovate their business models successfully.

The test of the third hypothesis (H3), which was proposed to investigate the direct link between BMI and CA, showed the relationship was statistically significant (p-value = 0.034; β = 0.200; t-value = 2.120). The overarching aim of this research is to investigate whether business model innovation mediates the relationship between BDA and CA. Results depicted that the mediation of BMI between the BDA and CA remained significant (p-value = 0.037; β = 0.168; t-value = 2.084).

Ensuring the accuracy of the lower and upper confidence limits is paramount. The guidelines outlined by Preacher & Hayes (2004) suggest that the acceptance or rejection of the mediation hypothesis hinges on whether the confidence interval for the mediation effect includes zero. A non-zero interval suggests the acceptability of the mediation hypothesis, while an interval encompassing zero warrants rejection. Therefore, to accomplish this, a two-step approach was employed in this study. The initial stage involved the evaluation of all direct relationships, both without and with mediators. Subsequently, in the second phase, all indirect effects were computed, and their significance was ascertained through bootstrapping. The analysis of indirect effects was conducted at the second stage, where all relevant mediators were computed. The mediation analysis results revealed a significant indirect effect of BDA capabilities on CA through the mediation of business BMI, as lower and upper bounds did not encompass zero (LCL 2.5% = 0.015, UCL 97.5% = 0.332). It provided evidence of the existence of mediation. Therefore, H4 was accepted.

The test of the fifth hypothesis (H5) revealed a moderating effect of EU on the relationship between BDA and CA. The negative interaction (p-value = 0.023; β = -0.056; t-value = 2.279) signified that the positive impact of BDA on CA was attenuated when environmental uncertainty was high. This suggests that while BDA is beneficial, its effectiveness in enhancing CA may be limited in highly uncertain situations.

Table 6: Results of the Direct Relationship of Hypothesis Testing

Path	Original sample (O)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values	2.5%	97.5%
BDA -> BMI	0.839	0.025	33.252	0.000	0.784	0.882
BDA -> CA	0.415	0.066	6.330	0.000	0.291	0.547
BMI -> CA	0.200	0.094	2.120	0.034	0.018	0.390
EU x BDA -> CA	-0.056	0.024	2.279	0.023	-0.099	-0.003
BDA -> BMI -> CA	0.168	0.081	2.084	0.037	0.015	0.332

Source: Authors' compilations.

6. FINDINGS AND DISCUSSION

The study aimed to investigate three objectives. The first objective was to investigate the effect of BDA capabilities on the CA of the telecom firms in Pakistan. The results showed that the BDA capabilities significantly affected the CA. The BDA comprised infrastructure capabilities, human resource capabilities, and management capabilities. The telecom firms had all three capabilities. According to the telecommunications firms, they could store an enormous amount of data, and the data was increasing at an enormous rate. One of the respondents mentioned:

"If the data being generated by the customer was 2 terabytes a few years ago, now the same user is generating 30 terabytes of data".

The availability of the data allows telecommunications firms to make information-based decisions. Telecommunication firms are currently equipped with the infrastructure, human resources, and management capabilities to handle and convert the data into useful information.

The second objective was to investigate the mediating role of BMI and competitive advantage. The results revealed that the BMI did not mediate the relationship between BDA capabilities and CA. One of the reasons for the insignificant mediation of BMI could be the hyper-competitiveness of the telecommunications sector. As one of the respondents from the telecommunications sector said:

"It is a hyper-competitive sector. If one company offers a product, the second company offers the same for three rupees less, and in the next two hours, the third company offers it at 10 rupees less. Unfortunately, although policies also have partly played a part in it, but I think where the competition has gone wrong is that our ARPU (Average Revenue per User) has reduced to a very low level, which the customer might think is great from the affordability perspective, but we are unable to improve the network because there is no money in the sector."

The respondent further added that:

"Although the ARPU is low, we are only able to keep our heads above the water due to the increasing number of subscribers."

This suggests that it is mostly the pricing strategy that is employed to attract customers, and there are no substantial innovative propositions to attract customers. One of the respondents had to say the following in this regard:

"Not really; in any competitive market, pricing is an issue. People would always choose the cheaper solution".

As telecom firms have enormous amounts of data, they use the data for providing various services, suggesting that the firms innovate business models. The respondents said:

"We remain within the limits and abide by the policies but monetise the data. As we have the data, we have the ability to provide exact information to any firm or business coming to us. We slice and dice the data, and then we tell them that there are 1 million customers who are identified. If they want targeted marketing, we can do it using our network".

The value is not generated only by one innovative solution provided. There are many services that are offered to the customers based on the evaluation of the data. These services are regularly used by the customers. According to the respondents:

"All the services that are being offered to the customers are based on the evaluation of the data. We cannot differentiate the specific value that is being generated from a single service. One should understand that transforming from being a simple telecommunications firm to the digital world is in itself an innovation in the business model. Now that we live in a digital world, we evaluate the type of services required by customers using data. We analyse the data and then we offer what our customers require."

It is interesting to see that the telecommunications firms are not only capable of offering the communication channel to the customers but also the services to the other public and private sectors. Now, the private and public sectors can seek the services of the telecom firms. Telecommunications firms have the capability to provide the public and private sectors with the required information. However, the respondents identified various challenges, which could become a possible barrier to innovating the business model. The respondents were very much concerned with the services to be offered to the public sector organisations. As one of the respondents highlighted:

"We can offer the services to both the private and public sectors. The issue is not with the private sector, but the public sector. One of the biggest customers can be the public sector, but they don't pay for the services. I will give you an example. During COVID-19, the government required data for the identification of the areas that were COVID-19-infected. The government asked the telecommunications firms for their assistance in identifying the COVID-19-infected areas based on the data that we had. We analysed our data and identified the COVID-19-infected areas. But this was all done in the name of corporate social responsibility. The government did not pay the telecommunications firms. On the other hand, if a customer has to buy a SIM, they have to register their biometrics, which is authenticated by NADRA. The government charges us for every biometric that is registered. If the government has enabled the monetisation of their services, why can't telecommunications firms monetise the services for the Government of Pakistan?"

The monetisation of the services was not the only issue why the telecommunication firms think innovating the business model is an issue. Two more concerns were shown by the telecommunications firms. The first is the limitations pertaining to the infrastructure/hardware, and the second pertains to human resources. Although telecommunications firms have the infrastructure capabilities, two limitations prevent the new services and innovations from being implemented. The first is the data protection bill, which bars the firms in Pakistan from storing customers' data on the network infrastructure/clouds outside Pakistan. This creates hardware constraints for the telecommunications firms. According to the respondents:

"The clouds available in Pakistan are not mature enough and cannot be relied upon."

Respondents further added:

"The future is in predictive analytics. This requires artificial intelligence-based solutions, which would provide this sector with a new dimension of competitive advantage. Unfortunately, we do not have the equipment to support predictive analytics."

Another respondent added:

"We wanted to develop an artificial intelligence-based chatbot; unfortunately, we could not test it due to the hardware limitation. We can procure the hardware, but it requires a lot of time and is usually very heavily taxed. Take an example of a graphics processing unit, which is required in the processing of huge amounts of data. Unfortunately, there are huge taxes and embargoes on the import of the hardware."

The respondents also highlighted that:

"As the dollar is also highly unstable, the purchase of the equipment also becomes costly for us. Therefore, any innovation in the business that can provide benefits to the customers cannot be offered due to the fluctuating dollar and government policies."

The respondents continued:

"The solution to the infrastructure problems is that the government should try bringing data centres of the international clouds, such as Amazon Web Services (AWS), Google, and Microsoft Azure, to Pakistan. These are very mature services and can solve the storage as well as processing issues."

Another respondent said:

"The government is encouraging the development of the cloud, which can be used for big data analytics, but it is the cost of the infrastructure which is a real challenge. The costs are too high, the conversion of Pakistani rupee to Dollar is risky, and there are taxes and duties on top of it. With the way technology is changing and customer requirements evolving, better infrastructure is not a requirement but a necessity. On the other hand, it is becoming equally difficult to get the technology which supports customer requirements."

The respondents not only added the issues with the infrastructure capabilities, but also with the human resource capabilities. Although the telecommunications firms, according to their requirements, establish good

“Good human resources is also difficult to find. There is a lot of brain drain from Pakistan. The people who know data science and work in the big data analytics area are uncertain about the future. Why would a person like to stay in Pakistan when, even after paying such heavy taxes, the government is not going to facilitate the taxpayers? People find attractive opportunities and exit the country.”

In such cases, where telecommunications firms are facing multiple challenges in infrastructure capabilities and human resource capabilities, it becomes a challenging task to innovate the business model to gain a competitive advantage. Therefore, insignificant mediation of BMI is due to the challenges being faced by telecommunications firms in further improving their infrastructure and human resource capabilities.

The third objective was to investigate the moderating effect of environmental uncertainty on the relationship between BDA capabilities and competitive advantage. Environmental uncertainty had a significant negative effect on the relationship. This suggests that environmental uncertainty reduces the positive effect of the BDA capabilities on competitive advantage. Environmental uncertainty was measured using market turbulence, technological turbulence and competitive intensity. Although telecommunications firms are continuously facing a dynamically changing market, they are trying their best to adapt and remain competitive in the market. There is evidence that telecommunications firms try to meet the requirements of their customers, but the firms have concerns that lead to the negative moderating effect of the environmental uncertainties on BDA analytics and competitive advantage.

The improvement in the infrastructure and the government policies are identified as the reasons. It has already been discussed in this section that telecommunications firms need to improve their infrastructure if they need to provide new services to customers. Heavy taxation, the embargo on the hardware, fluctuation in the rate of the dollar, and inconsistent government policies make it difficult for telecommunications firms to remain competitive in the market. A respondent highlighted in one of his comments:

“There is a reason why we are unable to jump to 5G, whereas there are countries that are implementing 5G now. This is because of the cost of infrastructure. Telecommunications firms are unable to develop the infrastructure because of the very high cost. Along with that, the economy of Pakistan is very unstable, which also destabilises the dollar.”

human resource capabilities, they have concerns about the brain drain from Pakistan. A good human resource is necessary to innovate the business models and provide solutions according to the dynamically changing market. The respondents from the telecommunications firms added:

“Good human resources is also difficult to find. There is a lot of brain drain from Pakistan. The people who know data science and work in the big data analytics area are uncertain about the future. Why would a person like to stay in Pakistan when, even after paying such heavy taxes, the government is not going to facilitate the taxpayers? People find attractive opportunities and exit the country.”

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It was further added by the respondent:

“In Pakistan, if you need a license, the telecommunications firms have to pay approximately USD 30 million upfront. Usually, the governments in Pakistan last 2-3 years, whereas the license is for 15 years, so governments don’t care about what is going to happen later. They intend to recover as much money as possible during their tenure.”

The respondent further added:

Since USD 30 million is a huge amount, the government has allowed deferred payments, but at Kibor plus some percentage. This thing is, given that there is depreciation of the rupee and inflation, a disaster for telecommunications firms. If I agree with the deferred payment, but if the dollar rate goes up (the rupee depreciates) and I am earning in rupees, the same USD 30 million that I had to give as a deferred payment will become USD 50 million. This is the reason why most of the operators suffered operational losses.”

One of the respondents further added:

“Warid and Telenor left because both were struggling. It is not possible that these companies were run with bad management; rather, there is something fundamentally wrong with how this sector is being run.”

On top of this, the competitiveness of telecommunications firms is further affected by the facilities that are expected to be provided by the government to the telecommunications sector. The respondent added:

“Our base stations are supposed to run on electricity. Due to the unexpected load shedding, we run the base stations on diesel. This eventually affects our overall cost, further affecting the competitive gains.”

As already discussed, the telecommunications sector faces high costs to procure hardware and other infrastructure development, which, along with government policies, result in the erosion of BDA capabilities and competitive advantage.

7. CONCLUSION

Telecommunications firms have developed BDA capabilities, which contribute to the competitive advantage of telecommunications firms. The telecommunications firms have established their local cloud and hired competent human resources who can perform data analytics based on the data stored on the cloud. The BDA analytics run by the firms are either for the improvement of their existing products or to identify their target market for their new products/services. By doing so, the telecommunications firms have been able to innovate their business models, enabling them to offer more than just a medium to communicate with their customers. Telecommunications firms, based on their innovative business models, have managed to gain a competitive advantage where they are able to differentiate themselves in the market. However, insights from the respondents from the telecommunications sector point towards multiple challenges in building BDA capabilities, especially infrastructure and human resources, due to the dynamically changing market (customers' requirements change rapidly) and rapid change in technology.

To address the dynamically changing requirements of customers and the evolution of technology, telecommunications firms need to improve their infrastructure continuously. The infrastructure, which includes the hardware, costs in US dollars, but due to the unstable Pakistani economy, the rate of the Pakistani rupee keeps fluctuating against the US dollar. The telecommunications firms in Pakistan, which acquire spectrum licenses in US dollars, earn in Pakistani rupees. Pakistan has one of the lowest ARPU in the world, and the ARPU has declined in US dollar terms over the last few years. As the ARPU of telecommunications firms is decreasing in this hyper-competitive market and due to overall macroeconomic challenges, the telecommunications firms have faced a considerable reduction in revenues in US dollar terms, which is threatening the survival of the telecommunications sector. Along with this, there are heavy taxes and embargoes on hardware imports.

Along with the infrastructure, there are issues related to another capability of BDA, namely, human resources. Telecommunications firms are finding it difficult to hold good human resources. One of the reasons for this is the imposition of heavy taxes by the government and the provision of inadequate facilities. Due to these reasons, any good and experienced human resource professional who finds a good opportunity abroad leaves the country. The telecommunications firms face challenges due to the lack of experienced human resources.

Although telecommunications firms are currently gaining a competitive advantage using BDA capabilities and, their' overall competitive advantage is being negatively affected due to the environmental uncertainties caused by market turbulence, technological turbulence, and competition intensity. The rapid technological change also changes customer preferences/requirements, causing intense competition. The reason for the negative moderating effect of the environmental uncertainty on the BDA capabilities-CA relationship is due to the government policies, unstable Pakistani rupee, heavy taxation, and lack of facilities. Although the government is encouraging the development of local clouds, it needs to facilitate the firms to develop the clouds so that they can compete in the international market.

8. LIMITATIONS OF THE STUDY

This study mainly focused on the telecommunications sector of Pakistan to analyse the effect of its BDA capabilities on its competitive advantage and to understand the role of BMI and environmental uncertainty. The telecommunications sector was selected for this study because, according to the literature, this sector has implemented and provided cloud services commercially to users in Pakistan. Since the telecommunications sector was the focus of this study, the data collected was limited to the telecommunications sector of Pakistan. Most of the service and manufacturing sectors were not a part of this study, limiting the scope of the study to the telecommunications sector.

In future, other sectors, including the manufacturing and services sectors of Pakistan, can be studied to assess their capabilities for the provision of cloud services and handling BDA capabilities to gain a competitive advantage. The health sector can particularly benefit from BDA capabilities. However, it needs to be seen how many sectors can develop the BDA capabilities, such as infrastructure capabilities, human resource capabilities, and management capabilities. Therefore, it would be interesting to study different sectors to analyse the challenges in the development of BDA capabilities and evaluate their effect on their competitive advantage.

As the development of BDA capabilities is an expensive affair, most of the issues and problems in the development of BDA capabilities may remain the same for other industries as well. For example, infrastructure development costs in US dollars, whereas the firms earn in Pakistani rupees. Therefore, a continuous fluctuation in the exchange will affect any other industrial sector that wants to develop the cloud for BDA capabilities. Moreover, better opportunities for the youth abroad and brain drain from Pakistan will also be a challenge for other sectors as well. However, a research study should help understand other industrial sectors' perspectives and the way forward.

Another limitation is the lack of the government's perspective in this study. As the focus of the study was only the telecommunications sector, the perspective of government agencies related to information and communication technologies is missing in this study. It would be interesting to conduct a study to get their perspective on the development of BDA capabilities in different industrial sectors in Pakistan.

9. POLICY RECOMMENDATIONS

Although telecommunications firms were found to have BDA capabilities to gain a competitive advantage and innovate their business model, the following concerns were noted during the course of research. Based on these concerns, recommendations are made for policy reforms.

Infrastructure

Clouds at the national level are not mature in comparison to the international clouds. One of the reasons is the lack of improvement in the infrastructure capabilities. Keeping in view the rapidly growing technology, telecommunications firms are unable to provide innovative BDA solutions. The reasons are high taxation, customs duties, and embargoes on the hardware equipment.

Recommendations

To take the cloud services to maturity, telecommunications firms must be provided with the appropriate infrastructure equipment for the improvement of their BDA capabilities. To do so, the government needs to develop a framework to facilitate telecommunications firms' easy access to the required hardware equipment. If importing hardware for the development of clouds with BDA capabilities is not possible, the government should try to attract international cloud providers to invest in Pakistan and bring their data centres to Pakistan. As the Data Secrecy Act does not allow firms in Pakistan to store data on international clouds, the government must look into the revision of the policy.

Exchange Rate Fluctuations

As the procurement of the hardware necessary for the development of cloud services and BDA infrastructure is done in US dollars, the procurement process poses a serious issue due to the unstable Pakistani rupee. For this reason, the telecommunications firms, which are already paying for the licenses in US dollars to the government, face difficulties in buying the required equipment.

Recommendation

Although the Data Secrecy Act does not allow Pakistani firms to store big data on international clouds, the government encourages the development of clouds at the national level. Therefore, the government should facilitate those organisations which intend to develop cloud services. The government may, in such cases, plan a supportive financing/subsidy so that the firms are provided with the hardware easily. Pakistan also has embargoes on the hardware that provides high processing capacity. Efforts should be made to lift the embargoes on such equipment.

Brain Drain

The telecommunications firms are facing a high turnover rate of professionals with expertise in BDA. According to the telecommunications firms, human resources having expertise in BDA leave after a short span of time due to international offers. The reason is better placement and facilities compared to Pakistan.

Recommendation

A framework needs to be developed by the government to retain the intellect within the country to reduce brain drain. The individuals with expertise in the area of computing/BDA/computer-related knowledge should be facilitated with better quality of living, financial stability, and stable infrastructure. The government should try to create a more secure environment in the country with equality and a guarantee of better living standards.

High Costs

Telecommunications firms are concerned that at the time of the purchase of a spectrum license, the spectrum's base prices are kept excessively high and benchmarked and denominated in US dollars, which makes it extremely difficult for the operators to invest in new technologies and infrastructure. Infrastructure is the backbone for digital enablement in the country. Operators can pay the license fee 100% upfront or 50% upfront and the rest of the 50% in 5-year instalments with LIBOR+3%. However, due to the fluctuations in the exchange rate, the business model on which they bought the license does not remain feasible because they earn in Pakistani rupees.

Recommendations

The licensing of spectrum for the telecommunications firms should be rationalised and aligned with the Pakistani market's realities. If the steps are taken to reduce the spectrum cost for telecommunications firms, it may allow them to leverage the cost to develop cloud infrastructure. This will further improve their BDA capabilities and allow them to adapt to the rapidly changing technology and market dynamics. The telecommunications industry must remain financially sustainable to invest in infrastructure, which serves as the foundation for the digital ecosystem and enablement.

Service Provision to the Government

The telecommunications firms that have enormous amounts of data remain concerned about the provision of services to the government. According to the telecommunications firms, the government usually treats the telecommunications firms as vendors and offers unreasonable rates for digital/ICT services, and puts pressure on vendor/service providers to reduce the tariff, which is against the legitimate commercial interests.

Recommendations

The government, while receiving the services from the telecommunications firms, should treat telecommunications firms as partners rather than as vendors. The tariffs offered by the government to the telecommunications firms should keep the firms' commercial interests in view. An agreement should be made between the government and the telecommunications firms that safeguards the commercial interests of telecommunications firms as well as benefits the government.

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TECH INDEX PAKISTAN: A STATISTICAL APPROACH TO UNDERSTANDING THE RELATIONSHIP BETWEEN TECHNOLOGY, COMPETITION, AND GROWTH

Muhammad Haris Hanif[1] and Mubeen Ahmed[2]

ABSTRACT

Given the importance of technology for economic growth and development, this research investigates Pakistan's technological landscape. A comprehensive tech-index was developed to compare and evaluate Pakistan's technology adoption and advancement level against other low-middle-income countries. These countries included Egypt, India, Sri Lanka, and Uzbekistan. The index was constructed using secondary data from 1990 to 2022. The methodological approaches used included the EM algorithm for imputing missing data, min-max normalisation for scaling, and geometric mean aggregation to create the index. The index reveals that Pakistan has modest gains in tech-index scores. However, these gains are relatively small compared to other South-Asian countries. Moreover, it faces significant challenges in maximising its technology level. Key findings also indicate that countries with cohesive policy implementation, along with high R&D and human development expenditures, tend to have higher technology adoption. This index is further utilised to decompose the relationship between Pakistan's technology landscape, market competition, and economic growth. These relationships were analysed through 2SLS, the Toda-Yamamoto causality test, and generalised impulse response functions. The results indicate that while technological advancement negatively affects competition, growth positively depends on Pakistan's technology level. Moreover, bi-directional causality is also evident between technological advancement and economic growth, while unidirectional causality is evident from technological advancement to market competition.

[1] MPhil Student, Government College University Lahore.

[2] BS (Hons.) Student, Government College University Lahore.

1. INTRODUCTION

Technology, Competition, and Economic Growth: A Global Perspective

In today's rapidly evolving world, the increasing pervasiveness of technology and its role in shaping economic dynamics, at both national and international levels, have become very significant. Countries worldwide strive to harness technology's power to drive economic growth and development. Thus, the relationship between technological innovation and economic growth has become a subject of great importance. According to the neoclassical growth theory, effective competition promotes innovation, productivity, and efficiency, leading to higher economic growth (Solow, 1956). On the other hand, market power and lack of competition can hinder economic progress by reducing incentives for firms to innovate and invest (Aghion et al., 2005). As countries compete to establish themselves as technology hubs, it is essential to have effective policies to foster healthy competition, protect consumers, and encourage innovation. Therefore, it is crucial to understand the effectiveness of technology development and adoption. Technological advancements have rapidly surged since the era of industrialisation. Similarly, technology adoption has transformed various sectors of the world's economy as technology holds great potential to drive economic growth.

The global economy has witnessed several transformative technological breakthroughs, ranging from the advent of the Internet to advancements in artificial intelligence and automation. These innovations have not only redefined traditional industries but have also created entirely new economic sectors. For instance, the rise of digital platforms and e-commerce has revolutionised trade and retail, while advancements in renewable energy technologies have paved the way for sustainable economic practices.

Countries that have embraced these shifts by investing in technology and fostering competitive markets have reaped significant economic benefits. For example, several countries, such as South Korea, Germany, and the United States, have demonstrated how strategic technological investments and robust innovation ecosystems can lead to sustained economic growth. At the same time, disparities in technology adoption highlight the importance of addressing structural barriers and capacity-building initiatives in developing countries. Despite its potential, technology's role in driving economic growth is often hindered by issues such as inadequate infrastructure, lack of skilled human capital, and policy inefficiencies. Addressing these challenges requires increased investment in technological infrastructure and fostering a culture of innovation through research and development (R&D).

Pakistan's Technology Landscape: Challenges and Opportunities

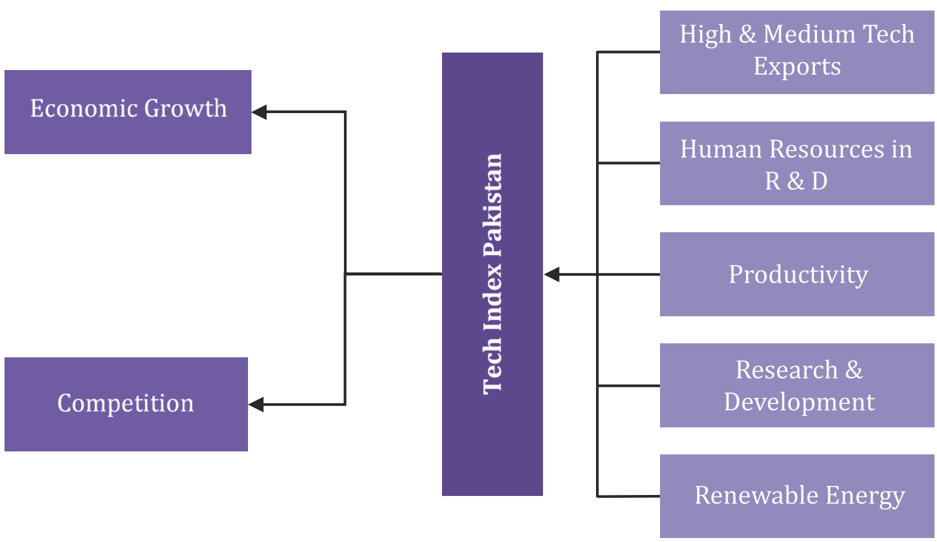
Pakistan has also witnessed significant technological advancements over the past few decades. Nonetheless, with its young and dynamic population, abundant talent pool, and growing digital infrastructure, Pakistan has the potential to become a significant player in the global technology sector. To fully realise this potential, it is crucial to understand the key indicators, challenges, and opportunities that shape the technology ecosystem in Pakistan. Thus, a unique set of opportunities and constraints marks the technology landscape in Pakistan. As Saeed & Awan (2020) have pointed out, in the case of Pakistan, R&D boosts GDP growth. The proliferation of mobile and broadband internet has expanded access to digital services, creating a foundation for innovation and entrepreneurship. Initiatives such as the Digital Pakistan Policy and establishing special technology zones reflect the government's commitment to fostering technological growth. However, a deeper analysis reveals persistent challenges, such as limited R&D expenditure, inadequate STEAM education, and a regulatory framework that often stifles innovation rather than nurturing it.

The role of the private sector in driving technological adoption and innovation cannot be overlooked. While Pakistan has seen the emergence of several tech startups and IT services firms, scaling these initiatives remains a challenge due to the lack of venture capital, mentorship, and market access. Despite the growing importance of technology, a better understanding of its impact on economic parameters remains understated. Thus, Pakistan still faces many challenges in completely exploiting the resources for technological development, adversely impacting economic growth. Acknowledging these challenges, infrastructure gaps, and lack of competition is also very important, as it sets the stage for identifying opportunities. Therefore, this research aims to propose targeted solutions and interventions by examining obstacles impeding technology-driven competition and growth.

Building a Tech Index: Rationale and Approach

The rationale behind this study is rooted in the pressing need to understand the role of technology in driving economic competitiveness and growth. Thus, the primary objective of this research project is to develop a technology index for Pakistan. This technology index depicts the country's overall situation concerning technology adoption, advancement, and proliferation. By thoroughly examining the dynamics of technological sophistication and competition, the study tries to uncover how technological advancements shape the competitive market landscape. The intention is to gauge the technological landscape's depth and breadth by examining the prevalence of advanced technologies and digital infrastructure and synthesising the findings into data-driven recommendations. These recommendations have been tailored for policymakers, industry stakeholders, and investors, providing pragmatic insights into exploiting technology for enhanced competition and sustainable economic growth in Pakistan. Figure 1 represents the schematic representation of the project. It shows the Tech Index's composition, which is composed of five sub-variables, and this study's post-index estimation framework.

Figure 1: Schematic Depiction of the Research Project



Source: Authors' illustration.

This research study is focused on finding answers to the following research questions:

- What is the current situation of technology adoption and advancement in Pakistan, and how does this contribute to the current growth?
- How does technology-driven innovation contribute to competitive advantage within Pakistani industries? By exploring the relationship

between technology-driven innovation and competitive advantage, this part focuses on uncovering the key factors that propel specific industries ahead of others.

- What is the correlation between technological sophistication, market competition, and overall economic growth in Pakistan? This question aims to comprehensively understand the relationships between technology investment, competition, and economic development.

Scope and Policy Relevance of the Study

The scope of the study lies in the absence of a comprehensive understanding of how technology, competition, and economic growth intersect in Pakistan. While technology adoption is on the rise, its implications for the competition side and overall economic growth remain understudied. Thus, this research addresses the critical gap in knowledge by digging into the intricate relationships between these three pillars. The problem encompasses the need to decode how variations in technology adoption and innovation strategies contribute to or hinder market competition and economic growth. The study aims to catalyse a systematic exploration beyond surface-level observations through such an approach. The ultimate goal is to provide actionable insights grounded in robust statistical analysis that can inform strategic decisions, policies, and investments to propel Pakistan toward a more technologically advanced and economically vibrant future.

This research holds profound significance in shaping and refining public policy in the country. As Pakistan strives for technological advancement and economic growth, the findings of this study can significantly inform and provide actionable recommendations for policymakers. This research provides a comprehensive and analytical framework to understand Pakistan's overall technology outlook through a technology index. Besides, it is also helpful in understanding how technology penetration is interplaying and whether it favourably contributes to a firm’s growth. The study also contributes to formulating innovation and technology policies that favour market competition and economic growth. Policymakers can leverage insights into the factors driving market competition to incentivise and support innovation, thus catalysing economic growth. The research sheds light on the dynamics of market competition influenced by technology. Policymakers can use these insights to formulate competition policies that ensure fair markets, encourage healthy competition, and foster economic growth. Understanding the correlation between technology investment, competition, and economic growth is essential for optimising investment policies. It will help to bridge the digital divide, promote digital literacy, and ensure that the benefits of technological growth are accessible to all segments of society.

The remainder of the study is organised as follows. Section 2 reviews the literature. Section 3 presents the methodology with data sources, while Section 4 describes the findings and discusses them. Section 5 presents the following steps and further plans for the study.

2. LITERATURE REVIEW

This part provides an overview of existing literature. It examines the development of current technology indices and their limitations, and explores the complex interrelationship between technology, competition, and economic growth. The aim is to identify gaps and limitations in the existing research, particularly concerning the context of Pakistan.

Limitations of Previously Existing Indices

In recent years, various indices have been introduced by many scholars and organisations to understand the technology levels and the interrelationship between technology and multiple variables. Most are very specific, covering only one aspect rather than presenting a holistic picture. For example, the Global Innovation Index (constructed by the World Intellectual Property Organization (WIPO)) primarily focuses on the innovation side, the Index of Technology Progress developed by Rodríguez & Wilson (2000) focuses on ICT and technology consumption, and the Technology Index Warner (2000) uses the Technology Transfer Index or Innovation Index. Moreover, all these indices are limited to specific years and countries, and do not include Pakistan. Therefore, this project focuses on developing a single composite index that covers fundamental technology-related aspects and is the starting point for creating reliable and effective policies.

Technology, Growth and Competition

As far as the connection between technology, competition, and economic growth is concerned, many scholars have tried to examine this relationship. A few of them have focused on the micro level by investigating the relationship between the intensity of competition, advanced manufacturing technology, and how it affects organisational performance. They conclude that a positive relationship exists between these variables (Fuadah et al., 2014). Similarly, existing literature also demonstrates a growing interest in technology adoption in emerging economies. Studies by Bujari & Martínez (2016) and Dereli (2019) present the transformative impact of technology on economic development, emphasising the need for high-level tech in national contexts and highlighting that the production and export of high-level tech adds great value to the overall GDP, thus speeding up economic growth. The development of such technologies, intensification of R&D, and increase in patent applications are therefore crucial to achieving economic growth.

The early supporters of the Schumpeterian growth models, Grossman & Helpman (1991), predicted that innovation and growth should decline with competition. That is because more competition reduces the rents and payoffs, preventing new firms from entering the innovation race. Later on, Aghion et al. (2001) developed new models of competition and presented the idea of economic growth through "escape-competition" and argued that there is the possibility that more competition could encourage innovation as the competition may increase the incremental profits from innovating, which eventually promotes the R&D investments as each firm will try to acquire the leads in technology over its rival. Gomaa (2014) also suggested the exact relationship between competition and economic growth and concluded that domestic competition complements an economy's growth rate.

Nevertheless, another side supports the belief that there has been a significant decrease in competition in many countries, impacting inclusive growth. This decline in competition intensity can be seen in the increase in market concentration as well as the ability of firms to influence prices or market power. This literature presents how important competition is for growth (Cherif & Hasanov, 2021). Other empirical studies have also provided mixed findings regarding the impact of competition on economic growth. Some studies suggest a positive relationship between competition and growth (Buccirossi et al., 2013), while others find no significant relationship (Baldwin & Forslid, 2000; Griffith et al., 2004). The literature above provides valuable insights into the relationship between technology, competition, and economic growth. Only a few studies offer real insight, particularly in the context of Pakistan. Moreover, most studies focus on developed economies, thus demanding research on Pakistan's unique challenges and opportunities.

3. METHODOLOGY AND DATA SOURCES

Methodology

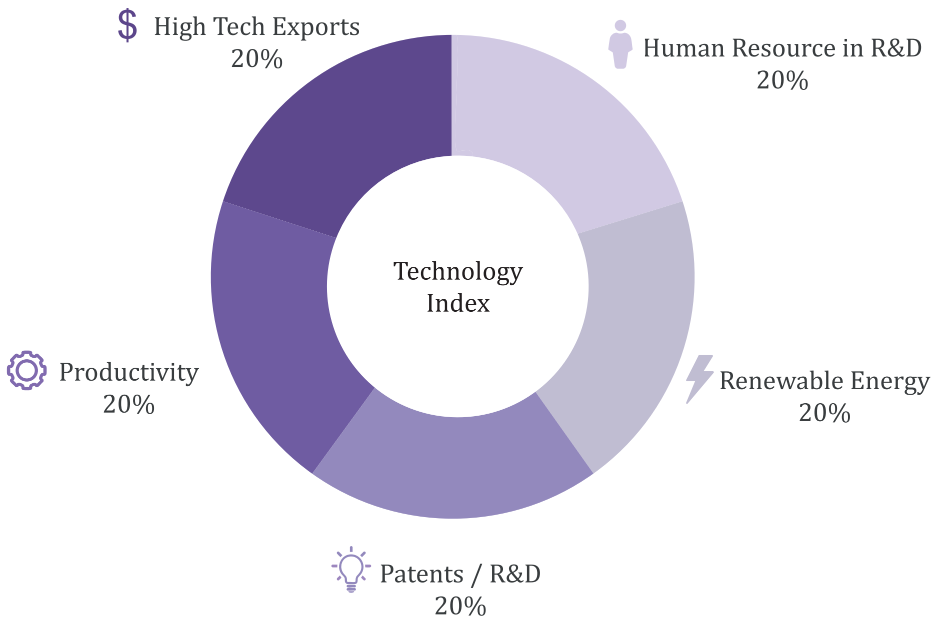
This study aimed to comprehend the intricate associations between technology, market competition, and economic growth. Since Pakistan must harness the advantages of technological advancement while upholding a competitive and sustainable market atmosphere, therefore, for such objectives, the primary step was to develop a measure of technology that gauges the country's technological adoption and advancement level over the years. Thus, this study first developed the Tech Index, which provided annual ratings of technological sophistication for Pakistan from 1990 to 2022. The index was built for five countries, namely, Egypt, India, Pakistan, Sri Lanka, and Uzbekistan. The aim of creating an index for such a cross-section was to perform uncertainty and sensitivity analysis to analyse the index's robustness. After the index formation, the relationship between technological advancement, market competition, and economic growth was studied using different econometric techniques. The data on all the variables came from secondary sources such as the UNDP, World Development Indicators, UNIDO, UNESCO, ILOSTAT, and WIPO. Table A1 in the appendix highlights the variables, their definition, and sources utilised to make the Tech Index. Table A2 in the appendix highlights the variables used in the study's econometric analysis. The following section outlines the data collection methods, design and composition, and analytical techniques for creating the index and econometric methods for analysing the relationships.

Tech Index Composition

The technology index captures the country's overall technological sophistication. It highlights a country's integrated capacity to innovate, deploy, and adopt commercially viable innovations, encompassing commitment to innovation, productivity gains, adoption of sustainable energy practices, competitiveness in high-tech trade, and the human resources dedicated to R&D. Thus, the index reflects innovation activity and the ability to convert ideas into marketable assets. The foundation for the composition is based on the Lowy Institute Asia Power Index and modified to the context of Pakistan. The index by the Lowy Institute consists of eight sub-indicators of technology, including high-tech exports, productivity, r&d expenditures, human resources in R&D, Nobel Prizes (sciences), supercomputers, satellites launched, and renewable energy. As for Pakistan, some sub-indicators, such as

Nobel Prizes (sciences), supercomputers, and satellites launched, are inapplicable, so they were omitted. However, the remaining five sub-indicators were assigned an equal weight of 20%, following the Lowy Institute's index, to develop the Tech Index. The composition and the weight assigned to the sub-indicators are shown in Figure 2.

Figure 2: Composition of Tech Index (Sub-indicators and Weighting Scheme)



Source: Authors' illustration.

Two indices are developed. The first index is almost the exact replication of the Lowy Institute's technology sub-indicator. However, in constructing the second index, residents' patent applications were used as a substitute for R&D expenditures due to significant missing data for R&D, especially for Pakistan. Although statistical imputation techniques addressed the missingness, imputed values might still not perfectly capture the actual trends. Thus, patent data provides a viable alternative. Meanwhile, patents and R&D are widely accepted proxies for the innovation process since both capture different but complementary dimensions. R&D expenditures reflect the financial and resource inputs allocated toward innovation activities, while patent applications serve as an output-based measure, representing tangible outcomes of these innovative efforts (Smith & Funk, 2021; Potepa & Welch, 2017). However, patent applications could also serve as a proxy for R&D activity since patent applications are usually filed earlier in the research process. Thus, incorporating patent data into the index measures innovation outputs and also signals the scale and intensity of ongoing innovative activities (Popp, 2019; Griliches, 1990).

Incorporating patent data also helps mitigate the potential biases introduced by imputed data while maintaining a robust measure of technological sophistication. Patents also directly influence market competition as they create exclusionary rights, establish barriers to entry, and shape competitive dynamics by granting monopolistic advantages or fostering innovation clusters. Therefore, given the study's objective of analysing market competition, the use of patents might also offer additional benefits, such as more direct insights into competitive changes and disturbances. Moreover, since patent application figures may be highly skewed in countries with larger populations or higher economic scales, we standardised this measure by calculating and using patents per capita (annual patent counts divided by population) to ensure cross-country comparability. For all sub-indicators, proxies were used. Data for these proxies were extracted from various resources, including UNIDO, UNESCO, ILOSTAT, WIPO, and the World Development Indicators. The proxies, their definitions, and sources are given in Table A1 in the appendix. The model for the calculation of the Tech Index is as follows:

Tech index with patents – Index 1:

$$Tech\ Index = f(EXP, PROD, PATENT, HR, RENEW)$$

The index calculation based on the geometric mean is as follows:

$$Tech\ Index = \sqrt[5]{(0.20 * EXP).(0.20 * PROD).(0.20 * PATENT).(0.20 * HR).(0.20 * RENEW)}$$

Tech Index with R&D expenditures – Index 2:

$$Tech\ Index = f(EXP, PROD, R\&D, HR, RENEW)$$

Similarly,

$$Tech\ Index = \sqrt[5]{(0.20 * EXP).(0.20 * PROD).(0.20 * R\&D).(0.20 * HR).(0.20 * RENEW)}$$

Where EXP indicates medium and high technology exports, PROD indicates productivity, PATENT stands for patent applications, R&D stands for R&D expenditures, HR indicates human resources in R&D, and RENEW indicates renewable energy. Both of these indices are constructed for five countries, including Pakistan, Egypt, India, Sri Lanka, and Uzbekistan. These countries are lower-middle-income countries per the World Bank's 2024 classification. Pakistan, India, and Sri Lanka are South Asian countries, Egypt is a North African country, and Uzbekistan is a Central Asian country.

Construction of Tech Index

The creation of the Tech Index was followed using the guidelines of the OECD/JRC Handbook on Constructing Composite Indicators (Joint Research Centre, 2008). The index was built in R using the COINr package.

Data Imputation Methods

The first step in constructing any index is imputing missing data, if any. However, before using any data imputation method, it is advisable to determine whether the missing data is due to MCAR (missing completely at random), MAR (missing at random), or MNAR (missing not at random). Given that we had economic data for lower-middle-income countries with significant missing data for the number of researchers and R&D expenditure, we assumed that our data is MAR. According to the OECD/JRC Handbook, missing data can be imputed either through implicit or explicit modelling. Implicit imputation techniques, like hot deck imputation, substitution, and cold deck substitution, are not based on statistical procedures. In contrast, explicit imputation techniques are based on statistical techniques, such as mean/median/mode imputation, regression imputation, the EM algorithm, and multiple imputation.

Multiple imputation is often considered the most robust approach for MAR data. However, it is inapplicable because it creates numerous complete datasets through an iterative process and then pools the regression results from all datasets. Since the study did not directly run any regression analyses, and the objective was to construct a composite index and perform uncertainty and sensitivity analyses, multiple imputation was inapplicable. Therefore, we opted for the EM algorithm to impute missing values. The EM-Algorithm performs well under MAR conditions and is considered superior to listwise and pairwise deletion, mean/median/mode substitution, and even regression imputation (Li et al., 2024; Dong & Peng, 2013; Nelwamondo et al., 2007; Schafer & Graham, 2002; Ghahramani & Jordan, 1993). Nonetheless, as the human resource variable is a stock variable, it was linearly interpolated for the missing values before applying the EM algorithm for its extrapolation and the rest of the variables' imputation.

Data Normalisation, Weighting, and Aggregation Scheme

After imputing the missing data, the next step in constructing a composite index was normalisation. Normalisation scales different variables to a standard scale. Various normalisation techniques include min-max, Z-scores, and distance to the target country. However, we used the min-max approach because it provides a clear and intuitive range (1 to 100) for comparing index scores over the years and countries. Thus, it aligns to make the index scores comparable across countries and makes it easy to communicate. The Z-score normalisation, which normalises data with a mean of 0 and a standard deviation of 1, could result in index scores of an undefined range and even in negative scores, thus making the results difficult to communicate and interpret. However, the distance to the target country approach requires a reference country for benchmarking. Thus, it made the min-max approach the most straightforward and meaningful for our purposes.

The next step was determining the appropriate weights for each indicator. We used equal weights for each indicator following the Lowy Institute Power Index. The final stage of construction was selecting the aggregation method. Various aggregation methods exist, such as arithmetic mean, geometric mean, and harmonic mean. The geometric mean was used because it is more robust to extreme values and better balances the contributions of different indicators. This method is beneficial when indicators have different units and scales. The harmonic mean, however, is extremely sensitive to zero and minimal values, which can distort the index (Greco et al., 2018; Joint Research Centre, 2008).

Uncertainty and Sensitivity Analyses

After constructing a composite index, it is necessary to check its robustness through uncertainty and sensitivity analyses. Uncertainty analysis (UA) studies how input changes affect the composite index value. Sensitivity analysis (SA), on the other hand, quantifies the amount of output variance attributed to such uncertainties (Saisana et al., 2005). Thus, these analyses were performed by challenging the key assumptions and steps taken to create the tech index, including the normalisation step, the weighting scheme, and the aggregation method. For normalisation, we considered how using Z-scores instead of the min-max method would affect the index. For weighting schemes, 100 replications were produced by randomly applying 25% noise to the original indicator weights. Finally, the arithmetic mean instead of the geometric mean was also considered for the aggregation method. However, it is worth mentioning that uncertainty and sensitivity analyses are typically considered for composite indices constructed at a single point in time, such as cross-sectional data. However, since the study used panel data, directly applying these analyses was not feasible. Therefore, we considered uncertainty and sensitivity analyses at three different points in time, i.e., 2000, 2010, and 2020.

Model Specification

The motive of the study is also to discern the relationship between Pakistan's technological advancement, market competition, and economic growth, since technology adoption and advancement also play a significant role in enhancing economic competition. Besides, it is also imperative to analyse these interlinks, given their significance for Pakistan's economic growth. Thus, based on the past literature and given relatively few degrees of freedom for our econometric models, our hypothetical model for market competition and economic growth could take the following functional form:

Model 1:

$$Competition = f(TI, HDI, FDI)$$

Model 2:

$$Economic\ Growth = f(Comp, TI, HDI, FDI)$$

In Model 1, competition is the market competition, and the number of industrial design applications was used as a proxy. These design applications could be used as a proxy for market competition since firms in competitive industries frequently depend on distinctive product designs to attract consumers and safeguard their market positions. Thus, an increase in these applications indicates product distinction, innovation to acquire market share, and the strategic employment of intellectual property to deter imitation, signifying heightened rivalry (Andersson et al., 2023; Yao et al., 2023). TI is the Tech Index developed in this study, HDI is the human development index, and FDI is the foreign direct investment (FDI). Economic growth is proxied by GDP growth. The variables, their definitions, and sources are also presented in Table A2 in the appendix.

In Model 1, for evaluating the effects of technology on competition, competition is the dependent variable, while the independent variables include Tech Index, human capital development, and FDI. Similarly, for Model 2, economic growth is the dependent variable, Tech Index and competition are core independent variables, while human capital development is a mediating variable, and FDI is the control variable. Both models' competition and economic growth variables were log-transformed to ensure consistency and comparability across all variables. Additionally, taking the log of competition and economic growth is supported by the fact that both variables are limited dependent variables. This transformation made our models semi-log and allowed for a general non-linear framework. The rest of the variables in the study are either indices or in percentage form. For example, FDI is represented as FDI inflows as a percentage of GDP, and HDI and TI are both indices based on the geometric mean. The above models were analysed using different econometric techniques, such as two-stage least squares, Granger causality, and impulse response functions (IRF).

Econometric Methodology

This study employed various econometric techniques, including the ordinary least squares (OLS), two-stage least squares (2SLS), and Granger causality, while IRFs were used to check the responses of variables to different shocks.

Two-Stage Least Squares (2SLS) Estimation

2SLS is a widely used econometric technique to address endogeneity issues in regression models. Endogeneity arises when one or more explanatory variables are correlated with the error term, violating the assumption of exogeneity required for OLS estimation. This issue leads to biased and inconsistent parameter estimates, distorting causal inference. In economic growth studies, endogeneity is particularly common due to feedback loops between growth and its determinants, omitted variables, and measurement errors (Moaniba et al., 2018; Swamy & Fikkert, 2002; Romer, 1989). Thus, using 2SLS was warranted because economic growth often exhibits simultaneity and dynamic relationships. Moreover, this study's Granger causality tests revealed reverse causality between technological innovation and GDP, where GDP causes innovation. Thus, such feedback loops necessitate using 2SLS to obtain consistent causal effect estimates. Under such instances, the 2SLS can lead to consistent estimates as it operates in two stages to deal with endogenous variables. In the first stage, the endogenous variable is regressed on exogenous and instrumental variables (IVs) to isolate the variation unrelated to the error term. In the second stage, the predicted values from the first stage are used as a regressor in the main equation to estimate its causal effect on the actual dependent variable. However, for the consistency of 2SLS, the selection of instrumental variables is critical, as they must satisfy two conditions, namely, relevance (significant correlation with the endogenous variable) and exogeneity (no correlation with the error term). In this study, since it was nearly impossible to identify appropriate instruments for variables such as the Tech Index – an aggregate measure that incorporates multiple dimensions of technological innovation, particularly given that existing studies often rely solely on patents as a proxy for technological innovation, we employed the lags of the endogenous variables as instruments.

Recognising these limitations, we employed the first lags of the endogenous variables as instruments, a common practice in the literature. However, for the validity of this approach, the lagged variables must meet the relevance and exogeneity conditions. The basic framework of the 2SLS model can be understood using the following notions. Consider a simple regression model as follows:

$$y_1 = \beta_0 + \beta_1 x_1 + \beta_2 z_1 + \cdots + \beta_{k-1} z_{k-1} + \mu_1 \quad (1)$$

In (1) above, y_1 is the dependent variable, x_1 is the endogenous variable, and z's are the exogenous variables. β's represents the intercept term and slope parameters and μ_1 is the error term. Due to the endogenous nature of x_1 variable, the exogeneity condition of OLS is violated, such that the covariance between x_1 and μ_1 is not zero, which renders OLS estimators inconsistent. The 2SLS can lead to consistent estimates by estimating the above model in two stages. The first stage (reduced form regression) can be estimated as follows;

$$\hat{x}_1 = \alpha_0 + \hat{\alpha}_1 z_1 + \cdots + \hat{\alpha}_{k-1} z_{k-1} + \hat{\alpha}_k z_k + \varepsilon \quad (2)$$

In (2), x_1 is the endogenous variable and only predicts the exogenous information. z_k is an additional exogenous variable and does act as an instrument. The rest of the parameters and variables are the same as defined earlier. (1) can be reestimated using the predicted values of x_1 ($\hat{x}_1$), which is exogenous. The prediction of x_1 is exogenous since it is purged of its endogenous part, which is the error term, and now it solely relies on the exogenoûs information. Thus, the second stage of 2SLS can be estimated as follows;

$$y_1 = \beta_0 + \beta_1 \hat{x}_1 + \beta_2 z_1 + \cdots + \beta_{k-1} z_{k-1} + \mu \quad (3)$$

All the variables and parameters in (3) are the same as explained earlier, and x_1 is the predicted value of x_1. Therefore, the estimation of 2SLS can yield consistent estimates in the presence of endogeneity; however, the instruments must be relevant and exogenous.

Granger Causality Analysis

This study also employed the Granger non-causality test to analyse causal linkages and determine the direction of causation. Causality often denotes the directed relationship between two variables, where changes in one variable lead to or predict changes in another. Establishing causal links is essential in empirical studies, especially in growth models, to understand how technological sophistication, market competitiveness, and economic growth interact. Conventional Granger causality tests are extensively employed for this objective. However, causality tests necessitate pretesting for stationarity, rendering them susceptible to the model's order of integration. To overcome these limitations, this study employed the Toda-Yamamoto causality test, which offers a robust causality analysis framework without requiring stationarity pre-tests. Similarly, it minimises the risks of model misspecification that may arise due to pretesting biases. Toda & Yamamoto (1995) proposed to employ a modified vector autoregressive (VAR) model that integrates the system's variables' maximum order of integration, d_{max}

Consequently, the Toda-Yamamoto methodology guarantees accurate inference by preserving the asymptotic distribution of the Wald test statistic, even in the presence of non-stationary series or data integrated at varying orders. The general framework of the Toda-Yamamoto causality test can be articulated as follows:

$$y_t = \alpha_0 + \sum_{l=1}^{q} \alpha_l y_{t-l} + \sum_{l=1}^{q} \beta_l x_{t-l} + \sum_{j=q+1}^{q+d_{max}} \beta_j x_{t-j} + \sum_{j=q+1}^{q+d_{max}} \alpha_j y_{t-j} + \varepsilon_t \qquad (4)$$

In (4), α and β represent the parameters, dmax denotes the maximum order of integration, and q indicates the optimal lag number. The parameters of the additional lagged variables are incorporated into the model as exogenous variables, excluding them from Wald's restriction test. The null hypothesis states that x does not Granger-cause y, or $Mx \rightarrow y = 0$.

Impulse Response Functions

This study also established a vector autoregressive (VAR) model to examine impulse response functions, which are crucial instruments in time-series models for assessing the dynamic behaviour of a system in reaction to shocks or innovations. Specifically, an IRF traces the effect of a one-time shock to one variable on the current and future values of all other variables in the system. The use of IRFs offers numerous advantages. First, IRFs account for the endogenous nature of the relationships among variables, enabling the identification of both direct and indirect effects. Second, they provide a time horizon for the impact of shocks, which is critical for understanding the persistence of effects. Finally, IRFs allow for a simultaneous examination of multiple interrelated variables, which are crucial in systems characterised by feedback loops, as with technological advancement, market competition, and economic growth.

This study used accumulated IRFs to capture the cumulative impacts of a shock over time, rendering them especially valuable for analysing the long-term consequences of technological progress and market competition on economic growth. The IRFs estimated in this study were derived from the generalised impulses introduced by Koop et al. (1996). This method accounts for the intricate interdependencies of the variables without enforcing limiting assumptions regarding their sequence, resulting in more resilient and comprehensible outcomes. Consequently, Generalised IRFs provide more reliable estimates than orthogonal IRFs (Ewing, 2003). The response standard errors of IRFs were bootstrapped utilising Kilian's (1998) bias-corrected confidence interval for small sample sizes. Thus, this method has been shown to provide unbiased estimates, particularly in small sample sizes like the 33-year data used in this study. The basic bivariate VAR model with only one lag can be defined as follows:

$$y_t = \alpha_1 + \beta_{11} y_{t-1} + \beta_{12} x_{t-1} + \mu_t \tag{5}$$

$$x_t = \alpha_1 + \beta_{21} x_{t-1} + \beta_{22} y_{t-1} + v_t \tag{6}$$

y_t and x_t in (6) indicate that the variables' current values depend upon their past values and on the past values of the other variable.

4. RESULTS AND DISCUSSIONS

This section presents and discusses the study's empirical findings.

Tech Index Pakistan

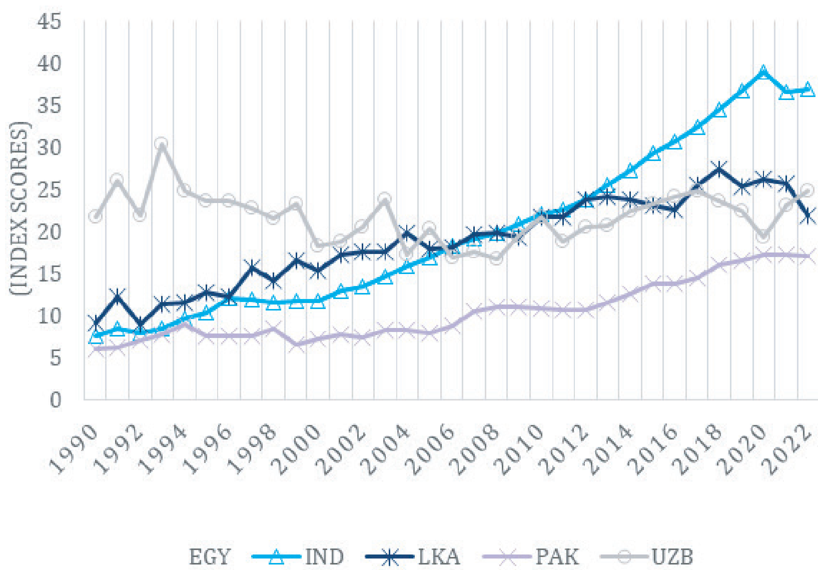
This section discusses the study's initial results, primarily of the Tech Index. As previously discussed, two indices were developed initially. One has the patents variable (Index 1), while the other has the R&D expenditures (Index 2), which is presented in Appendix 2 as Table A3. This section exclusively discusses the results of Index 1, constructed using patent data, for four key reasons. First, uncertainty analysis demonstrated that Index 1 exhibited more stability over time, with less sensitivity to changes in its formation assumptions. Second, Index 1 aligns more closely with the scores and ratings of other established technology indices, such as the Global Innovation Index. Third, it is potentially less biased, relying less on data imputation techniques. Finally, as previously discussed, using patents in Index 1 provides more direct and reliable insights into market competition dynamics. The uncertainty and sensitivity analysis results for both indices are attached in Appendix 3.

For Index 1, the uncertainty analysis revealed that changing the index methodology could have impacted the countries' index scores for 2000 and 2020, particularly the scores of two countries by two points. For 2010, it could have impacted the scores of four countries. Similarly, the uncertainty analysis for Index 2 revealed that changing the index methodology could have affected the index scores of three countries in 2000, 2010, and 2020. The sensitivity analysis of both indices gave different results for each point in time. For index 1, it can be generalised that the aggregation method followed for normalisation could induce much variance in the index scores over the years. However, the weighting scheme had almost negligible impact on index scores. For index 2, all three choices of weighting, normalisation, and aggregation methods could induce much variance. Overall, it was found that the variance caused by the assumptions of the second index resulted in higher uncertainty than that of the first index.

Figure 3 presents Index 1 scores for five countries from 1990 to 2022. Based upon Index 1, Pakistan witnessed consistent but modest growth, peaking in 2020 at 17.22. Significant growth phases were observed from 1990 to 1994, 2005 to 2007, and 2012 to 2020. Meanwhile, in 1990, Sri Lanka and India started just above Pakistan, such that the scores of India and Sri Lanka are 7.50 and 9.02, whereas that of Pakistan is 5.99. After 33 years, in 2022, India and Sri Lanka scored relatively much better than Pakistan at 36.89 and 21.81, while Pakistan's score is 17. India experienced an upward trend and showed signs of consistent growth from 1990 onwards. Sri Lanka also showed a positive growth trend, but it was modest compared to India. Its trajectory slowed and flattened, especially after 2012, and after an abrupt upsurge from 2016 to 2018, it started a declining trend until the end of 2022. Egypt also showed modest growth in its Tech Index scores. It showed a significant growth trend in its scores after 2007, but it slowed and started declining after 2019. Uzbekistan showed many sudden and abrupt fluctuations, improvements, and declines in its Tech Index scores, but it shows a declining trend over the years.

The analysis of the line charts for the Tech Index reveals several key findings. Firstly, India's consistent improvement and achievement of high Tech Index values indicate a strong level of technological advancements and implementation of the technology adoption framework. It suggests India has effectively capitalised on its policy framework to develop and maintain a leading position among the selected countries. Sri Lanka's stagnant growth, particularly in the latter half of the period, highlights substantial obstacles to adopting and reaping the effects of technological change. It suggests a lack of effort to enhance their technology ecosystems. Egypt showed significant growth, particularly in the latter half of the period, highlighting substantial improvements in technological infrastructure. It suggests a focused effort to enhance their technology ecosystems. While showing stagnant growth, Pakistan has experienced modest increases in recent years. It indicates potential challenges faced since the start, possibly due to economic or infrastructural constraints. At last, Uzbekistan showed a declining trend, suggesting the country's inability to adapt, upgrade, and keep pace with the world's changing technological landscape.

Figure 3: Tech Index Scores (Comparison between Five Countries across Time)



Source: Authors' computations.

Impact of Policy Shocks on Tech Index: A Comparative Analysis

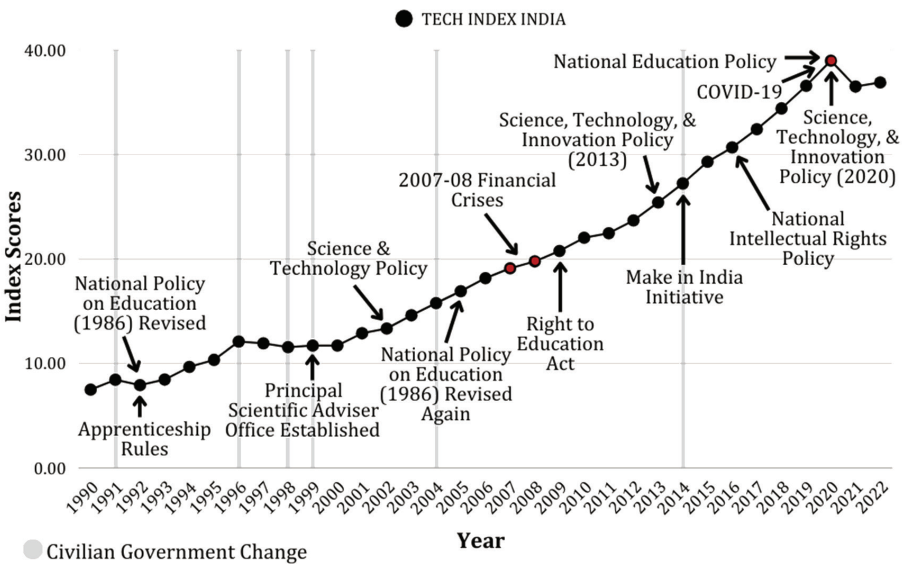
Figures 4 to 7 explain the fluctuations in the Tech Index related to the implementation of technology policies, as well as external factors such as global economic shifts or technological disruptions. Among the selected lower-middle-income nations, India stands out as the most significant case of sustained technological advancement. Its post-1990s progress, evident in the Tech Index, stems from reforms during that period and strategic groundwork laid in earlier decades. Right after independence, India focused on expanding scientific research and developing indigenous capacity in the field of science. These objectives were the focus of 1958's Scientific Policy Resolution (SPR) and the Third and Fourth Five-Year Plans. Jawaharlal Nehru's quote provides an appropriate illustration of India's technology and industrial policy: "*I believe, as a practical proposition, that it is better to have a second-rate thing made in our own country than to rely on the first-rate thing which we have to import*" (Forbes, 1999). Similarly, to develop human capacity, the Kothari Commission (1964–66) made science and mathematics education compulsory up to the 10th grade, and the National Policy on Education (1968) further emphasised the importance of science education (Mammen & Nirupama, 2024). Not only this, education has been a central focus in India since independence, as evidenced by its prominent role in every five-year plan and the government's consistent increase in its education spending over the years (Tilak, 2007; Motkuri & Revathi, 2024). Nonetheless, the significant overhaul and accelerated efforts in the technological domain came under the 1983 Technology Policy Statement (TPS).

As India continued with its inward-looking industrial and trade policies, the TPS recognised that simply creating indigenous technology was not enough; India had to learn how to adapt and absorb appropriate foreign technology. This policy statement seriously focused on transferring and diffusing imported technology across Indian industries. At the same time, India's sixth and seventh five-year plans aimed at becoming technologically self-reliant. They introduced tax incentives for domestic R&D, public funding for R&D institutions, and import restrictions on technology once imported technology has been diffused, thus urging organisations to engage in reverse engineering. Throughout the 1970s and 1980s, India's government restricted FDI unless it met certain conditions, like joint ventures with Indian firms and local R&D commitments.

The economic liberalisation of 1991 marked the turning point in the Indian economy as it reduced trade barriers, eased restrictions on foreign investment, and opened India's market to global competition. Since India had already built an engineering and research workforce in prior decades and had nurtured a culture of local R&D, it absorbed the influx of foreign capital and technology that followed. Moreover, before the 1990s, India's R&D expenditures rivalled those of South Korea and Taiwan, reflecting its sustained commitment to innovation (Forbes, 1999). Subsequently, policies like the 2003 Science and Technology Policy (STP) and subsequent five-year plans each built upon this momentum. They emphasised bridging the gap between academia, industry, and government – the "triple helix" model. The Science, Technology & Innovation Policy (STIP) 2013 formally embedded innovation into the national strategy, aiming to elevate India to the ranks of global innovators.

The 11th and 12th Five-Year Plans were subsequently built upon this vision and focused on initiatives such as "Make in India," "Startup India," and "Skill India" that further encouraged entrepreneurship, R&D commercialisation, human capital development, and industry-academia linkages. Meanwhile, complementing these efforts, the 2016 National Intellectual Property Rights (IPR) also strengthened the legal framework to safeguard creators. Therefore, the cohesive and decades-long policy framework explains India's technological ascent. This phased, adaptive approach underscores the importance of long-term planning and policy continuity in achieving sustainable technological progress.

Figure 4: Impact of Policy Shocks and Exogenous Changes on the Tech Index of India



Source: Authors' compilation.

In contrast, Pakistan's policy interventions in the technological domain show mixed outcomes with notable fluctuations and no sustained growth in the Tech Index. At the time of independence, Pakistan inherited just one out of the 20 universities and only four out of 40 laboratories that were in the pre-independence British India. Recognising the deficit, it invested in building research infrastructure, especially during the 1960s, when about 150 R&D organisations and 19 universities were set up. By the early 1970s, Pakistan had formed the Ministry of Science and Technology, the Pakistan Science Foundation, and a Science Policy Cell. In 1984, Pakistan adopted its first S&T Policy, aiming at self-reliance and building research infrastructure. An action plan came in 1985 but faced poor implementation and limited impact (Bhutto et al., 2012). Besides, unlike India, these policies missed the compulsion and incentive structure for reverse engineering and local R&D.

Another key part of these plans involved the commercialisation of R&D through the PCSIR (Pakistan Council for Scientific & Industrial Research) and STEDEC (a public corporation intended to market locally developed products and processes). Unfortunately, PCSIR and STEDEC never really took off; decades later, they have only a handful of commercialised products in their name. In parallel, Pakistan maintained an import substitution policy that favoured large-scale manufacturers. Those big manufacturers relied heavily on imported second-hand machinery, propped up by protective tariffs and cheap capital. Meanwhile, the small and medium enterprises that formed a huge part of Pakistan's industrial base lacked resources and policy support to expand and do R&D (Naim, 2001).

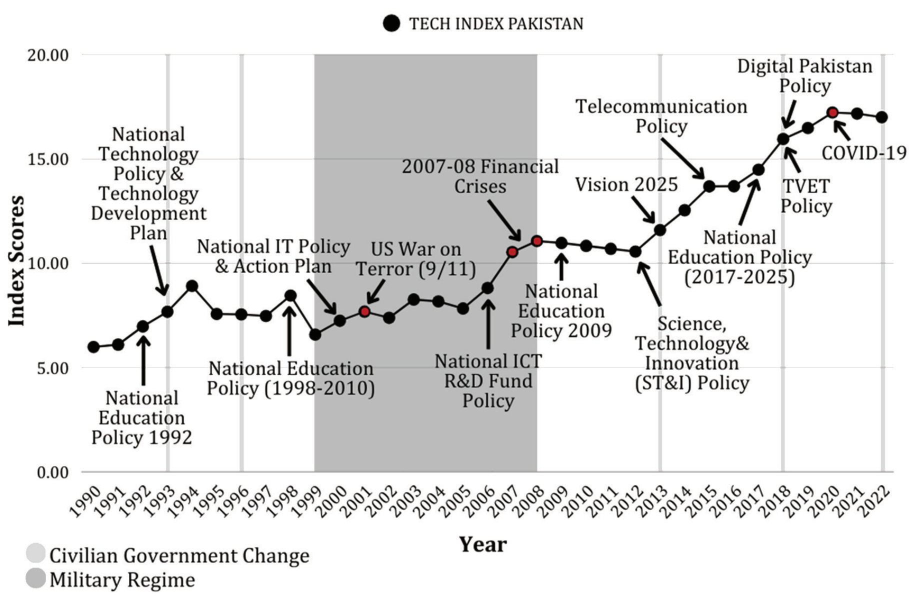
Similar to India, in the early 1990s, Pakistan also liberalised, but it did so without the absorptive capacity or strategic focus that India had. Subsequently, the 1994 National Technology Policy tried to align the R&D organisations with market demand, but it ran into the same obstacles – weak industry linkages and insufficient follow-through on R&D incentives or compulsion. While foreign investors invested in specific sectors, the scale was nowhere near that in India, partly because Pakistan had not built a robust local talent pool or stable environment for tech-driven businesses. Earlier, the 1970s nationalisation efforts had already scared off both foreign and domestic investors, as well as human capital (Naim, 2001).

In 1996, Benazir Bhutto's Government sought advice from a commission of foreign experts, which called for high-level political commitment, accountability in R&D, and better academia-industry-government coordination. These recommendations were partially included in the Ninth Five-Year Plan, but once again, policy execution faltered. Over the years, new universities and R&D centres appeared, but most remained isolated from the private sector, duplicated work, and never evolved beyond basic teaching or rudimentary research.

By the 2000s and onward, Pakistan still had no strong triple-helix framework. Public spending on R&D remained low, and the few policies aimed at reversing that trend were either underfunded or not fully implemented. Unlike India, which integrated technology into its broader economic strategy, Pakistan often handled S&T in a silo, failing to link it with industrial policy, foreign investment rules, or export strategies. Without consistent incentives for reverse engineering or advanced local R&D, Pakistan's industries stayed reliant on imported technology. The result is a landscape with more technology consumption than creation. The growth spurts that did happen were primarily confined to telecommunications or consumer goods rather than across the entire industrial spectrum. Besides, the figures reveal that despite attempts to enhance R&D capacity and promote digital infrastructure, the lack of substantial funding and weak institutional frameworks hindered sustained growth. However, following the 2012 Science, Technology, and Innovation (ST&I) Policy, Pakistan exhibited steady growth in its Tech Index, likely driven by this policy framework and subsequent reforms.

In 2013, the new government also prioritised the implementation of Vision 2025 through its 11th Five-Year Plan, which also composed the Science, Technology, and Innovation Strategy (2014–2018). This period also coincided with relative political and macroeconomic stability, creating an enabling environment for technological advancement. However, from 1993 onwards, frequent political upheavals likely undermined policy continuity and contributed to stagnant progress in the Tech Index. Even an equivalent trend was also observable in India, where the Tech Index stagnated between 1996 and 1999 amid political turbulence and leadership changes.

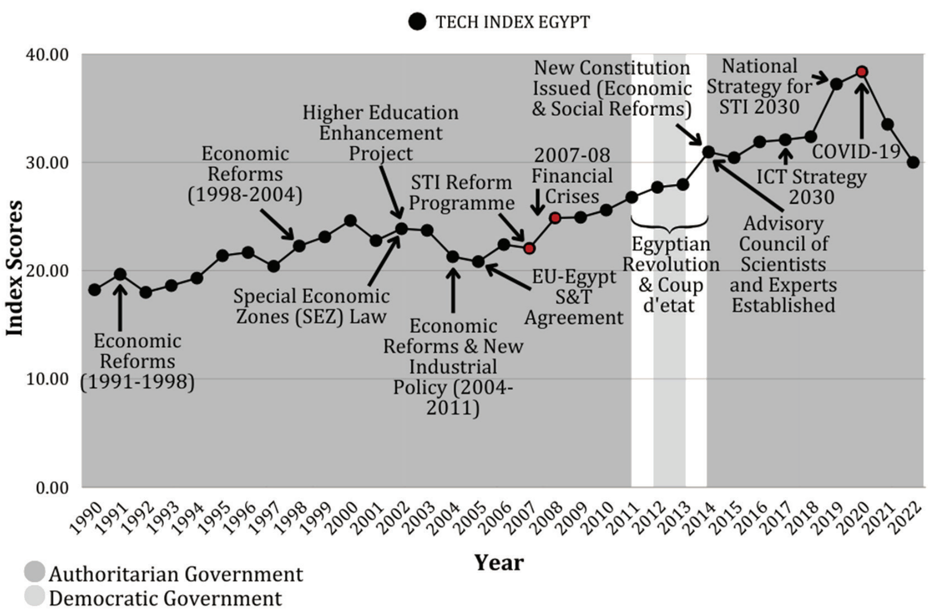
Figure 5: Impact of Policy Shocks and Exogenous Changes on the Tech Index of Pakistan



Source: Authors' compilation.

Egypt has demonstrated consistent progress in its technological landscape since 2007, driven by strategic policy reforms. The Special Economic Zones (SEZ) Law (2002) and Industrial Policy (2004) laid the groundwork by liberalising foreign investment and enhancing industrial competitiveness. This momentum was further bolstered by the 2007 EU-Egypt Science and Technology (S&T) Agreement and the Science, Technology, and Innovation (STI) Reform Programme, which positioned science as a cornerstone of national development. These coordinated efforts attracted global corporations such as Vodafone, Microsoft, and IBM, whose investments extended beyond capital inflows to actively strengthen Egypt's local R&D infrastructure and workforce development. By aligning regulatory reforms with international partnerships, Egypt transformed into a hub for technological innovation and knowledge transfer in the region. Besides, the graphs highlight that the period of political stability under President Abdel Fattah el-Sisi provided a conducive environment for policy implementation, allowing long-term plans like Vision 2030 to take shape. Therefore, while initial growth was moderate, consistent efforts in fostering a conducive environment to attract foreign investment bolstered the index's growth. Egypt's ability to integrate policy planning with economic goals was crucial in sustaining technological advancement.

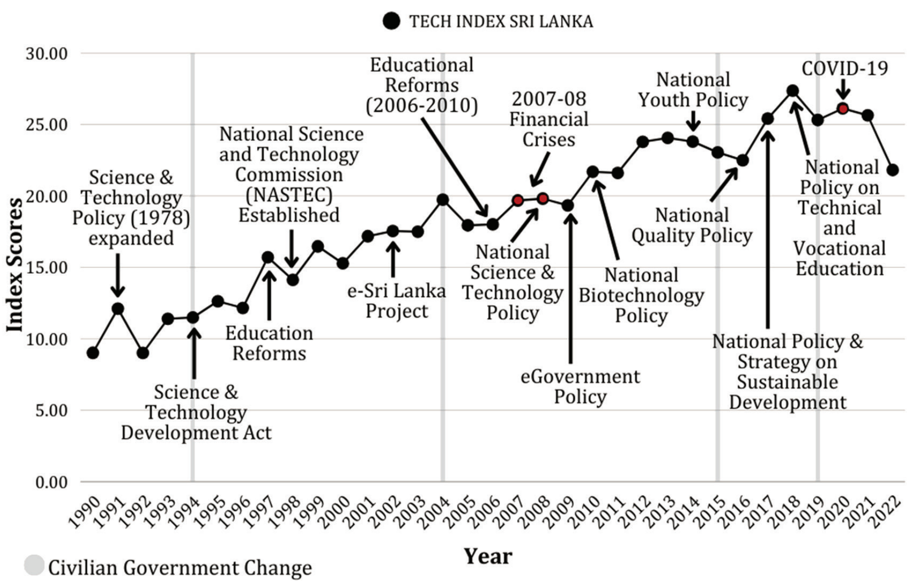
Figure 6: Impact of Policy Shocks and Exogenous Changes on the Tech Index of Egypt



Source: Authors' compilation.

Although Sri Lanka's technological expedition has not been transformative like India's or Egypt's, the country has experienced gradual improvements in technological advancement following specific policy interventions. Adopting the National Science & Technology Policy (2008), eGovernment Policy (2009), National Youth Policy (2014), and National Quality Policy (2016) significantly reduced the administrative sludge and enhanced human capital. The graphs demonstrate that implementing these policies often exhibited a lag effect, with noticeable impacts on the Tech Index appearing in subsequent years as the initiatives gained traction. Moreover, during political and economic stability periods, such as the early 2010s, Sri Lanka made strides in promoting digital infrastructure and high-tech manufacturing. Establishing institutions supporting R&D further solidified the country's commitment to fostering innovation. However, the pace of growth slowed during periods of political upheaval, highlighting the challenges of sustaining long-term strategies in a fluctuating governance environment.

Figure 7: Impact of Policy Shocks and Exogenous Changes on the Tech Index of Sri Lanka



Source: Authors' compilation.

Ordinary Least Squares (OLS) & Two-Stage Least Squares (2SLS)

This section analyses the relationship between technological advancement, market competition, and economic growth through least-squares regressions. However, due to the potential endogeneity problem, the 2SLS was also estimated along with the OLS for both Models 1 and 2.

Estimates of Model 1 (Relationship between Technology Index and Competition)

The estimates of Model 1, in which the impact of technological advancement, FDI, and the HDI on market competition is analysed, are given in Table A4 (Appendix 4). Similarly, the estimates of Model 2 are presented in Table A5 (in Appendix 4), which shows the impact of technological advancement, market competition, FDI, and HDI on economic growth. In Model 2, the first lag of the dependent variable (GDP) is also included as an independent variable, accounting for unobserved dynamic processes that could cause residuals to be correlated over time. Thus, this strategy helped mitigate the serial correlation problem by reducing it to marginal significance (10% level).

Moreover, as discussed earlier, economic growth often exhibits inertia, where past growth influences current growth. Thus, theoretical and econometric reasonings motivate the use of lagged dependent variables in the second model. In contrast, the lag of the dependent variable as an independent variable was not included in the first model because market competition is often more susceptible to immediate changes due to policy shifts, market entry or exit, and competitive strategies. Similarly, even sudden technological innovations can disrupt market dynamics, leading to rapid changes in competitive landscapes. Therefore, past competition may not adequately explain current competition levels, making the inclusion of a lagged dependent variable less theoretically justified in the first model. Moreover, since Model 1 is less susceptible to the problem of serial correlation, there was no econometric justification for using the lagged dependent variable in the first model.

The regression estimates of Model 1 revealed similar insights when estimated using either OLS or 2SLS. The 2SLS was used to control the endogenous nature of the FDI variable, as found by the Toda-Yamamoto causality analysis, as shown in Table A6 (Appendix 4). The estimates indicate that the technology index (TI) has a negative and statistically significant relationship with market competition in both models. In the OLS estimation, the coefficient for TI is -0.0512 (significant at the 10% level), while in the 2SLS estimation, the coefficient is -0.0551 (also significant at the 10% level). It suggests that higher technological innovation may initially reduce market competition, possibly due to increased market concentration by technology leaders or barriers to entry created by technological advancements. The FDI variable has a negative but statistically insignificant coefficient in both models, with values of -0.0274 in the OLS model and -0.0713 in the 2SLS model. These findings imply that FDI does not directly affect market competition in the sample countries. In contrast, HDI demonstrates a strong positive and highly significant relationship with market competition in both models. The OLS estimate shows a coefficient of 11.3984, while the 2SLS estimate is 11.4200, both significant at the 1% level. These results highlight the critical role of human development in enhancing market competition, likely through the promotion of skilled labour, innovation, and institutional quality, which foster competitive market environments. The constant term (C) is positive but statistically insignificant in both models, suggesting no substantial baseline effect on market competition beyond the variables included in the models.

Regarding model fit, the R-squared values for both OLS (0.7653) and 2SLS (0.7417) indicate that the independent variables explain a substantial portion of the variation in market competition. The F-statistics for both models are highly significant at the 1% level, affirming the joint significance of the explanatory variables. The Durbin-Wu-Hausman endogeneity test for the 2SLS model yields a p-value of 0.5460, indicating strong evidence of endogeneity of the FDI variable and advocating for using the 2SLS model over the OLS. However, the Cragg-Donald F-statistic of 44.8064 exceeds the threshold of 10 and Stock-Yogo critical values at 10%, 15%, 20%, and 25%. Thus, it suggests that the chosen instrument (lagged FDI) is strong and relevant. Besides, the Durbin-Watson statistics (1.7400 for OLS and 1.7688 for 2SLS) indicate no severe autocorrelation issues. However, the Breusch-Pagan serial correlation LM test is significant at the 10% level for the OLS model (5.8958), suggesting the presence of serial correlation. In the 2SLS model, this issue is not pronounced (3.8768, insignificant). In order to correct the problem of serial correlation in the OLS model, the Newey-West Heteroskedastic and Autocorrelation Consistent (HAC) standard errors were used. The Breusch-Pagan-Godfrey heteroskedasticity test shows no evidence of heteroskedasticity in either model. Finally, the Jarque-Bera test indicates that the residuals are normally distributed in both models, as evidenced by non-significant statistics (1.7917 for OLS and 0.9744 for 2SLS).

Estimates of Model 2 (Relationship between Economic Growth (GDP), Competition and Technology Index)

The regression analysis results for the relationship between GDP and its explanatory variables are given in Table A5 (Appendix 4) and provide several critical insights. Both OLS and 2SLS regressions were done with Newey-West HAC standard errors to correct for heteroskedasticity and autocorrelation. The 2SLS model accounted for the potential endogeneity of FDI and TI by using the first lags of these variables as instruments, chosen for their presumed correlation with the endogenous variables and uncorrelation with the error term. The estimated coefficients in Table A5 (Appendix 4) reveal interesting dynamics. The market competition (COMP) variable is insignificant in both the OLS and 2SLS models, suggesting a negligible role for market competition in economic growth under simple regression assumptions. Similarly, FDI has a negative coefficient in both models, though it is statistically insignificant. This result implies that FDI may not have a direct, immediate impact on economic growth in the sample, potentially due to inefficiencies in capital allocation or delayed spillover effects. In contrast, the TI variable consistently shows a significant and positive impact on GDP across both models. The coefficient increases from 0.0037 in the OLS model to 0.0066 in the 2SLS model, highlighting the critical role of technological advancement in driving economic growth. However, in the 2SLS framework, the variable becomes statistically significant at a 1% significance level instead of 5%.

Similarly, HDI is positively and significantly associated with GDP, with coefficients of 2.0491 and 2.3611 in the OLS and 2SLS models, respectively. It underscores the importance of human capital development in enhancing a country's productive capacity and long-term economic performance. The lagged GDP term [GDP (-1)] is also highly significant in both models, with coefficients of 0.6986 (OLS) and 0.6299 (2SLS), indicating the persistence of economic growth over time. The constant term is also significant in both models, reflecting baseline factors contributing to GDP growth that are not captured by the included variables.

The diagnostic statistics further validate the models' performance. The R-squared values are exceptionally high for both models, at 0.9983 and 0.9981, respectively, suggesting that the models explain nearly all variation in GDP, which might be because the HDI uses per capita income as one of its primary constituents in describing the HDI. Besides, the F-statistics of both models are significant at the 1% level, confirming the joint significance of the independent variables. For the 2SLS model, the Durbin-Wu-Hausman endogeneity test results are insignificant and support the hypothesis that FDI and TI are endogenous, justifying the use of the 2SLS framework over the OLS. The Cragg-Donald F-statistic (12.9104) exceeds the threshold of 10 and Stock-Yogo critical values at 10%, 15%, 20%, and 25%, thus indicating that the chosen instruments (lagged values of FDI and TI) are strong and relevant. Even after using the first lag of the dependent variable, the Breusch-Pagan Serial Correlation LM test indicates the presence of serial correlation, although at a weaker significance level (10%). Similarly, the

Breusch-Pagan-Godfrey test confirms the presence of heteroskedasticity. However, both issues were dealt with using HAC standard errors. Finally, the Jarque-Bera test results suggest that the residuals are normally distributed, as evidenced by non-significant p-values (0.2551 and 0.2710 for OLS and 2SLS, respectively).

Causal Relationship between Technology, Economic Growth, and Competition (Toda Yamamoto Causality)

The results of the Toda-Yamamoto causality test are presented in Table A6 (Appendix 4) and provide valuable insights into the complex relationships between technological innovation (TI), FDI, human development (HDI), market competition (COMP), and GDP. The findings show that technological innovation Granger-causes GDP and market competition at a 10% significance level, indicating its critical role in driving economic growth and fostering a competitive business environment. It underscores the importance of investing in technological advancements, as they improve productivity and create disruptive changes that reshape market dynamics. Furthermore, HDI Granger-causes GDP and FDI at a 10% significance level, highlighting how improvements in human development indicators, such as education, health, and income levels, play a pivotal role in enhancing economic growth and attracting foreign investments. It suggests that policies to improve human capital can yield significant dividends in terms of economic and investment outcomes. Furthermore, GDP is also shown to Granger-cause FDI and TI at 1% and 10% significance levels, which indicates that higher economic growth attracts foreign investments and fosters technological advancements. This relationship emphasises the need for a stable macroeconomic environment to stimulate innovation and foreign investment. Additionally, market competition Granger-causes FDI at a 5% level, suggesting that a competitive market environment attracts foreign investors because it signals openness, opportunity, and economic vibrancy.

However, the test also reveals several non-significant relationships. For instance, FDI does not Granger-cause GDP, which implies that the direct impact of foreign investments on economic growth might depend on the quality and efficiency of investment allocation. Similarly, HDI, market competition, and FDI do not significantly influence technological innovation, indicating that technological advancements might be driven more by internal factors such as R&D expenditure, institutional support, or innovation systems rather than external market or development indicators.

Generalised Impulse Response Functions

The results of the generalised impulse response functions (GIRFs) provide valuable insights into the dynamic relationships between economic growth, human development (HDI), technological innovation (TI), FDI, and market competition (COMP). The accumulated responses to one standard deviation innovation reveal the temporal effects of these variables on one another, shedding light on their economic interactions and policy implications. The response spans over ten periods, with the 95% confidence intervals computed using Kilian's (1998) bias-corrected bootstrap methodology for small sample sizes and is based on 999 bootstrap replications and 499 double bootstrap replications.

The solid blue line represents the accumulated response of the variable to the shock in other variables. In contrast, the shaded light green region indicates the 95% confidence interval, capturing the range within which the response is expected to fall. The accumulated response of GDP to shocks in HDI shows a short to medium-term positive effect. Initially, the response is close to zero. However, it becomes positive and significant around the third period, peaking around the fifth period before stabilising and slightly declining over time. However, it stays largely positive until the end of the 10th period. It suggests that improvements in human development contribute significantly to economic growth.

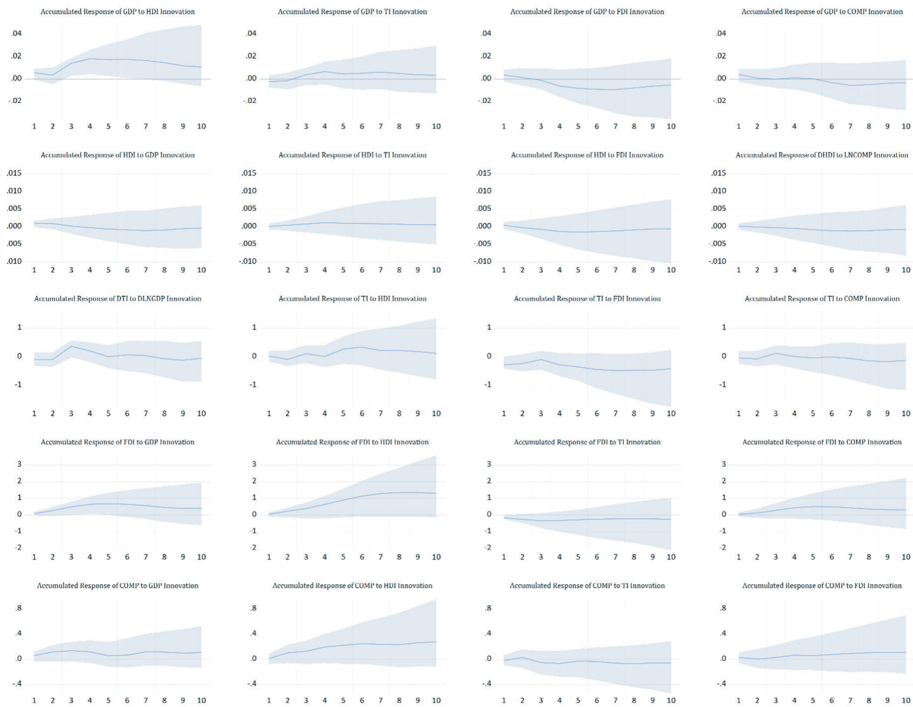
Similarly, GDP also responds positively to shocks in technological advancements. The initial response of GDP to the innovation is slightly negative but turns positive around the second period, increasing steadily and peaking at approximately the fourth period. Beyond this point, the response stabilises and slightly declines over time. These results suggest that technological innovation exerts a delayed but positive effect on GDP in the short to medium term, aligning with theoretical expectations that innovations enhance productivity and economic growth. However, the impact of technological innovation is not as strong as that of the HDI.

Moreover, the FDI shock has an initial positive but quickly negative and persistent impact on GDP, potentially reflecting inefficiencies in the absorption of foreign investments or structural economic challenges. Finally, market competition shock has a negligible effect on GDP, but the GDP response turns slightly negative after the fifth period. This suggests that structural barriers and institutional weaknesses, like informal economy dominance, poor infrastructure, monopolies, and regulatory inefficiencies, might stifle the benefits of competition in Pakistan. Meanwhile, the reaction of the HDI to shocks in any of the variables within the system is minimal, with the response line consistently hovering close to the zero line. It indicates that human development and capital improvements are primarily unresponsive to changes in economic growth, technological innovation, foreign investment, and market competition.

The response of technological innovation to GDP shocks is initially slightly negative, but after the second period, it starts to increase rapidly and reaches a maximum in the third period. Thereafter, the shock begins to die as the response line tends to zero for the rest of the period. The significant positive impact shows that economic growth supports innovation through enhanced resources and opportunities. Initially, HDI shocks induce almost no response to technological advancements. However, after the fourth period, the response is significant and positive, reinforcing the mutually beneficial relationship between human capital and technological progress. The accumulated response of technological advancement to FDI is negative throughout, with the most substantial negative effect occurring between the sixth and ninth periods, which suggests that foreign investments may focus on resource extraction or low-tech industries, which could suppress domestic innovation efforts. Lastly, the shock in the market competition has a negligible impact on the levels of technological innovation as the response line nears the zero axis throughout the period.

For FDI, shocks in GDP, HDI, and COMP lead to a steadily increasing positive response in FDI, reflecting that economic growth, human development, and market competition attract foreign investment. Conversely, technological innovation shocks result in a weaker but negative response throughout, suggesting that rapid advancements may create uncertainty for foreign investors or increase entry costs. Finally, market competition exhibits a positive response to GDP shocks, peaking around the third period and sustaining till the end, indicating that economic growth fosters competitive market structures. HDI shocks also elicit a steadily increasing positive response in competition, suggesting that human development enhances market dynamics. Technological innovation shock results in a weaker but persistent negative response from market competition, reflecting that innovation reduces and eases competitive pressures. FDI shocks induce a weak but persistent positive response in competition, implying that foreign investments might create balances and distort market concentration.

Figure 8: Generalised Impulse Response Functions



Source: Authors' calculation.

5. CONCLUSION

This research comprehensively evaluated Pakistan's technological landscape by developing a Tech Index, facilitating a comparative analysis with other lower-middle-income countries, namely, Egypt, India, Sri Lanka, and Uzbekistan. The findings highlight that while Pakistan has demonstrated consistent growth in its technological sophistication over the past three decades, it remains significantly behind its peers in key sub-indicators such as patents, high-tech exports, productivity, human resources in R&D, and renewable energy adoption. Findings indicate that countries with high R&D investment, education expenditures, and cohesive technology policy frameworks tend to lead others in technological advancement. Strategic policies, including strong intellectual property regimes, skill development programmes, and focused investment in renewable energy and high-tech industries, explain India's and Egypt's better performance. On the other hand, Pakistan lags because of systemic challenges of underfunding R&D, non-implementation of technology policies, a poor institutional framework, and policies not encouraging innovation and competition.

The econometric analysis was conducted to determine the complicated relationships between technological advancement, competition, and economic growth. In addition, econometric analyses revealed the intricate relationships between technological advancement, competition, and economic growth. While technological innovation positively contributes to GDP growth, its initial impact on market competition appears negative, possibly due to increased market concentration and barriers to entry. The findings also underscore the significant role of human capital development in fostering competition and economic growth, highlighting the need for policies prioritising education, skill development, and R&D capacity-building. The generalised impulse response functions demonstrated the positive impacts of technological innovation and human development on economic growth while revealing the dynamics between competition, FDI, and technology adoption.

This research emphasises the urgent need for Pakistan to adopt a holistic and integrated approach to technological development. Drawing lessons from the success stories of India and Egypt, Pakistan must focus on increasing R&D investments, enhancing its patent ecosystem, promoting high-tech exports, and fostering renewable energy adoption. Addressing structural barriers such as regulatory inefficiencies, inadequate funding, and a lack of stakeholder collaboration will be critical for closing the technology gap with its regional peers. In conclusion, the Tech Index is a diagnostic and strategic tool offering valuable insights for policymakers, stakeholders, and industry leaders to design targeted interventions. By capitalising on technology as a driver of economic growth and competition, Pakistan has the potential to transform its technological landscape and achieve sustainable development in the coming decades.

6. POLICY RECOMMENDATIONS AND FUTURE DIRECTIONS

This study highlights that Pakistan remains significantly behind in technology adoption and advancement, a gap that has adversely impacted the country's economic growth. The lack of progress in embracing and implementing advanced technologies has limited Pakistan's ability to compete globally and capitalise on opportunities for innovation-driven development. As a result, technological stagnation continues as a barrier to achieving sustainable economic growth and improving the nation's competitive standing. At the same time, the peer countries are more focused and have better technology levels, contributing significantly towards these countries' growth. To draw better and actionable policy recommendations, it is critical to first understand what these other countries are doing that Pakistan is missing and then what possible pathway Pakistan can adopt. This part first provides the cross-country comparison between the Tech Index performances and the policy differences; then, the next part offers the actionable policy recommendations that can be followed to get better outcomes.

Technology Index Performance: Cross-Country Comparisons and Policy Differences

This part focuses on drawing a comparison between the countries and explaining the differences at the index level, how other countries successfully adopted policies that stimulated an increase in technology, and why Pakistan lags. Over the years examined, graphs reveal that India and Egypt have consistently shown upward trends in all sub-indicators, whereas Pakistan's progress has been uneven. This reflects structural weaknesses in Pakistan's innovation and industrial strategies, coupled with limited international collaborations and a lack of regional integration in key sectors.

Firstly, as shown in Figure 9, high-tech exports are markedly higher in India and Egypt, driven by government initiatives like India's "Make in India" campaign and Egypt's Industrial Policy and Special Economic Zones framework. These programmes offer tax breaks, export subsidies, and incentives for technology-driven industries. Conversely, Pakistan's reliance on traditional low-value industries like textiles undermines its ability to achieve similar high-tech exports. Similarly, due to the lack of reverse engineering, growth and exports of the agriculture and industrial sectors remain constrained by the balance of payment (BOP). Moreover, limited domestic R&D in export sectors and weak integration into global value chains are critical constraints. Furthermore, unlike Pakistan's persistent bureaucratic inefficiencies and inefficient institutions, India and Egypt have streamlined business processes through unified digital platforms. These centralised systems, designed to expedite approvals for foreign and domestic investors, have played a critical role in enhancing transparency and reducing administrative delays.

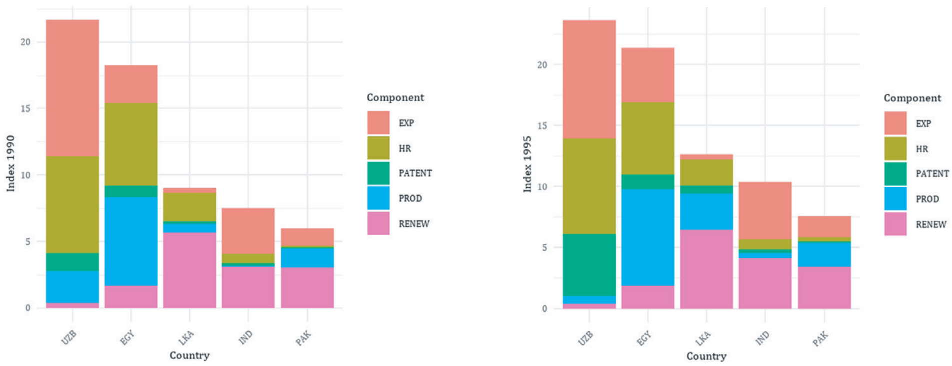
Moreover, India's National IPR Policy of 2016 promotes innovation through financial incentives and a supportive legal framework for patent filing. Therefore, there is consistent growth in patent applications. Egypt offers customised support to startups and individuals for intellectual property filings through the Technology Innovation and Entrepreneurship Center

(TIEC). Meanwhile, in Pakistan, there are no accessible mechanisms, and public awareness remains limited. Similarly, institutional support is weak, resulting in minimal patent activity.

Thus, India and Egypt outperform Pakistan significantly in patent registration. Besides, India and Egypt consistently show higher productivity due to focused workforce development programmes. India's Skill India Mission has made a point of upskilling and reskilling programmes for youth and people from other marginalised groups. Similarly, under the 2014 Economic Reforms, Egypt proposed a series of education reforms and, through partnerships with global organisations and other countries, is providing targeted, skill-based education and employment opportunities. In Pakistan, contrary to that, productivity has been chiefly stagnant due to an education system that does not match market needs, limited skill development initiatives, and weak industrial automation.

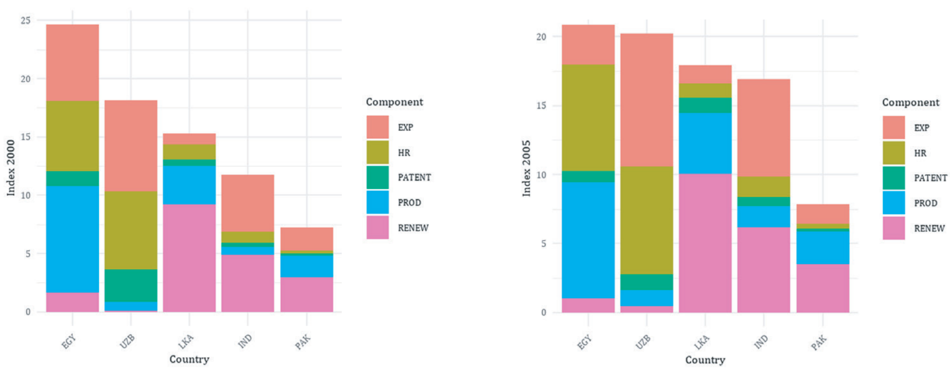
Furthermore, India’s investment in scientific research through institutions like the Indian Institutes of Technology (IITs) and the establishment of the National Innovation Council have increased its R&D workforce. Egypt’s Scientific Research Strategy 4.0 (2019) under Egypt Vision 2030 has similarly emphasised creating a robust research ecosystem. Pakistan’s inconsistent funding for education and research, brain drain, and poor infrastructure for R&D have led to a significantly lower density of researchers per million people. The transition to renewable energy supported by the government is another major factor. Egypt and India have led the adoption of renewable energy, supported by large-scale projects like Egypt’s Benban Solar Park and India’s National Solar Mission. These initiatives include public-private partnerships and financial incentives to boost renewable energy capacity. Despite launching the Alternative and Renewable Energy Policy 2019, Pakistan struggles with implementation due to regulatory hurdles, reliance on fossil fuels, and inadequate investment in renewable projects. The comparative performance highlights a need for Pakistan to diversify its industrial and technological base. For example, India’s focus on IT and Egypt’s emphasis on energy innovation underlines the importance of sector-specific policies, a critical area where Pakistan has lagged.

Figure 9: Comparative Composition of Tech Index and Contribution of Each Constituting Sub-Indicator in 1990 & 1995



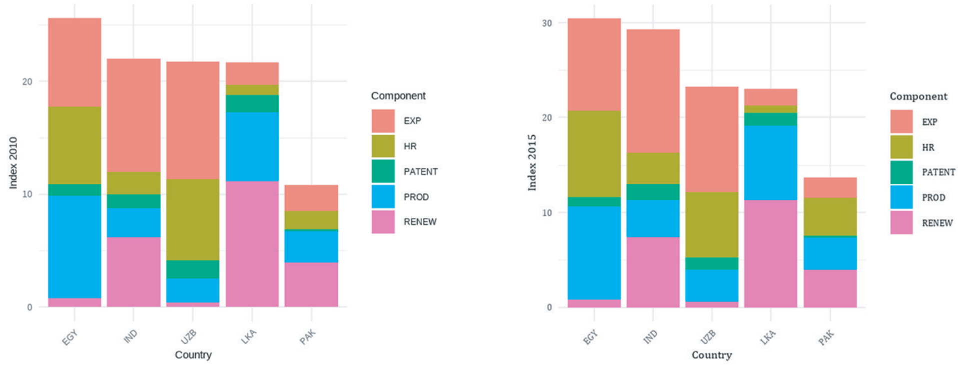
Source: Authors' calculations.

Figure 10: Comparative Composition of Tech Index and Contribution of Each Constituting Sub-Indicator in 2000 & 2005



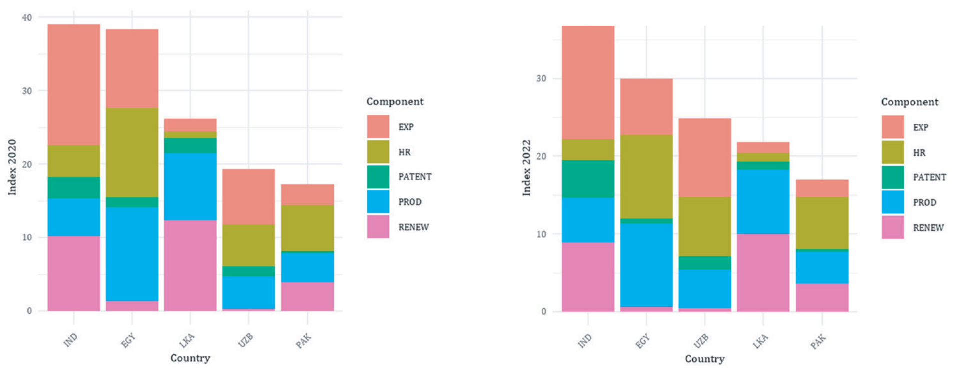
Source: Authors' calculations.

Figure 11: Comparative Composition of Tech Index and Contribution of Each Constituting Sub-Indicator in 2010 & 2015



Source: Authors' calculations.

Figure 12: Comparative Composition of Tech Index and Contribution of Each Constituting Sub-Indicator in 2020 & 2022



Source: Authors' calculations.

Policy Recommendations

Pakistan's technological and market landscape faces profound structural challenges, where neither technological progress nor market competition significantly drives economic growth. Despite advances in policy frameworks, Pakistan's policies lack continuity, cohesion, and alignment with broader economic goals, diminishing their effectiveness. The prominent examples are S&T Policy (1984), National Technology Policy (1994), and Digital Pakistan Policy (2018). Although all these policies had a great vision, they were poorly funded and implemented, therefore never realising their full potential. This reflects a bigger problem in Pakistan, where most policy initiatives never succeed due to a lack of resources and poor implementation.

On the other hand, countries like India have adopted and successfully capitalised on cohesive and decades-long policy frameworks to advance technologically. Recently, the Intellectual Property Rights (IPR) Policy and Startup India initiatives have also highlighted that their efforts have clear implementation strategies and are well-funded in fostering innovation and entrepreneurship across sectors. Egypt's Vision 2030 is another example of aligning its policies across various sectors to ensure continuity and effective long-term outcomes. India's and Egypt's policy coherence contrasts sharply with Pakistan's fragmented approach, where policies often lack coordination and fail to align with broader economic goals.

Another issue in Pakistan's technological and market landscape is the weak enforcement of competition policies, allowing entrenched firms to dominate key sectors without fostering innovation or efficiency. Competition enforcement must go beyond legal frameworks and dismantle market barriers that protect inefficient state-owned enterprises and established industrial groups. One recommendation for Pakistan is to improve the funding and implementation of key policies, particularly those related to technology and innovation, to ensure they align with competition policy and national economic objectives. Besides, long-term planning and insulation from political changes are crucial for Pakistan, and a way to do this is to have a dedicated, autonomous, efficient, and centralised body overseeing the implementation of technology policies. In addition, a mechanism should be in place to track the progress of such policies to ensure that they stay on course despite political or institutional changes.

In addition, Pakistan has faced significant challenges in R&D investment, which accounts for less than 0.3% of GDP, which is one of the lowest rates globally. On the other hand, India has made significant strides in R&D, allocating a higher percentage of its GDP towards R&D, benefiting from both public and private sector investments. This commitment to innovation has translated into tangible outcomes as India continues to generate higher technological advancement and innovation outputs. Egypt, similarly, has focused on strengthening its technological capabilities through its industrial policy and centres, like the Industrial Modernization Center, which aims to enhance Egypt's capacity for innovation and R&D. However, Pakistan's limited investment, coupled with fragmented infrastructure, significantly undermines the country's ability to compete effectively on a global scale.

To address these challenges, Pakistan must prioritise increasing its R&D funding and building the necessary infrastructure to support innovation. A concrete recommendation is to create a Competitive Technology Fund (CTF) and dedicated R&D funding bodies to incentivise innovation in high-tech sectors such as IT, renewable energy, and biotechnology. The fund should be performance-based, awarding grants or low-interest loans to companies and startups demonstrating high-impact technological advancements. This approach aligns with India's Technology Development Fund (TDF), significantly boosting industry-led innovation. Besides, compulsion and incentive structures should also be developed to necessitate and encourage co-investment in domestic R&D efforts from private industries.

Similarly, foreign tech importers should be required to invest a percentage of import costs in domestic R&D or skill development. Meanwhile, reverse engineering should also be preferred and incentivised within industries instead of relying on foreign raw materials, especially machinery. Moreover, as there is a causal link between technology and economic growth, the focus should be on developing commercially viable technologies, which could contribute to better growth outcomes through increasing productivity or capital accumulation.

Pakistan must also shift its focus to vertical technology transfer to bridge the gap between research and commercialisation. Although Pakistan has established many institutions for that purpose, including the STEDEC Technology Commercialization Corporation of Pakistan and the Pakistan Council of Scientific and Industrial Research (PCSIR), these offices have been unable to make any significant improvements due to their lack of effectiveness. Thus, accountability should be reinforced in these institutions, and performance-based metrics should be implemented; similarly, funding and incentive structure should be tied to clear outcomes such as patents, commercialisation success, and industry collaboration. Each office should have clear goals and a one-window digital streamlined process to facilitate collaboration between academia, research institutions, and industries and ensure that R&D outputs are transformed into market-ready innovations. These institutions should also provide legal, financial, and logistical support for patent filings, licensing agreements, and technology deployment. Countries like Egypt have successfully implemented similar models under the Academy of Scientific Research and Technology, accelerating their innovation pipeline.

Human capital is another foundational pillar for technological progress, and without a skilled workforce, investments in R&D and market reforms are bound to have a constrained impact. The basis of India's approach to workforce readiness lies in structured programmes like the Skill India Mission, which targets the dissemination of vocational training and digital skills among millions of youths. Over the years, with international collaboration, Egypt has also employed various education and skill dissemination programmes that aim to mainstream workforce development in line with its broader economic goals and prepare the workforce for the future of work, especially in technology and industrial sectors. These structured programmes have yielded positive results in better workforce employability and productivity in India and Egypt. In Pakistan, however, that is not very promising. Programmes like the Prime Minister's Youth Skills Development Program have been relatively small in scale and short-term, leading to no long-term impact. Such fragmented and short-term initiatives cannot satisfy the labour market’s needs and result in a workforce incapable of driving innovation and economic growth. The main recommendation for Pakistan is to scale up skills development programmes, modernise STEAM education curricula, align university programmes and research with industry needs, and expand technical training institutes focused on high-tech manufacturing and digital skills. In addition, an intense monitoring and evaluation system should be in place to ensure the continuity and effectiveness of such programmes.

Moreover, Egypt and similar countries have made substantial achievements in renewable energy through strategic projects like the Benban Solar Park, which drew massive international investments. Similarly, the National Solar Mission of India has shown how strategic subsidies and regulation clarity can inspire private investments in renewable energy projects. These initiatives have positioned both countries as leaders in the renewable energy sector, leveraging their natural resources and attracting global investment. Pakistan, however, has struggled to replicate this success due to inefficiencies in its bureaucratic and political processes and inconsistent policy enforcement. Pakistan's Alternative Energy Development Board has faced significant challenges in mobilising investments and creating a conducive environment for renewable energy development. A key recommendation to improve Pakistan’s renewable energy sector is to streamline bureaucratic processes and establish clear, long-term energy policies based on diversified renewable energy sources. This would help meet energy needs and contribute to broader economic growth and sustainability. Moreover, Pakistan should adopt international collaborative practices and benchmark its national performance against leading international and regional countries. Participating actively in international forums and fostering partnerships with technology leaders can bring resources and expertise to Pakistan, and aligning national policies with global goals like SDGs can attract foreign investments.

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APPENDICES

Appendix 1: Variables, Definitions, and Data Sources

Table A1: Sub-Indicators of Tech Index, their Relevant Proxies, Definitions, and Sources

Variables	Weightage	Proxy	Definition	Source
EXP	20%	Medium & High-tech exports (% of manufactured exports)	It is the share of medium and high technology exports in total manufactured exports.	United Nations Industrial Development Organization (UNIDO), Competitive Industrial Performance (CIP) database
PROD	20%	Output per worker (GDP constant 2017 US$)	It is the total volume of outputs (GDP) produced per unit of labour measured in terms of the number of employed persons or hours worked during a day.	International Labor Organization (ILO - Modelled Estimates)
HR	20%	Researchers in R&D (per million people)	The number of researchers engaged in R&D is expressed as per million. Researchers are professionals who conduct research and improve or develop concepts, theories, models, techniques, instrumentation, or software for operational methods.	United Nations Educational, Scientific, and Cultural Organization (UNESCO) Institute for Statistics

Variables	Weightage	Proxy	Definition	Source
RE	20%	Share of modern renewables in total final energy consumption (% of total primary energy consumption)	Percentage of primary energy consumption coming from all modern renewable energy sources.	International Energy Agency, World Energy Balances
PATENT	20%	Patent applications by residents	Number of patent applications filed by residents through the patent cooperative treaty procedure or with a	World Intellectual Property Organization (WIPO),

Source: Author's illustration.

Table A2: Variables Used, their Proxies, Definitions, and Data Sources

Name of variable	Nature of variable	Measurement	Proxies used	Definitions and Sources
Tech Index	Independent variable	Technology advancement and technology adoption	Tech index (made up of sub-indicators made up of (Hi-tech exports, labour productivity, R&D spending/patents, human resources in R&D, and renewable energy)	It measures the technological landscape and sophistication of the country. Source: Developed by Authors
Economic Growth	Dependent variable	Gross Domestic Product	GDP (constant LCU)	Gross Domestic Product at constant market prices based on constant local currency. Source: World Development Indicators

Name of Variable	Nature of Variable	Measurement	Proxies used	Definitions and Sources
Competition	Independent/ dependent variable	Competition in the market	Competition intensity (No. of Industrial design applications, residents)	Applications to register an industrial design with national or regional Intellectual Property (IP) offices and designations received by relevant offices through the Hague System. Source: World Development Indicators
Foreign Investment	Control Variable	Direct foreign investment.	FDI, net inflows (% of GDP)	Cross-border investment associated with a resident in one economy having control or a significant degree of

Source: Authors' compilations.

Appendix 2: Estimated Index Results

Table A3: Tech Index 1 (with Patents) and Tech Index 2 (R&D Expenditures) Scores

Tech Index 1 (Patents)					
Year	EGY	IND	LKA	PAK	UZB
1990	18.22986	7.497947	9.021034	5.988409	21.64902
1991	19.65817	8.437825	12.11352	6.098684	25.94909
1992	17.99135	7.930896	9.008483	6.969346	21.87542
1993	18.62082	8.456613	11.39574	7.667554	30.21318
1994	19.31406	9.666333	11.49403	8.914886	24.71643
1995	21.38231	10.34576	12.63026	7.56727	23.59731
1996	21.68223	12.09849	12.16205	7.549023	23.56592
1997	20.40213	11.93156	15.69797	7.468751	22.64776
1998	22.2841	11.55984	14.12721	8.450602	21.42119
1999	23.12094	11.70505	16.46729	6.584323	23.16756
2000	24.62217	11.72415	15.27946	7.2407	18.14697
2001	22.76739	12.89251	17.17934	7.677131	18.79216
2002	23.86995	13.34654	17.54662	7.382991	20.53865
2003	23.72368	14.61227	17.50328	8.260453	23.67239
2004	21.2906	15.77831	19.74284	8.170483	17.25118
2005	20.827	16.91781	17.9351	7.83394	20.23163
2006	22.41131	18.16829	18.00524	8.808317	16.8441
2007	22.06188	19.11492	19.67556	10.53272	17.5797
2008	24.84525	19.77186	19.8056	11.05577	16.61021
2009	24.92203	20.76877	19.336	10.97089	19.50289
2010	25.58427	22.02617	21.6882	10.82621	21.72335
2011	26.76193	22.4653	21.60812	10.69388	18.82364
2012	27.7042	23.6891	23.78243	10.5627	20.50327
2013	27.95186	25.4182	24.06097	11.58732	20.5661
2014	30.95289	27.22582	23.80357	12.53667	22.4334
2015	30.41674	29.29842	23.03642	13.67911	23.22799
2016	31.87502	30.67922	22.49415	13.68869	24.04536
2017	32.07549	32.43164	25.41445	14.4817	24.71618
2018	32.35646	34.41393	27.35749	15.9498	23.5765
2019	37.22013	36.58471	25.31402	16.48151	22.33464
2020	38.35275	38.98479	26.11969	17.21768	19.27026
2021	33.49057	36.50192	25.64489	17.17489	23.08488
2022	29.99533	36.89183	21.8065	16.99737	24.86165

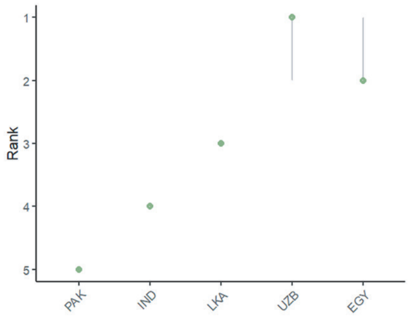
Tech Index 2 (R&D Expenditure)					
Year	EGY	IND	LKA	PAK	UZB
1990	19.67049	14.87926	13.73139	9.948629	22.40563
1991	23.3455	16.98031	18.09395	11.92647	21.10254
1992	18.14116	15.76743	11.30992	6.938082	21.56073
1993	20.05799	16.98231	14.68707	10.87322	23.85407
1994	22.07754	19.01507	16.80432	14.807	22.08941
1995	22.78271	20.01323	14.76243	11.23663	21.70747
1996	24.17372	22.65681	15.4076	10.85999	20.61044
1997	23.38751	22.31474	18.57798	11.42304	20.9241
1998	24.63151	21.32822	17.91123	10.81679	20.33282
1999	24.76695	21.84788	17.82957	8.722638	22.85455
2000	26.7571	22.15627	16.87216	9.575405	17.97678
2001	26.29791	24.01559	17.75425	11.28191	18.24228
2002	27.43249	24.40371	17.29023	11.94195	19.60513
2003	30.43535	25.7765	19.09263	12.51287	21.00172
2004	27.45667	27.52311	21.81932	16.98682	19.43246
2005	25.62828	29.35957	17.31475	14.28311	22.16752
2006	27.06881	30.48193	18.84612	17.03803	17.52183
2007	26.86725	31.59869	19.25427	21.99499	18.16159
2008	31.22317	33.11435	16.69104	21.07169	17.28368
2009	35.2879	33.91103	17.33856	21.03846	21.02956
2010	35.03835	34.39555	19.22925	19.43793	19.80429
2011	38.45141	34.84094	18.77774	19.50027	17.89293
2012	38.86756	36.20252	19.20998	16.26993	20.18735
2013	41.9466	37.73303	16.9068	19.75068	19.74718
2014	45.2921	39.56612	16.15997	19.93467	20.96096
2015	46.29338	42.21565	18.17425	21.59301	23.10643
2016	46.41433	43.57899	18.46248	23.31457	23.46391
2017	45.0016	45.05311	20.73313	22.14207	22.88286
2018	46.46058	47.05636	21.58326	25.36988	19.30117
2019	55.07148	48.47041	18.00104	22.52815	18.30382
2020	59.21675	49.84774	20.23727	19.9455	17.55521
2021	52.8102	47.42836	20.11396	22.19314	20.10144
2022	52.16724	46.1407	17.7984	23.93661	23.01119

Source: Authors' calculations.

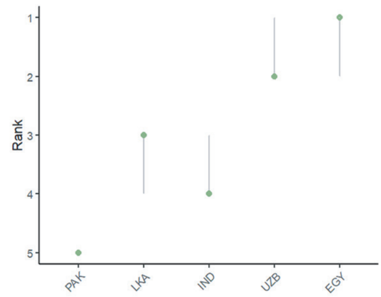
Appendix 3: Uncertainty & Sensitivity Analysis

Index I (Patents)

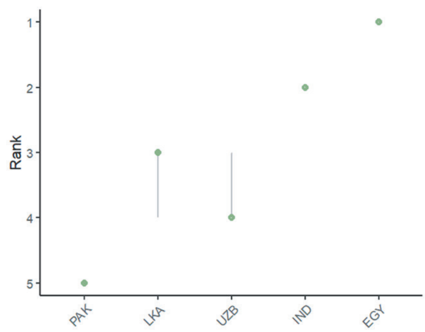
Uncertainty Analysis 2000



Uncertainty Analysis 2010

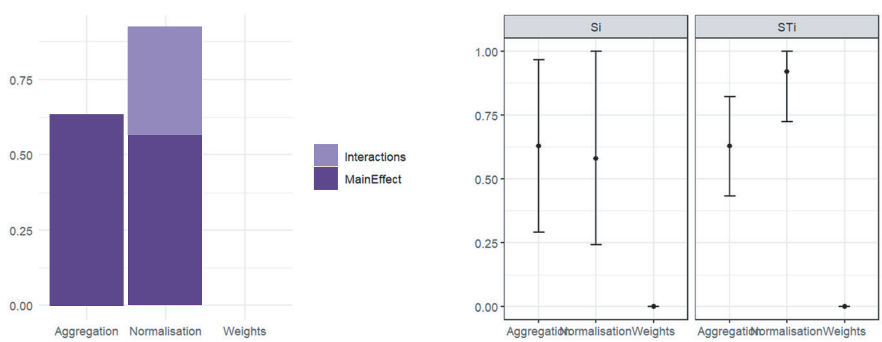


Uncertainty Analysis 2020

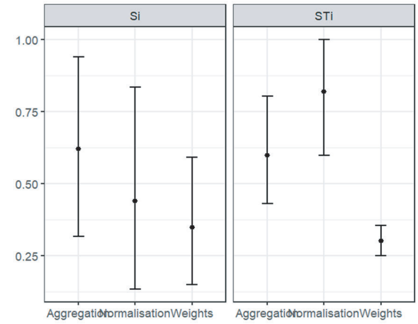


Index I (Patents)

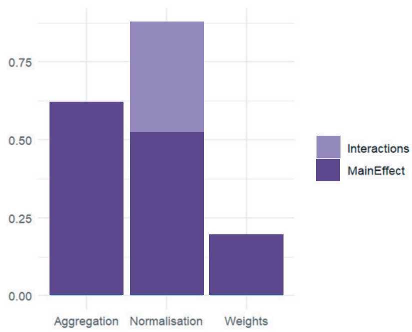
Sensitivity Analysis 2000

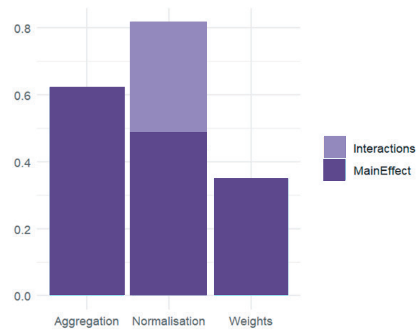


Sensitivity Analysis 2010



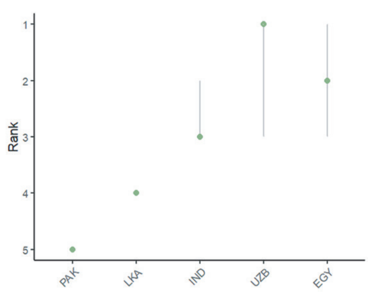
Sensitivity Analysis 2020



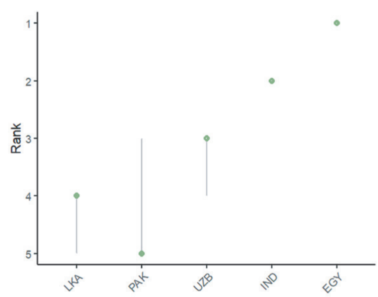


Index II (R&D Expenditures)

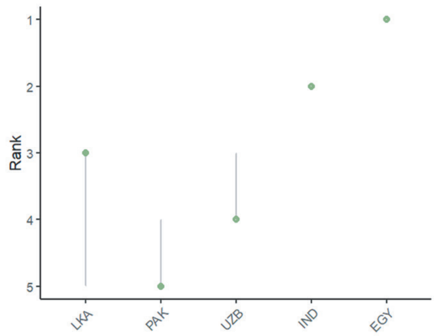
Uncertainty Analysis 2000



Uncertainty Analysis 2010

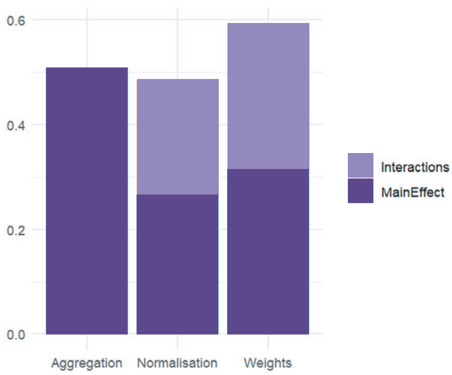


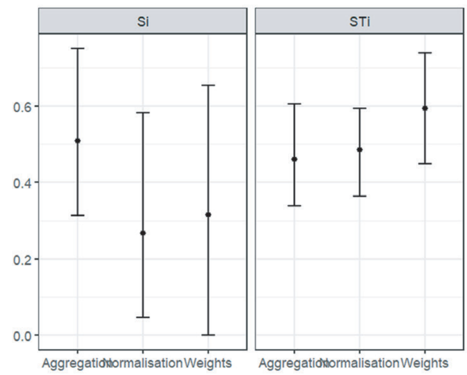
Uncertainty Analysis 2020



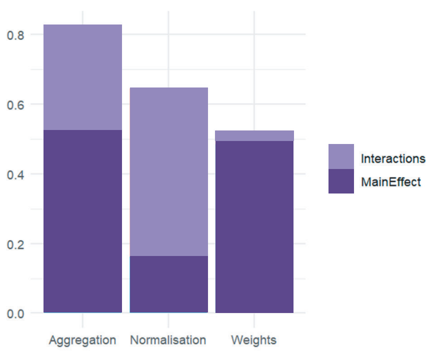
Index II (R&D Expenditures)

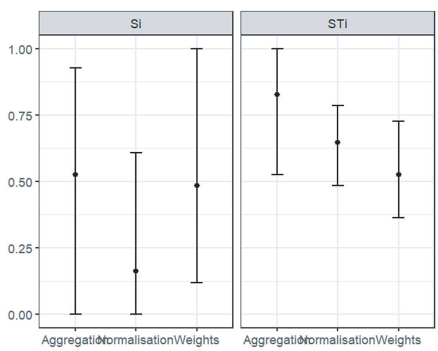
Sensitivity Analysis 2000



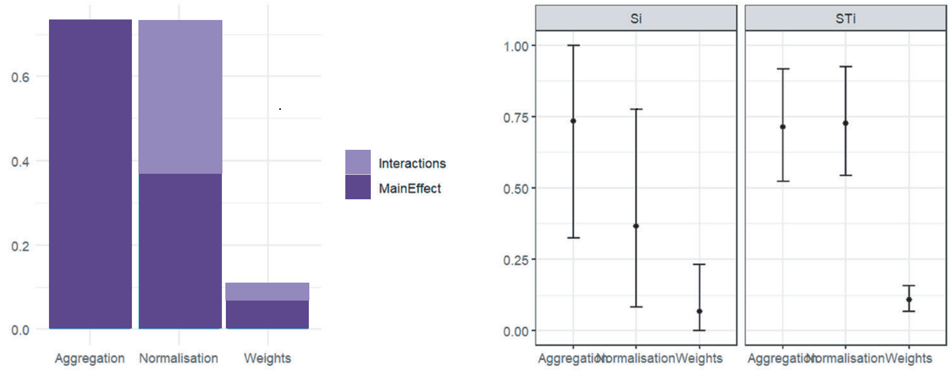


Sensitivity Analysis 2010





Sensitivity Analysis 2020



Appendix 4. Post-Index Estimations

Table A4: Regression Estimates of Model 1 (Relationship between Technology Index and Competition)

Dependent Variable: COMP	OLS Estimates		2SLS Estimates	
	Coefficients	HAC Standard Errors	Coefficients	Standard Errors
TI	-0.0512*	0.0281	-0.0551*	0.0306
FDI	-0.0274	0.0402	-0.0713	0.0869
HDI	11.3984***	2.1947	11.4200***	2.1391
C	0.8412	0.7493	0.9195	0.7200
R-Squared	0.7653		0.7417	
F-Statistic	31.5285***		27.0462***	
Durbin-Wu-Hausman Endogeneity Test (FDI)	...		0.5460	
Cragg-Donald F-Stat.	...		44.8064	
Durbin-Watson Statistic	1.7400		1.7688	
BP Serial Correlation LM Stat.	5.8958*		3.8700	
BPG Heteroskedasticity Stat.	1.3715		1.8629	
Jarque-Bera Normality Test	1.7917		0.9744	

Source: Authors' calculations.

Table A5: Regression Estimates of Model 2(Relationship between Economic Growth (GDP), Competition and Technology Index)

Dependent Variable: GDP	OLS Estimates		2SLS Estimates	
	Coefficients	HAC Standard Errors	Coefficients	HAC Standard Errors
COMP	0.0018	0.0087	0.0046	0.0249
FDI	-0.0018	0.0021	-0.0041	0.0041
TI	0.0037**	0.0018	0.0066***	0.0015
HDI	2.0491***	0.6189	2.3611***	0.5082
GDP(-1)	0.6986***	0.1053	0.6299***	0.0402
C	8.2701***	2.8957	10.1851***	1.1114
R-Squared	0.9983		0.9981	
F-Statistic	2990.119***		2826.435***	
Durbin-Wu-Hausman Endogeneity Test (FDI, TI)	-		2.8958	
Cragg-Donald F-Stat.	-		12.9104	
Durbin-Watson Stat.	1.6923		1.5582	
BP Serial Correlation LM Stat.	5.2604*		4.7045*	
BPG Heteroskedasticity Stat.	15.0783**		11.5586**	
Jarque-Bera Normality Test	0.2551		0.2710	

Source: Author's calculations.

Table A6: Toda-Yamamoto Causality Test

Direction	Chi-sq Statistic	Direction	Chi-sq Statistic
GDP ← TI	4.7031*	COMP ← GDP	0.1058
GDP ← FDI	3.3900	COMP ← TI	5.3756*
GDP ← HDI	4.9387*	COMP ← FDI	0.0324
GDP ← COMP	4.1091	COMP ← HDI	2.1112
FDI ← GDP	13.0955***	TI ← GDP	5.4822*
FDI ← TI	2.9161	TI ← FDI	0.3443
FDI ← HDI	4.8494*	TI ← HDI	2.9541
FDI ← COMP	7.0729**	TI ← COMP	0.6918
HDI ← GDP	1.0518	HDI ← FDI	0.9451
HDI ← TI	0.0497	HDI ← COMP	0.7576

Source: Authors' calculation.

Exploring the Avenues for the Adoption of Agricultural Unmanned Aerial Vehicles by Small to Large Landholding Farmers

Shoaib Rashid Saleem[1] , Muhammad Faisal Ali[2] , Muhammad Naveed Tahir[3] , and Abdul Saboor[4]

ABSTRACT

Pakistan's agriculture plays a vital role in its economy as it contributes about 25% to the national GDP. Unmanned aerial vehicles (UAVs) are proving to be fast and effective methods of crop monitoring and agrochemical spraying. However, adoption rates of UAVs in Pakistan are very low, and a comprehensive study is required to determine the limiting factors and identify constraints in the adoption of UAV technologies in Pakistan. A survey-based study was carried out in the cotton belt of the Punjab province to identify the willingness of farmers to adopt UAVs for different cropping systems with a special focus on cotton and maize. Along with using the available secondary datasets, farmers and other stakeholders were also surveyed for this study. Secondary datasets and key informant interviews (KIIs) were conducted to identify the key constraints in the adoption of UAVs. The study's results show that 59.91% of farming households believe drone use can reduce agriculture's environmental footprint, with 41.37% seeing it as beneficial. The preferred payment model is the pay-per-use model, with wheat and cotton farmers being the highest-rated users. The study supports various models, flexible structures, and implementable options considering crop type variants and agricultural family structures. These constraints helped to crystallise the development of the farmer survey for data collection purposes. Young and educated farmers showed significant interest in the use of UAV technology in agriculture. However, a large number of farmers are concerned about the cost

[1] Assistant Professor, PMAS-Arid Agriculture University, Rawalpindi.

[2] Research Fellow, Pakistan Institute of Development Economics (PIDE), Islamabad.

[3] Director, Institute of Geoinformation and Earth Observation, PMAS-Arid Agriculture University, Rawalpindi.

[4] Dean, Faculty of Social Sciences, PMAS-Arid Agriculture University, Rawalpindi.

of UAVs. Also, the study identified constraints in the development of national policy for UAV adaptation in Pakistan. The findings of this research will help in devising a comprehensive strategy to adopt UAVs on a large scale and develop a national policy to adopt UAV technologies in Pakistan.

1. INTRODUCTION

Background and Context of the Study

Pakistan's agriculture contributes 19% of GDP, employs 45% of the population, and provides livelihood to 60% of the population. However, challenges like slow technological innovation and inadequate extension services hinder food security (Kamal et al., 2022). The Government of Pakistan has recently launched a significant initiative, establishing the Special Investment Facilitation Council (SIFC), with a particular focus on revitalising key industries, including agriculture (Bukhari et al., 2024). However, Pakistan's agriculture sector is facing several challenges, which include poor seed quality and management, limited adoption of technology, a shortage of skilled labour, and the prevalence of small landholding. Therefore, supporting the agricultural sector is essential to bolster Pakistan's fragile economy (Abbas & Sultan, 2023). To address these challenges effectively, the agricultural sector requires the implementation of efficient, sustainable, innovative, modern, and environmentally friendly approaches. These measures are crucial for bridging the yield gaps per acre between Pakistan and developed countries.

Precision agriculture, as defined by the International Society for Precision Agriculture, is a management concept rooted in intensive data collection and processing to inform targeted actions aimed at enhancing the efficiency, productivity, and sustainability of agricultural practices (Vinod et al., 2025). The authors, such as Lamb & Brown (2001) and Fulton & Port (2018), have advocated the use of various technologies, ranging from data collection methods, such as remote sensing, field proximal sensing, and geographic information systems, to advanced data processing techniques like artificial intelligence (AI), deep learning (DL), machine vision, and image processing. Another research study, Taseer & Han (2024), has investigated the use of unmanned aerial spraying systems (UASS) in precision agriculture to combat pesticide overuse, highlighting the benefits of alternative pesticides and AI-driven flow rate optimisation. Additionally, precision agriculture involves technological innovations such as smart sprayers, smart spreaders, digital sensors, and auto guidance systems.

Developed countries are utilising technologies like photogrammetry and remote sensing for precision agriculture, using unmanned aerial vehicles (UAVs) to improve crop productivity and reduce workload (Velusamy et al., 2021). The yield monitoring approaches for horticultural crops highlight the need for commercial solutions and combining technologies for better accuracy and robustness. It discusses the precision required for different tasks (Longchamps, et al., 2022).

Many researchers (Islam et al., 2024; Mavridou et al., 2019; Mohyuddin et al., 2024; Omia et al., 2023; Paul et al., 2022; Tian et al., 2020) have used different machine vision and other sensing technologies with crop growth parameters in various cropping systems. Farmers monitor crops daily to detect potential threats like diseases, pests, and slow growth. Traditional methods include visual inspection and manual sampling. For over 50 years, colour and infrared photography have been used, and camera-mounted drones are used for field mapping and crop monitoring (Hafeez et al., 2023). However, spraying with UAVs has proven to be faster, efficient, effective, less laborious, and cost-effective compared to traditional technologies being used for agrochemical spraying (Moskvitch, 2015). Proper planning and management of targeting hotspots of weeds and pests with UAVs can minimise and save large amounts of unnecessary chemical applications. Future precision agriculture will incorporate sensors, robotics, IoT, machine learning, cloud computing, big data storage, security, and analytics.

Knapsack and boom sprayer requires operators to be directly in contact with the pesticide and could ultimately result in excessive exposure. A study in Egypt (Elhalwagy et al., 2010) found that knapsack motor sprayers caused 0.76% contamination on the head, 4.8% on the body, and 5.8% on the legs, while conventional sprayers caused 3.6%. This could lead to health issues. Extended exposure to these agrochemicals can lead to severe health issues and cause many diseases in humans, including respiratory disorders and cancer. However, UAV operators can easily position themselves outside the field and can avoid direct contact with pesticides. UAVs are also ultra-low volume (ULV) systems when compared to conventional spraying techniques. Therefore, they reduce the impact of chemical residues on nature and people compared to traditional spraying methods. Overall, the adoption of UAVs could be farmer and end-user-friendly, which could also result in improved soil fertility and minimal harmful impacts on human health.

The regulatory framework governing UAV operations is another challenge in Pakistan, and the limited availability of technical expertise and training programmes remains a significant bottleneck. The maintenance and operation of UAVs require specialised skills in drone piloting, sensor calibration, data collection, and processing using advanced software (Ahmad et al., 2025). However, most farmers and agricultural scientists lack the background knowledge to benefit from UAV technology efficiently. Establishing capacity-building initiatives, promoting Public-Private Partnerships (PPPs), and integrating UAV training into agricultural education are essential steps to increase the potential of UAV adoption.

Pakistan's small landholding is one of the major challenges for farmers to adopt UAVs and other precision agriculture technologies due to the economic challenges faced by small farmers. High initial investments, unskilled operators, lack of technical training facilities, and unavailability of technical training are potentially the main reasons for lower adoption rates of UAVs. The need for farmer-friendly regulations, a structured approval mechanism from relevant governmental bodies, and a detailed policy framework is imperative for the wide-scale adoption of UAV-based precision agriculture in Pakistan. The introduction of subsidised programmes, leasing models, and cooperative ownership of UAVs can also provide this technology to small and medium-scale farmers. Additionally, integrating UAVs into existing agricultural extension programmes and forming UAV service cooperatives can provide farmers with on-demand access to drone-based monitoring and spraying services without requiring direct ownership. The UAV-based precision agriculture techniques have demonstrated significant improvements in yield optimisation, resource efficiency, and environmental conservation in China, the USA, and Japan (Tsouros et al., 2019).

The agricultural sector is undergoing transformation due to food security and environmental sustainability, with emerging technologies like drones, sensors, and genetic editing enhancing supply chain management. However, limited awareness in Asia leads to resource wastage (Gamage et al., 2024). Remote sensing allows early detection of crop stress, pest infestations, and soil moisture variability, reducing yield losses due to climate-induced factors. Despite these challenges, the long-term benefits of UAV adoption in precision agriculture outweigh the initial hurdles. With appropriate policy interventions, increased awareness, and investment in research and development, UAVs can play a transformative role in optimising resource use, improving farm productivity, and ensuring environmental sustainability. As Pakistan strives to modernise its agricultural sector under initiatives like the SIFC, prioritising UAV technology can serve as a key enabler in achieving precision agriculture goals. By addressing existing barriers and fostering an ecosystem conducive to UAV adoption, Pakistan can enhance food security, strengthen its agricultural economy, and move towards a more sustainable and technology-driven farming landscape.

A comprehensive study is required to not only identify major constraints from a regulatory point of view, but also to integrate the farmers' perspective into the potential policy document for a nationwide plan of propagating these technologies. By adopting UAV-based precision agriculture, Pakistan may improve farm efficiency, manage resources sustainably, enhance food security, and contribute to national economic stability, potentially making agriculture a more resilient and high-performing industry in the future.

An Economic Overview of the UAVs

Average crop spraying UAV costs about PKR 2-5 million, depending on the country of manufacturing and spray tank volume. The average area required to spray for covering the initial capital investment without considering the labour charges and movement costs varies from 4,000 to 10,000 acres at a spraying cost of PKR 500 per acre (without the cost of chemicals). However, adding the skilled labour cost (PKR 200/acre) and movement charges (PKR 100/acre), the number of acres required to spray increases up to 10,000 to 25,000 acres. An average drone can cover between 10 and 50 acres in one day, depending on the climatic conditions and transportation time required between different agricultural fields. Therefore, the time required in terms of numbers of operational days to cover the initial capital investment to purchase a drone is between 1,000 days (10 acres/day) to 200 days (50 acres/day) for a drone costing PKR 2 million, while the number of operational days to cover the initial capital investment to purchase a drone is between 2,500 days (10 acres/day) to 500 days (50 acres/day) for a drone costing PKR 5 million.

Table 1: UAV Capital Costs and Cost Recovery

Drone Cost (PK Million)	Acres of Spraying Required at PKR 500/Acre	Acres of Spraying Required After Deducting Labour & Fuel Costs at PKR 200 /Acre	Days Required to Cover Capital Costs at 10 Acres/Day	Days Required to Cover Capital Cost at 25 Acres/Day	Days Required to Cover Capital Cost at 50 Acres/day
2	4,000	10,000	1,000	400	200
3	6,000	15,000	1,500	600	300
4	8,000	20,000	2,000	800	400
5	10,000	25,000	2,500	1,000	500

Source: Authors' calculations.

Purpose and Scope of the Study

This study aims to examine the factors influencing farmers' readiness to embrace agricultural UAVs, focusing particularly on three crops, namely, cotton, sugarcane, and maize. The choice of these crops is intentional, as they require intensive spraying. Additionally, the study seeks to offer valuable insights to policymakers for crafting a comprehensive strategy to establish and promote a national UAV policy for agriculture. To achieve this, a qualitative approach is employed to pinpoint the key regulatory barriers impeding the advancement of the UAV market in Punjab. Thus, the study has three primary objectives:

1. Identify various constraints, including regulatory constraints linked with the adoption of UAV technologies and their import.

2. Assess the willingness to pay of farmers to adopt UAV technologies for both monitoring and spraying purposes.

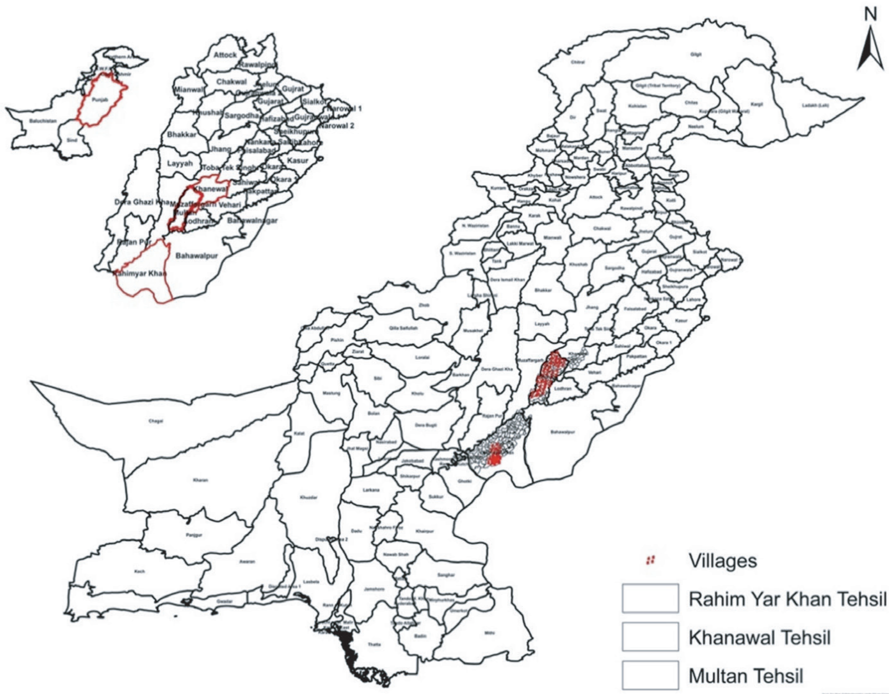
3. Present recommendations based on the study's findings.

2. METHODOLOGY

Sampling Locations

The study was designed to collect survey-based information from the major agricultural cities of Pakistan, especially focusing on the cotton belt of Pakistan (Multan, Rahim Yar Khan, and Khanewal) (Figure 1). This selection was primarily motivated by the significant number of agrochemical applications required in these districts, ranging from approximately 8 to 10 during the cotton crop's growing season, to mitigate pest and weed damage.

Figure 1: Districts in Pakistan for the Study on the UAV adoption



Source: Authors' compilations.

The study is divided into two major segments: interviews with stakeholders and farmers' surveys.

Interviews with Stakeholders

Interviews were conducted with key stakeholders to gather comprehensive insights into the integration of UAVs in the agricultural sector. The stakeholders interviewed were private service providers, agrochemical companies, government institutions, national agricultural research centres, and agricultural universities in Punjab. The interviews explored various aspects such as the constraints faced in purchasing and importing UAVs, service delivery, pricing mechanisms, operational challenges, skill requirements, market limitations, and necessary improvements. Additionally, the interviews focused on the governmental support needed, current policies and regulations, and the potential role of UAVs in enhancing agricultural productivity.

The questions asked of the relevant stakeholders are provided in Annexure A.

Farmer Surveys

The selected districts of Multan, RYK, and Khanewal were visited, and the survey was conducted among cotton, sugarcane, and maize farmers. The sampling was semi-biased as both progressive and unprogressive farmers, small and large landholding farmers, were targeted in these three districts. Additionally, farmers from each administrative unit were selected based on their proportional representation. A total of 228 farmers were interviewed during the study. The focus of the questions was the availability of drones in the locality, willingness to adopt, willingness to pay, constraints and challenges faced by farmers, and how demographics such as age groups and literacy rates are affecting the adoption of UAVs.

Research plan

The research plan of the study is summarised in Table 2.

Table 2: Research Plan

Research Methodology	Questionnaire, case study
Research Strategy	Exploratory research
Instruments	Structured and semi-structured interviews, questionnaires
Time Horizon	6 months
Locations	Cotton districts (Multan, Rahim Yar Khan, Khanewal)
Industry	Agriculture
Respondents	Farmers (traditional & progressive) & other stakeholders
Techniques	Surveys
Sample Size	384 (statistically justified sampling size)

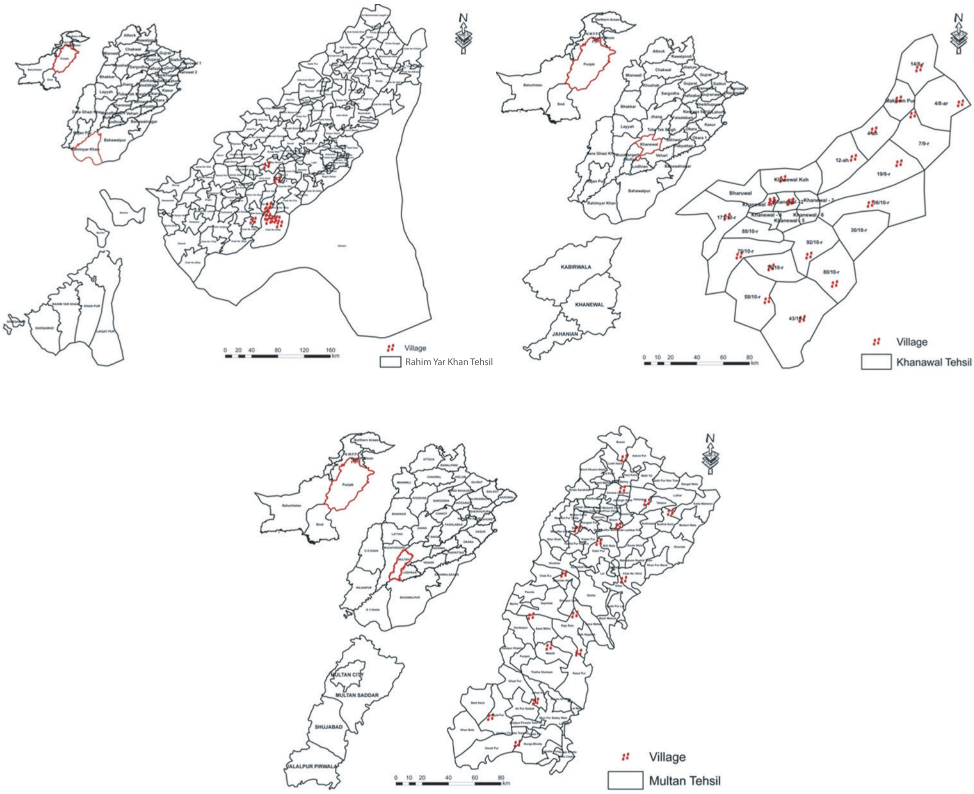
Source: Authors' illustration.

Rahim Yar Khan: A total of 07 villages were visited, and a total of 100 farmers were interviewed during (Figure 2a).

Khanewal: A total of 18 villages were visited, and a total of 55 farmers were interviewed (Figure 2b).

Multan: A total of 16 villages were visited, and a total of 73 farmers were interviewed (Figure 2c).

Figure 2: Sampling Locations in (a) Rahim Yar Khan (b) Khanewal (c) Multan



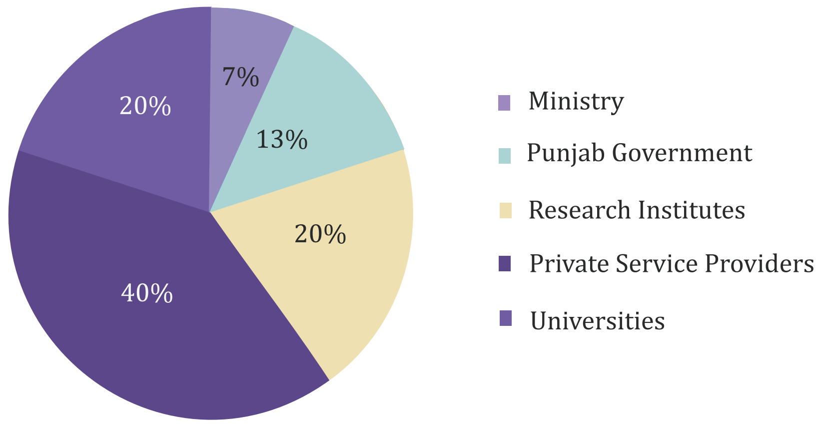
Source: Authors' illustration.

3. RESULTS AND DISCUSSION

Interviews with Stakeholders

A total of 15 stakeholders were interviewed during the study (Figure 3). This stakeholder feedback was crucial in identifying regulatory and policy hurdles, informing a robust policy framework for UAV integration, and evaluating the commercial viability and market development potential of UAVs in agriculture. This information was assessed through content analysis. Furthermore, these interviews also provided a solid foundation by identifying the representative attributes and their levels for developing a product or service for farmers that is generally accepted and economically feasible, helping to determine their willingness to pay.

Figure 3: Stakeholders Interviewed During Key Informant Interviews (%)



Source: Authors' calculations.

Key Constraints and Challenges Identified

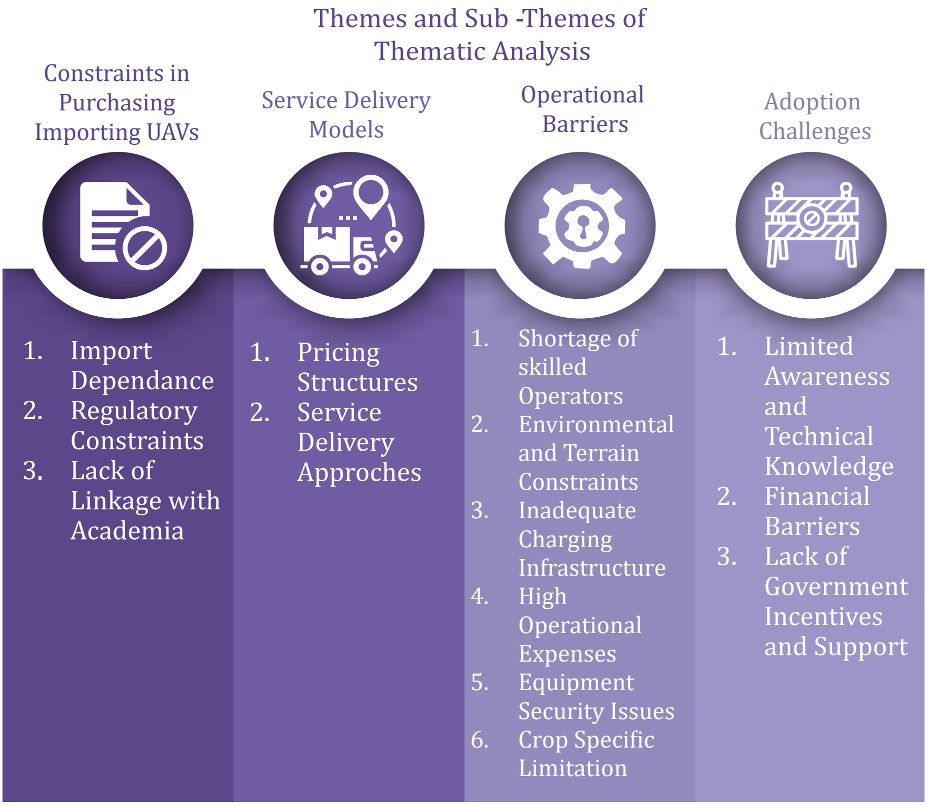
Thematic Analysis is a common qualitative research method that involves identifying themes and sub-themes (Bryman, 2016). This study followed the framework of thematic analysis proposed by Braun & Clarke (2012). There are five steps in this framework. The first step involves collecting and familiarising with the data. After this, the data is reviewed multiple times to identify themes and sub-themes. During this step, six themes and 14 sub-themes emerged. The third step is the indexing of the themes and sub-themes; in which they are coded with numerical values for interpretation.

Followed by coding of the themes and sub-themes, all of them are rearranged and summed. In the last step, based on the codes and the summarisation, the data is interpreted comprehensively for meaningful and insightful interpretations.

Constraints in Purchasing/Importing UAVs

Dependence on Imports: In Pakistan, there is a limited number of UAV service providers, and all of the UAVs are imported. Currently, there are no UAV manufacturing facilities in Pakistan. The heavy import dependence often leads to high costs due to the high exchange rate fluctuations and economic stockpiling in the international supply chain. Respondents advocated an incentive-based R&D mechanism for the local production and assembly of UAVS.

Figure 4: Thematic Analysis



Source: Authors' illustration.

Regulatory Barriers: The lack of clear and well-defined regulatory frameworks for importing UAVs further exacerbates the import and purchase of UAVs. Numerous governmental departments are directly and indirectly involved in import licensing and clearance, making it more complicated and time-consuming. One of the respondents mentioned they face more than a year of the clearance process after the import of UAVs. The lack of a well-defined regulatory framework has created uncertainty in both legal and operational activities as a result of new entrants hesitating to participate in the UAV service sector.

Weak Academia-Industry Linkages: In Pakistan, there is a gap between academia and industry. Due to this, Pakistan lags in technological advancement. With the help of evidence-based research, awareness and knowledge can be disseminated effectively. According to the respondents, they are willing to coordinate with the academic and research think tanks for the local manufacturing of UAVs.

Service Delivery Models

Pricing Structures: We conducted interviews with different organisations, each of which offers a different pricing model. Respondents mentioned various factors that influence their pricing model. According to one of them, their organisation offers spraying services at a subsidised price of around PKR 1,000 per acre. Their main objective is to uplift and provide services to small landholding farmers with areas under five acres. However, others are charging different prices according to the area, fragmentation of land, and the number of operational trips. In Pakistan, the average commercial rate for spraying services falls between PKR 750 and PKR 2,400 per acre.

Service Delivery Approaches: Like various pricing models, the service delivery model does not have a single form. Different organisations provide services in different ways. Some organisations prefer direct engagement with the farmers, while others have adopted the B2B framework. They provide drone technology to different firms, which deliver services. Moreover, there is a limited number of digital platforms for drone spraying services. For such a mechanism, farmers need to request the service. Small landowners usually form a group and buy such services to minimise the operational cost. Although various price and service delivery models are operating in Pakistan, respondents mentioned various challenges in scaling up their service, such as low acreage and seasonal constraints.

Operational Barriers

Shortage of Skilled Operators: In the case of operational activities, respondents mentioned that a lack of a skilled workforce is a major concern. Currently, Pakistan is facing a shortage of certified UAV pilots. In addition to technical knowledge, drone pilots need to possess a strong understanding of agronomy. To address this issue, all service providers prefer to hire agricultural graduates for operational activities. Some of them pointed out that the recruitment of agricultural graduates is not useful because they lack technical engineering knowledge about UAVs and do not have expertise in handling such technology. To overcome such issues, service providers arrange internal training sessions for recruits to equip them with the necessary knowledge and skills. All respondents agreed that some government organisations, like NAVTTC and TEVTA, are providing some courses on UAVs, but the existing programmes are not fulfilling the demand for skilled labour. Therefore, a national-level diploma programme with the collaboration of technical institutes and engineering universities needs to be offered in Pakistan.

Environmental and Terrain Constraints: The physical environment presents additional challenges in the accurate and efficient operation of UAVs. The irregular layout of land boundaries, fragmented spaces, trees, and power infrastructure create difficulties during spraying. Furthermore, the weather has exacerbated the situation. According to the respondent, drone spraying is only feasible in the morning because temperatures later exceed 45-50°C, limiting the operators' ability to use UAVs.

Inadequate Charging Infrastructure: The discharge time of the battery is relatively high for drones. Thus, during the operation, batteries need to be charged frequently. Unfortunately, in the rural areas, charging facilities do not exist. Therefore, a lack of charging infrastructure poses an additional operational constraint for service providers.

High Operational Cost: The high operational cost is another issue in providing UAV services. Pakistan imports UAVs and their spare parts. In the case of mechanical failure during service, a lack of a well-established framework for importing agricultural drones adds to operational costs. The transportation cost, fuel cost, and free trial demonstration also significantly increase the operational cost. The UAV technology is considered more economically feasible for farmers holding 200-300 acres of land, which makes it slightly infeasible for small landholder farmers due to the high operational cost.

Equipment Security Issues: Respondents mentioned a lack of insurance schemes for drones, as well as additional barriers to the operation of UAVs. First, the cost of UAVs is very high, and secondly, uneven and fragmented land further makes UAVs vulnerable to damage. Under such conditions, the lack of equipment insurance schemes becomes a hindrance to operating, especially in the case of small landholders.

Crop-Specific Limitations: Although UAV spraying is beneficial for all crops, high operational and maintenance costs make it best suited for crops that are highly dense and tall. The respondents mentioned that, in Pakistan, this technology is highly suitable for rice, sugarcane, and maize. For these crops, using a UAV is less labour-intensive and time-consuming than manual spraying.

Adoption Challenges

Limited Awareness and Technical Knowledge: Farmer perceptions play a vital role in the adoption of new farming techniques. According to the respondents, the young and well-educated farmers show more willingness in the adoption of UAVs than the older farmers. Older farmers have orthodox beliefs about technology and believe in old and traditional methods of spraying techniques. However, a few of them also mentioned that a free-of-cost pilot demonstration has successfully transformed the thinking pattern of the old and traditional farmers. During the demonstration, service providers also informed farmers about the cost-effectiveness, efficiency, and coverage of UAV-based spraying. Apart from this, one of the important initiatives taken by one of the service providers is the incentive model. According to him, their companies provide special discounts to farmers when farmers bring them additional clients. These initiatives have shown positive results and also spillover effects on other neighbouring farmers.

Financial Barriers: For a UAV start-up, a huge investment is required. One of the respondents mentioned that the initial average cost of a UAV start-up is between PKR 4 million and PKR 6.5 million, as the average cost of drones is PKR 2-3 million, the average monthly operating cost is PKR 1-1.5 million, and the average logistic cost is PKR 1-2 million. Since this business has not been established as a proper commercial model in Pakistan yet, commercial banks do not offer any financing schemes.

Lack of Government Incentives and Support: Respondents mentioned that the government's support for the deep penetration of UAVs is negligible. There is no regulatory framework or agricultural drone policy in Pakistan. According to the respondents, the government needs to clearly define no-fly zones, SOPs for operators, and the opening of financial avenues for the adoption of agricultural technology in Pakistan. Although the government has received several UAVs from China and Korea, the government does not even use them for free trials and demonstrations; all such activities are conducted by private service providers. Moreover, the private service providers also need the government's support for the local manufacturing and assembling of UAVs in Pakistan.

Recommendations:

1. The government should act like a facilitator and develop a well-structured regulatory and policy framework. With the help of such frameworks, agricultural institutes, research think tanks, and engineering universities can collaborate effectively and promote the local production of UAVs.

2. In the short term, the government should digitise the import licensing and NOC procedure to import UAVs and their spare parts.

3. Compulsory courses should be included for technical and practical knowledge about agricultural technology in universities, so they have both scientific and technical knowledge.

4. Like the solarisation project of tube wells, a subsidised or low-interest scheme needs to be introduced for UAVs to cover the huge investment and maintenance costs.

5. Increase awareness and knowledge about UAVs by conducting awareness sessions and advertising testimonials videos of farmers who have already adopted UAVs.

Details of these surveys are provided in Appendix.

Famers' Interviews

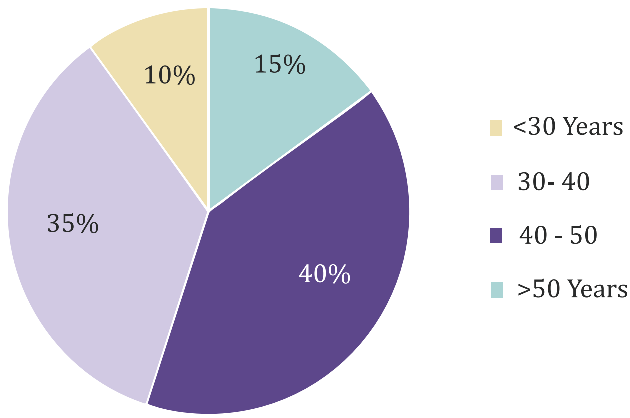
The use of UAVs, or drones, is gaining recognition in agriculture for their potential to improve efficiency in crop monitoring, pesticide spraying, and overall farm management. However, the adoption of UAV technology in the agricultural sectors of Khanewal, Multan, and Rahim Yar Khan districts is still in the early stages. The survey conducted in these areas aimed to assess the awareness, adoption, and challenges surrounding UAV technology among local farmers.

Demographic Breakdown of Drone Adoption

The demographic profile of the respondents provided valuable insights into the factors that influence the adoption of UAV technology in these districts.

Age Distribution: Age plays a significant role in the likelihood of adopting the UAV technology. The age distribution revealed that 40% of the respondents were between 30 and 40 years old, and 35% were in the 40-50 years range (Figure 5). Younger farmers (under 30 years) made up 15% of the respondents, while 10% were above 50 years.

Figure 5: Age Distribution of Interviewees

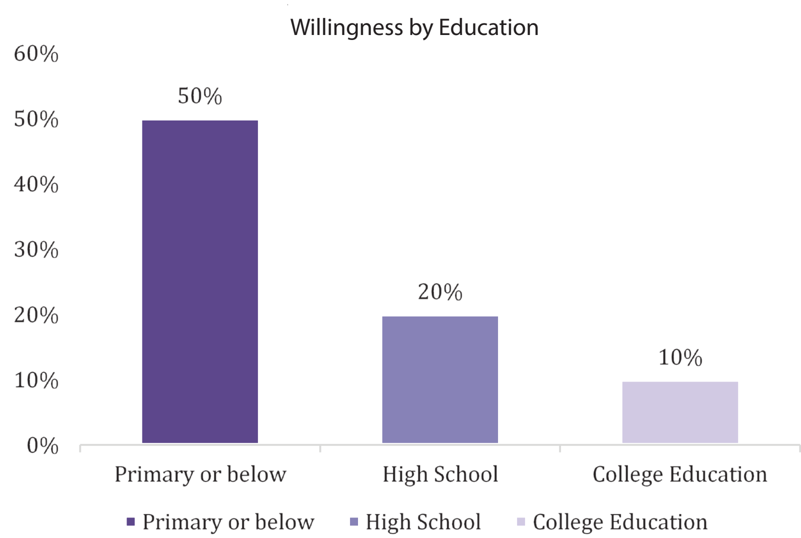


Source: Authors' calculations.

This suggests that most respondents, especially those in the 30–50-year age group, are in their prime working years and may have the financial stability to invest in new technologies. However, younger farmers are more likely to embrace new technology, with 50% of them expressing an interest in using UAVs if the costs were reduced.

Education Level: Education is another significant factor influencing UAV adoption. 50% of the farmers in Khanewal, 60% in Multan, and 40% in Rahim Yar Khan had only completed primary or middle school education (Figure 6). Only 20% of the respondents had completed high school, and 10% had received some form of higher education (college or university). Farmers with higher levels of education are more likely to understand and appreciate the potential of drone technology, with 60% of those with a college education expressing interest in UAV adoption. In contrast, only 30% of those with a primary education showed interest, underscoring the need for targeted education and awareness programmes to bridge the knowledge gap.

Figure 6: Literacy Rate among Interviewees



Source: Authors' calculations.

Current Status of Drone Technologies in Khanewal, Multan, and Rahim Yar Khan Districts

District-wise Analysis

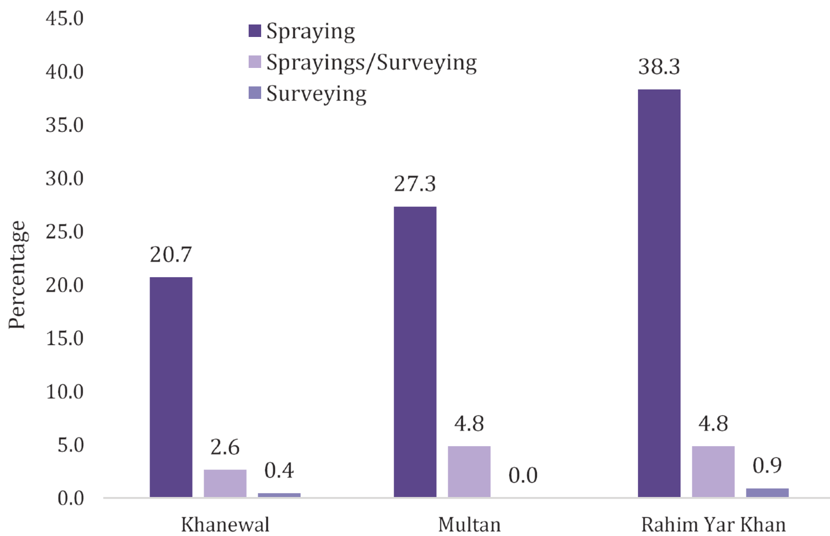
The following themes were covered in interviews.

Farmers' Perception of UAVs: The study examined the utilisation and adoption of drone services in agriculture in three major districts of South Punjab. Khanewal shows moderate usage for spraying but limited use for surveying. Rahim Yar Khan, according to the analysis, has the lowest adoption, indicating barriers such as affordability, lack of awareness, or limited access to UAV services. Statistical data revealed that in Rahim Yar Khan, drones are most commonly used for spraying (38.3%).

The spraying/surveying is relatively consistent across the three districts (2.6%–4.8%). However, using UAVs for only surveying is less common or non-existent, as it is 0.4% in Khanewal, 0.9% in Rahim Yar Khan (0.9%), and 0% in Multan (Figure 7). In Rahim Yar Khan and Multan, labour reduction was reported at 60%, while it was 50% in Khanewal, indicating some benefit from UAV usage, as shown in Figure 8. The cost reduction is the highest in Rahim Yar Khan. Additionally, Rahim Yar Khan leads in spray reduction percentages, with 40% (14.5%) and 50% (13.7%), indicating more efficient spraying with UAVs in the district (Figures a & b).

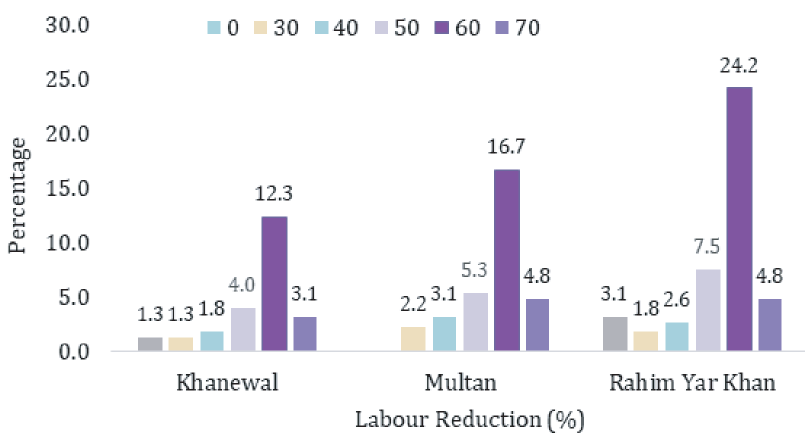
The study indicates that drone adoption in specific service types is low, but general acceptance is growing. Farmers prefer flexible, low-commitment models like pay-per-use and revenue-sharing due to uncertain income cycles. Multan has the highest drone adoption, particularly for spraying, aligning with advanced agricultural practices and tech-based solutions. Khanewal and Multan have negligible responses, with most farmers reporting no labour reduction and no cost benefits due to poor UAV implementation or inefficiencies. However, farmers in Multan and Rahim Yar Khan believed drones can improve application precision by over 50%.

Figure 7: District-wise Drone Usage



Source: Authors' calculations.

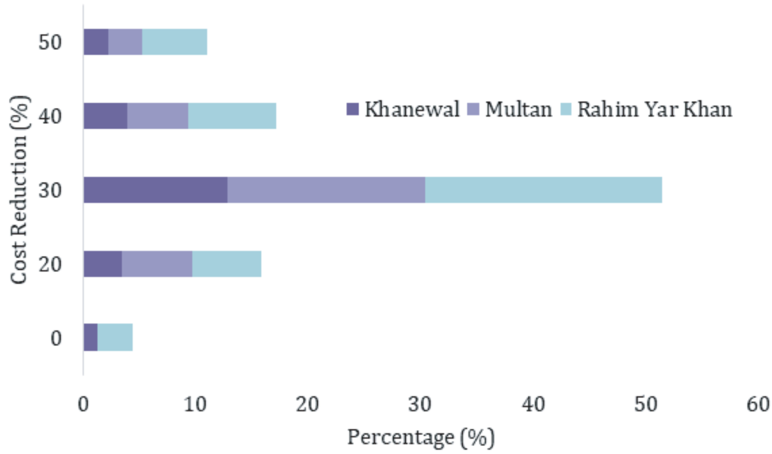
Figure 8: District-wise Labour Reduction Due to UAV Adoption



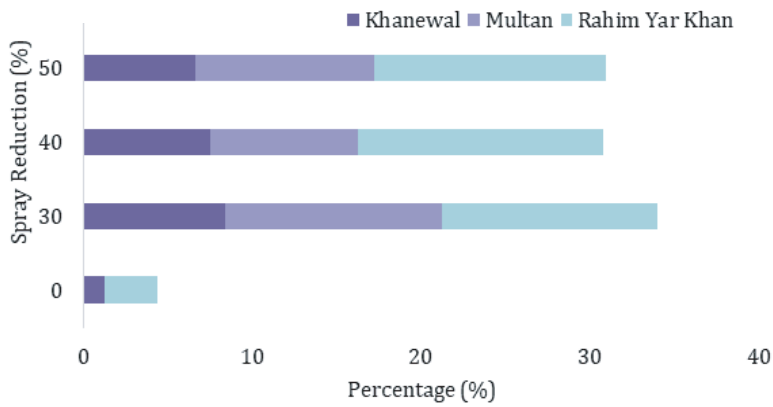
Source: Authors' calculations.

Figure 9:

a) Cost Reduction Using UAVs



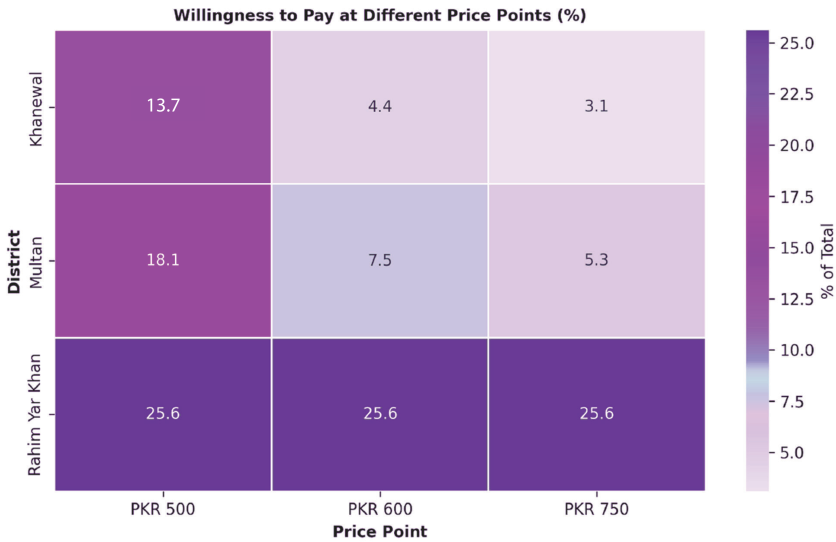
b) District-wise Spray Reduction Using UAVs



Source: Authors' calculations.

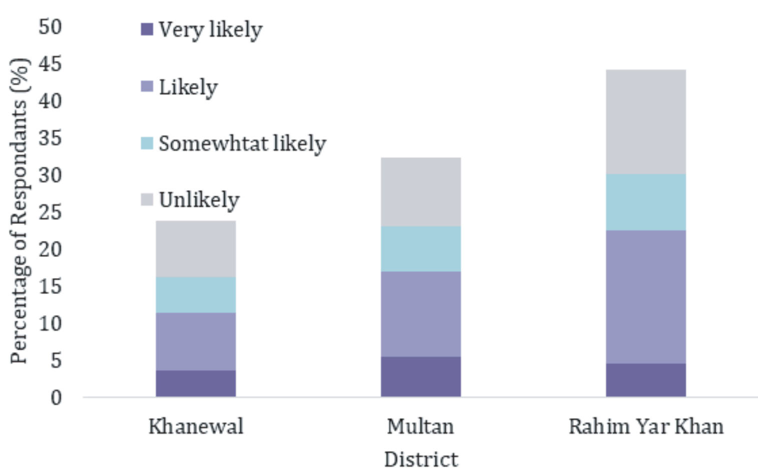
Willingness to Adopt UAVs: The Rahim Yar Khan district was the most willing to pay for UAV service costs at all price points, and Multan followed with moderate willingness, decreasing with price increases. Khanewal had the lowest willingness to pay beyond PKR 500, suggesting greater price sensitivity among respondents, as shown in Figure 10. Cost is the biggest deterrent across all districts, followed by lack of perceived need or benefit. Multan showed a higher interest in UAVs if they are affordable, while Khanewal was moderately inclined. Most farmers found UAVs "somewhat beneficial," especially in Rahim Yar Khan, but a significant share found no benefit, indicating scepticism or early-stage exposure. Figure 11 shows the likelihood of UAV adoption in Khanewal, Multan, and Rahim Yar Khan. Multan has a moderately high likelihood of adopting the UAV technology at 32.2%, while Khanewal, with 23.8%, has the lowest likelihood. However, 14.1% said it is likely, while 18.1% said it is unlikely but are nevertheless engaged. Rahim Yar Khan has the highest adoption potential, with 44.1% of respondents likely to adopt. Despite interest, there is significant scepticism across all districts, suggesting the need for awareness campaigns, demonstrations, or incentives to boost confidence in UAV technology for agriculture.

Figure 10: Willingness to Pay for UAV Services at Different Price Points



Source: Authors' calculations.

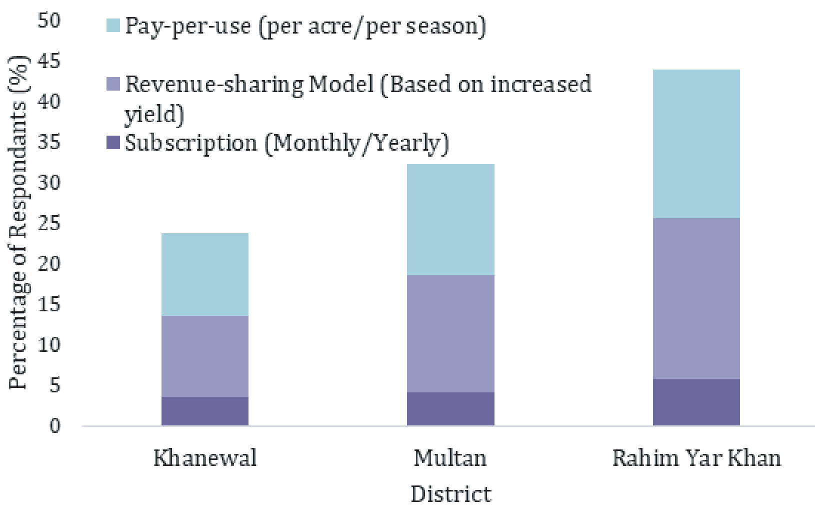
Figure 11: District-wise Likelihood of UAV Adoption at Suitable Rates (%)



Source: Authors' calculations.

Payment Models for UAV Services: The farmers in Multan and Rahim Yar Khan believed that drones can reduce environmental impacts by applying inputs more precisely. The usage-based fee model allows farmers to pay only when they need the UAV service, such as spraying or crop monitoring. This model is popular due to its flexibility, cost-effectiveness, low risk, and better alignment with actual needs. Subscription-based models are least preferred due to inconsistent income, perceived inflexibility, upfront commitment risk, and lack of bundling incentives. Figure 12 shows farmers' preferences for different payment models for the adoption of the UAV technology. The revenue-sharing model is the most preferred, followed by the pay-per-use model, which is practical and familiar to farmers. The revenue-sharing model involves the service provider sharing profits from increased yield, saved inputs, or reduced labour due to UAV use. This model attracts risk-averse or low-income farmers and helps where farmers are not convinced yet of the drones' value. The subscription model is the least preferred because farmers are generally more open to performance-based or usage-based payment models, suggesting flexible and risk-sharing pricing strategies are more likely to be accepted for UAV-based agricultural services. Most farmers have seasonal cash flows, and paying for months when they do not use the service is wasteful. Subscriptions also offer bundled perks, but for small farmers, UAV services do not yet offer clear year-round value to justify a fixed fee.

Figure 12: District-wise Preference for UAV Payment Models



Source: Authors' calculations.

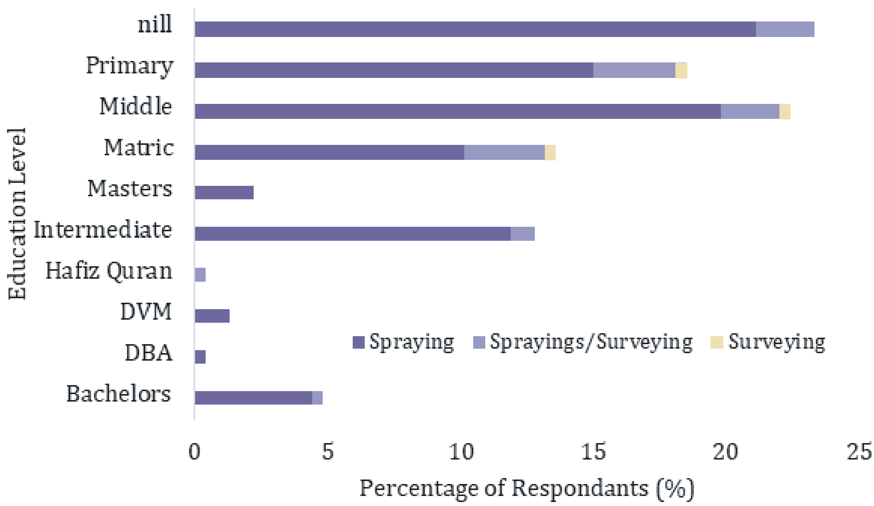
Effects of Literacy on UAV Adoption

Farmer Perception about UAVs: The analysis revealed that drone usage in agriculture is primarily driven by educated farmers, with intermediate and middle-educated individuals having a higher share of drone usage for spraying. The varying education levels affect farmers' engagement with drone technology, as depicted in Figure 13. The data illustrate that literate individuals are primarily non-users of drones, indicating a need for targeted awareness and training to improve adoption in less-educated farming communities, while individuals with middle to intermediate education show the highest usage. Primary- and matric-level groups show average participation in both basic and advanced drone applications, indicating their adaptation.

The heatmap in Figure 14 illustrates how different levels of education and the percentage of spray reduction using UAVs are related. It explains how the understanding and knowledge of UAVs' efficiency in pesticide spraying differ with education levels. The farmers who had primary, middle, or matric levels of education achieved 40-50% spray reduction using UAVs. Similarly, farmers with no formal education also achieved some reduction (from 0% to 50%). The cost reduction figure chart shows that the respondents with no formal education (23.3%), middle (22.5%), and primary (18.5%) education levels reported the highest levels of cost reduction using UAV. Most savings were concentrated in the 30% and 40% reduction brackets, making up over 68% of the total responses. Users with lower education levels, who are often directly involved in farming, perceived more tangible financial benefits from UAV adoption.

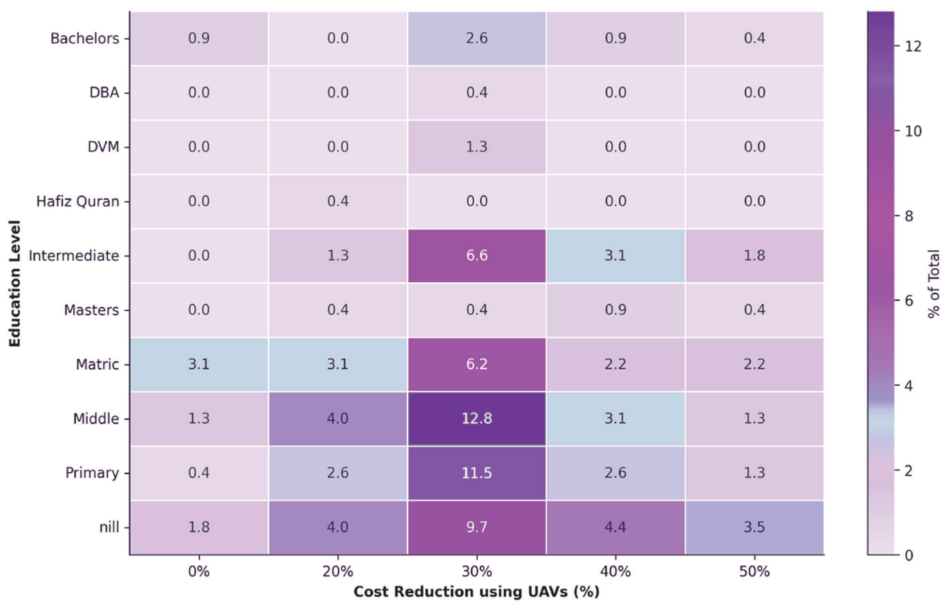
The spray reduction heatmap reveals that respondents with no education (23.3%), middle (22.5%), and primary (18.5%) education also reported the highest spray savings, indicating that UAVs contribute substantially to input efficiency, particularly for farmers involved in manual spraying tasks. The overall data indicate a varied perception regarding the benefits of spray reduction across the education spectrum, with the most pronounced positive perception coming from those with middle and primary education. The study suggests that UAV adoption is increasingly accompanied by literacy, especially at the intermediate education level, due to specialised knowledge and active farming engagement. This could lead to increased adoption of responsible drone usage in agriculture.

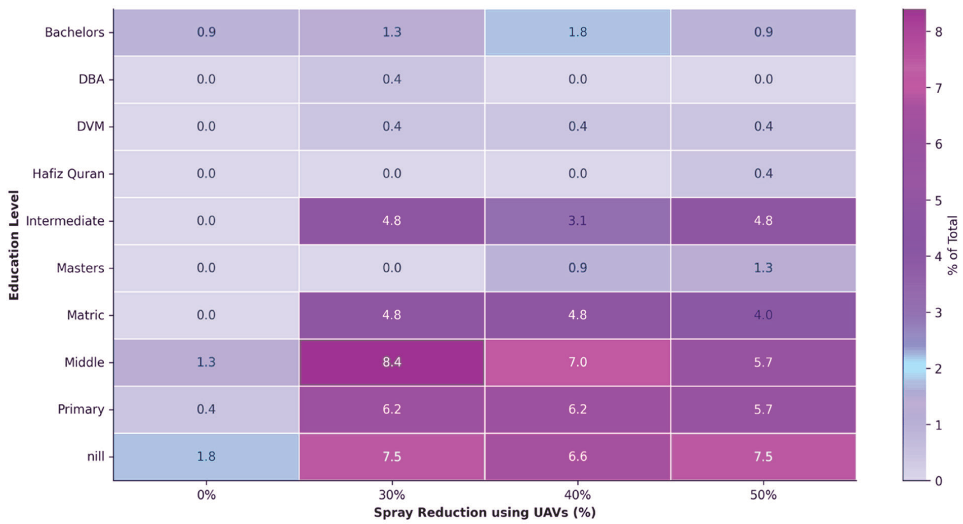
Figure 13: Literacy Levels and Perceptions of Drone Usage in Agriculture



Source: Authors' calculations.

Figure 14: The Education-wise Perception of Cost and Spray Reduction (%) Using UAVs





Source: Authors' calculations.

Willingness to Adopt UAVs: The analysis of the effect of education on farmers' willingness to pay (WTP) for drone usage in agriculture was assessed at three price points: PKR 500, PKR 600, and PKR 750 per application (Figure 15). Most willing respondents were from lower education groups, with 57.3% willing to pay PKR 500. The willingness dropped slightly as the price was increased, with only 37.4% agreeing to PKR 600. The largest agreeing groups were from no (12.8%), middle (7.5%), and primary (5.7%) education levels. At PKR 750, the willingness decreased further, with only 33.9% accepting the price. However, farmers with no (12.8%) and middle (6.2%) education remained the most willing, while higher-educated respondents showed lower acceptance. Farmers with basic to moderate education (middle to metric) were more willing to pay at PKR 500, likely due to greater awareness, financial resources and higher literacy. As the price was increased from PKR 500 to PKR 600, willingness to pay dropped significantly, suggesting that PKR 500 serves as a psychologically acceptable price point for many farmers. The higher price was met with resistance due to low disposable income and a perceived imbalance of value versus expenditure.

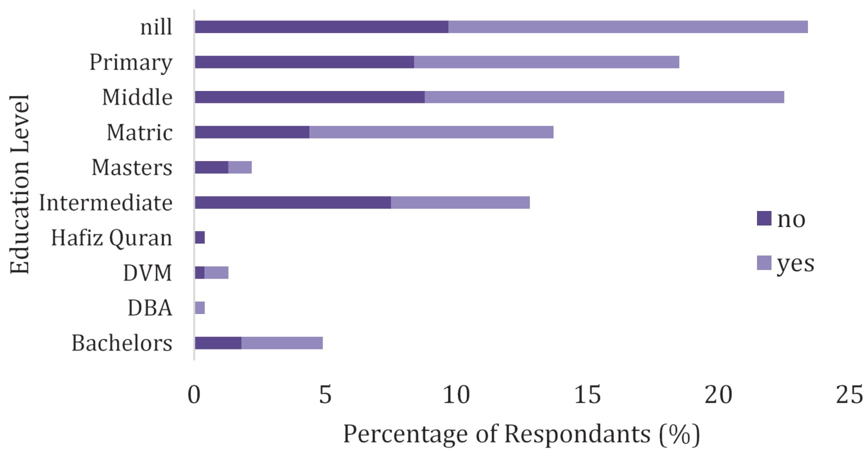
The impact of education on the likelihood of adopting drone (UAV) services at a suitable and affordable rate showed that respondents fall under the "Unlikely" category, stating they were "Likely" to adopt UAV services. Factors like awareness, trust, and perceived utility also play a role. The analysis suggests that although the highest percentage of responses was in the "Unlikely" category, there is still a potential for adoption. Middle education level respondents had the highest rate of openness to UAVs (7.0%), with 8.8% showing strong conversion potential through targeted training. Matric and intermediate-educated groups showed promise for early adoption. Higher education (Bachelor's, Master's, DVM) respondents had more evenly distributed responses, reflecting mixed perceptions of cost-benefit.

Despite many showing hesitance ("unlikely"), a large number of respondents showed some level of likelihood of adopting UAV services if pricing is suitable. Middle and primary-educated farmers are the most promising segment for targeted interventions, as depicted in Figure 16. The education level significantly affects the perception of the usefulness and environmental implications of UAVs in agriculture. Individuals with middle school education and no formal education had the highest proportions of perceptions of UAVs as somewhat beneficial or not beneficial (Figure 17).

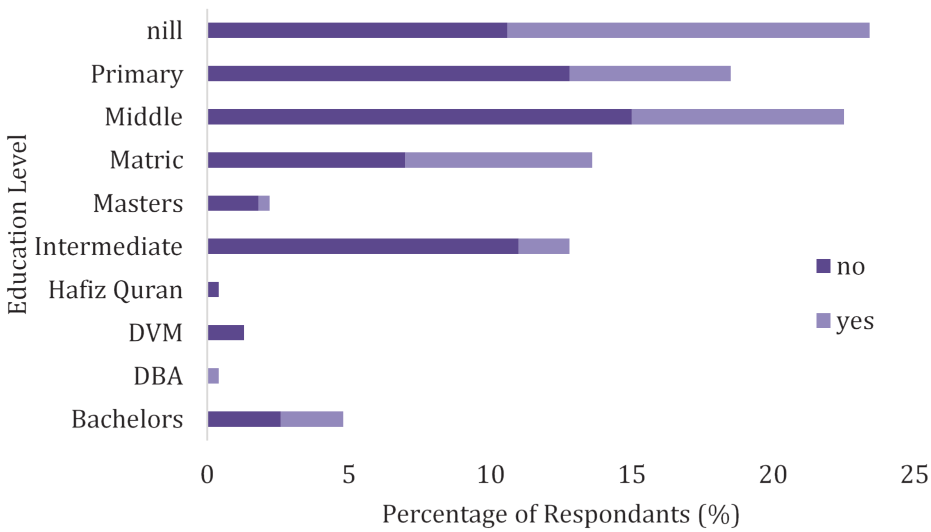
Therefore, from the policy perspective, these insights suggest that marketing strategies for UAV services should be priced below PKR 500 for wider acceptance. Farmers with higher education levels had a more balanced view, while farmers with middle, primary, and matric education levels believed that UAVs contribute positively to reducing environmental degradation. However, those without formal education had a mixed view, with high belief in UAVs' benefits and uncertainty. Education plays a crucial role in shaping perceptions about agricultural technology, particularly UAV adoption and its environmental implications.

Figure 15: Education Levels and Willingness to Pay for UAVs

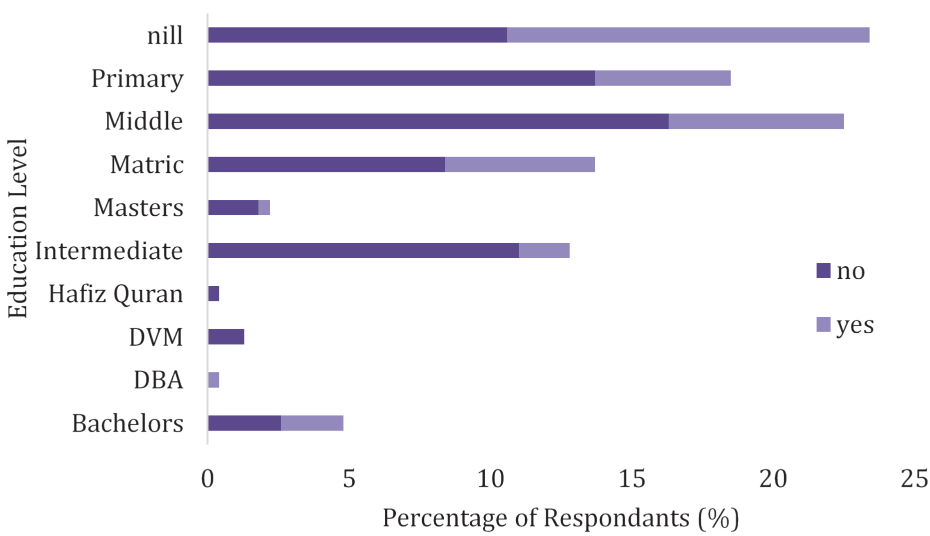
a) At PKR 500



b) At PKR 600

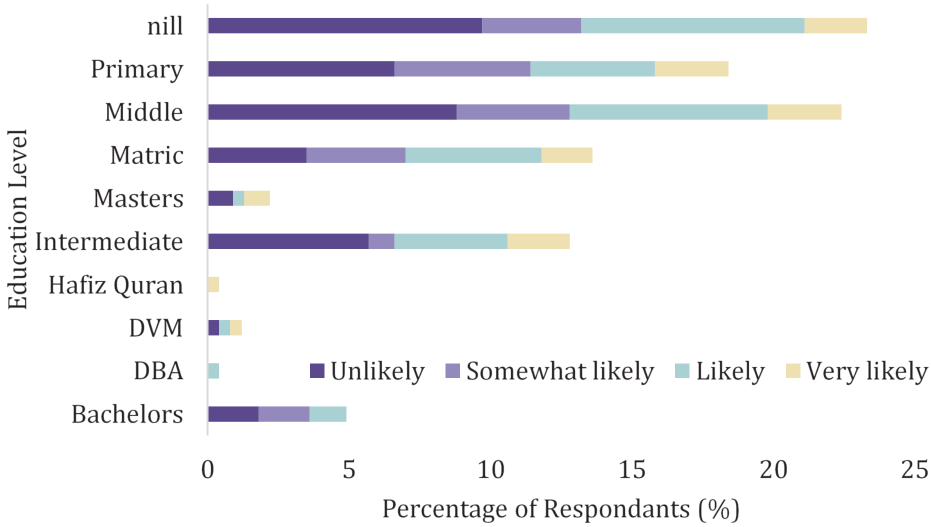


c) At PKR 750



Source: Authors' calculations.

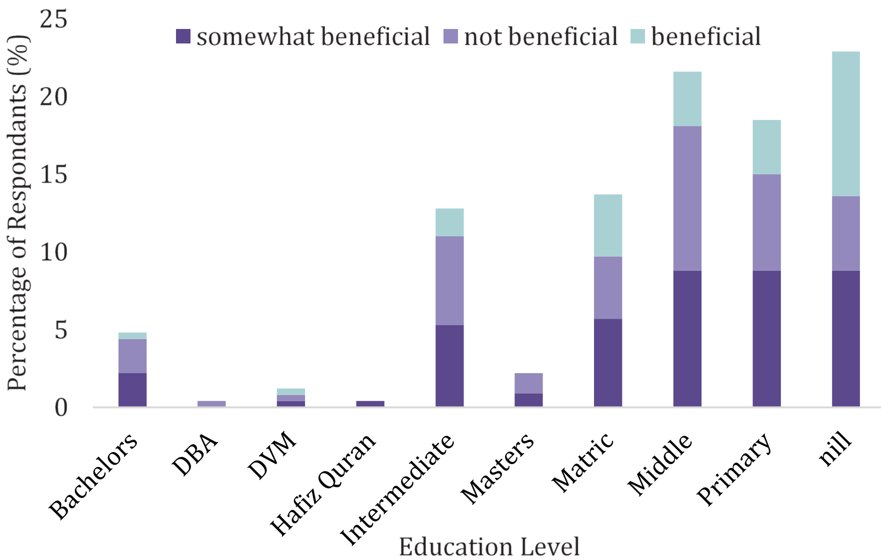
Figure 16: Likelihood of UAV Adoption at Suitable Prices Across Different Education Levels



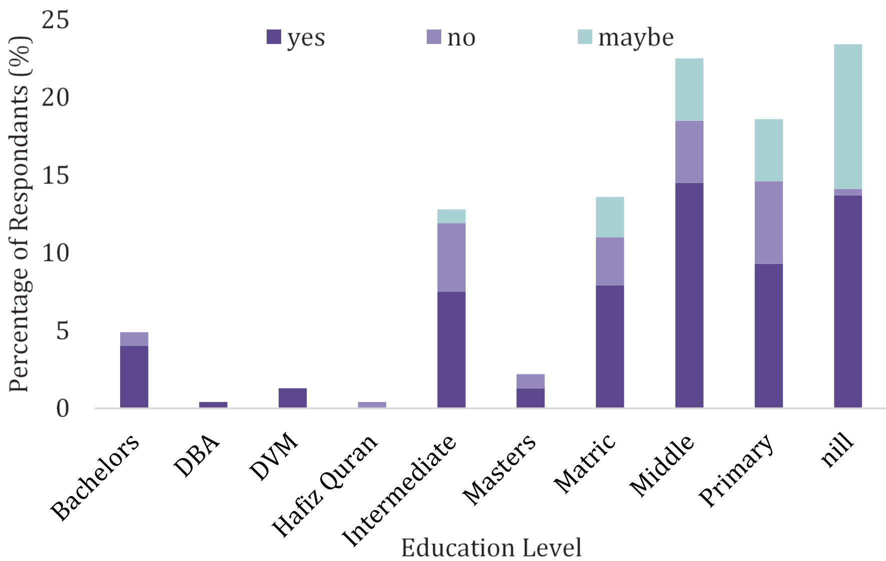
Source: Authors' calculations.

Figure 17: Relationship Between Education Level and

(1) The Perceived Benefits of UAV Technology in Agriculture



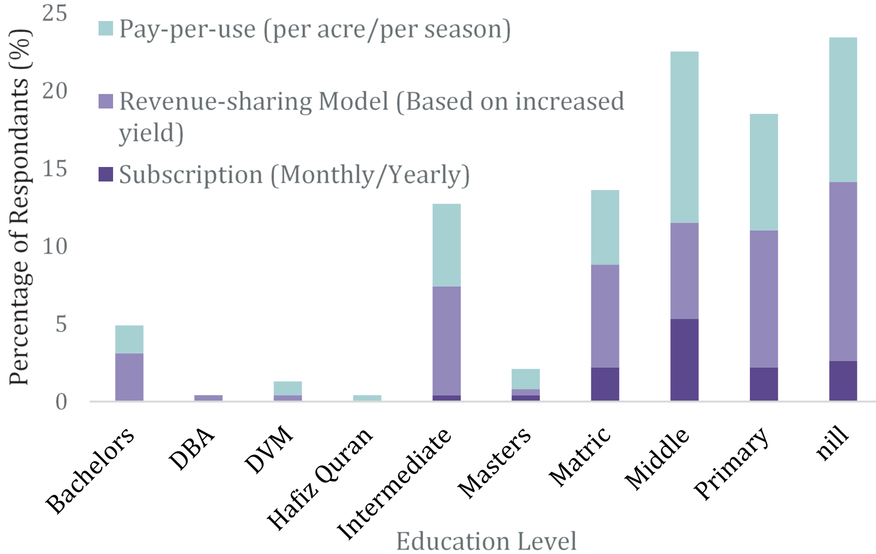
(2) The Belief that UAVs Help Reduce Environmental Impacts



Source: Authors' calculations.

Payment Models for UAV Service: The statistical results show that revenue-sharing is the preferred payment model across all education levels, particularly among those with no formal education and primary education. Subscription-based models received the least interest from the farmers with lower levels of education, but higher interest from the farmers with primary, middle, and matric levels of education. Higher education holders had a slightly more even distribution between pay-per-use and revenue-sharing, reflecting better awareness and risk evaluation of different financial models. Pay-per-use was moderately preferred, especially by farmers with no, primary, and middle education levels, indicating a desire for flexibility and cost control. This suggests a preference for performance-linked affordability among lower-income or less formally educated farmers. This analysis helps identify how education influences financial decision-making in the adoption of precision agriculture services, allowing service providers to customise pricing strategies for broader adoption.

Figure 18: Educational Level vs Preferred Payment Model for UAV Applications



Source: Authors' calculations.

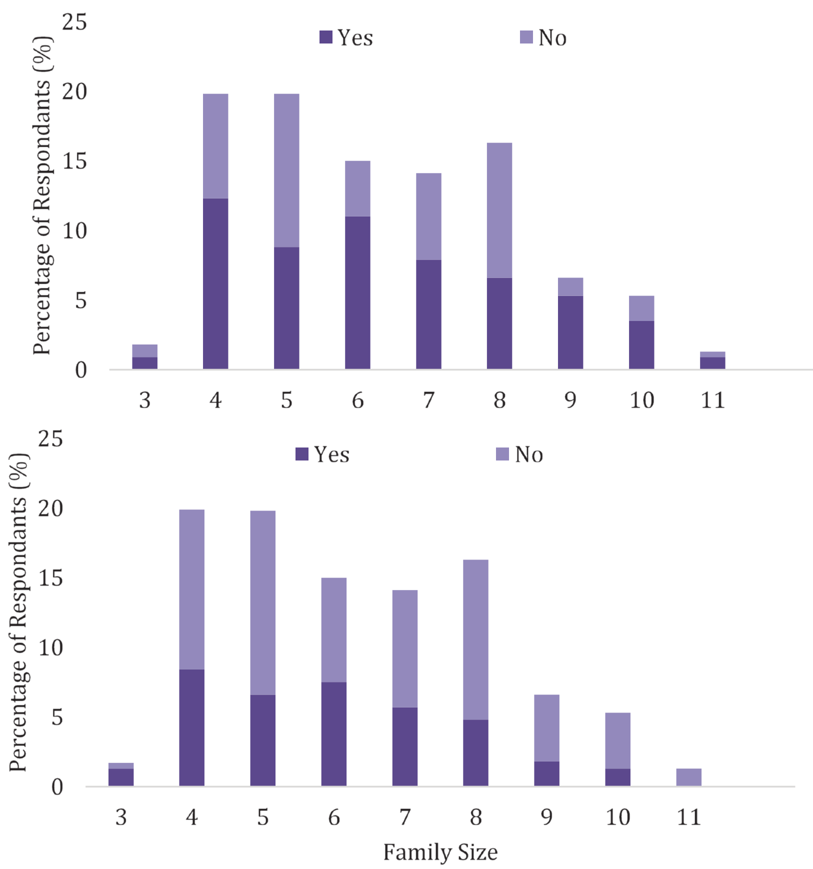
Impact of Family Size on UAV Adoption

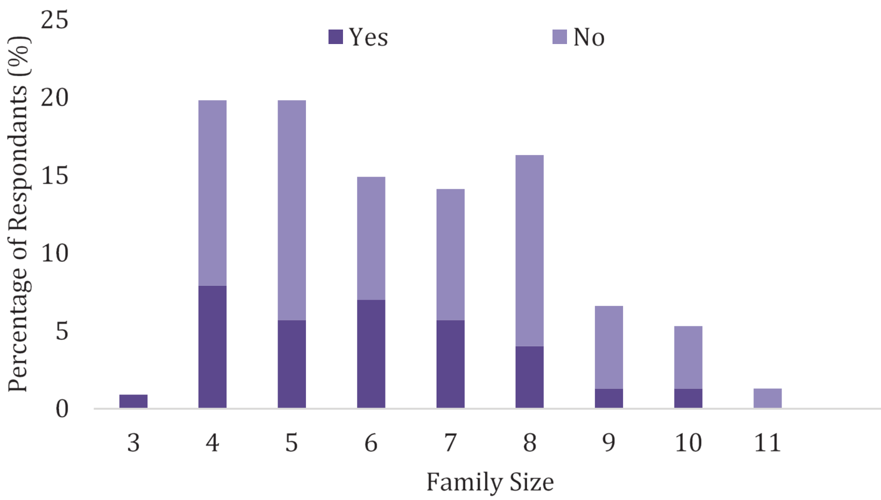
Farmer Perceptions of UAVs: The adoption of UAVs in agriculture is also influenced by the size of the family. Smaller and larger families showed lower adoption, suggesting that medium-sized families have the optimal labour-to-land ratio for mechanisation like drones. Only 4 to 6-member families showed the highest usage, particularly for spraying purposes. The 8-member families engaged in diverse drone applications, including spraying, surveying, and combined usage (Figure 19). The data (Figure 20) reveals that families with 4 to 6 members experienced the highest cost reduction benefits, contributing over 45% of total responses. Families with 4 and 5 members showed significant reductions of 30% and 50%, while larger families (10-11 members) showed limited cost savings.

Drone usage leads to significant cost reductions across various family sizes, with medium-sized families experiencing the highest benefits. The spray reduction pattern mirrors cost trends but is more spread across family sizes. Families with 4 to 6 members reported the highest benefits, especially in the 10%–30% spray reduction range. Families with 7 to 8 members also showed significant spray savings, particularly in the 20%–50% range, indicating broader drone adoption or larger spray areas. Medium-sized families (4–6 members) consistently benefited most from cost and spray reduction, making them the ideal target for UAV promotion programs.

Although higher reductions (30%–50%) are achievable, they are less common, possibly due to knowledge gaps or drone operating inefficiencies. The heatmap in Figure 20 illustrates the willingness to pay for UAV services. The first heatmap shows the percentage of respondents in each family size willing to pay PKR 500, PKR 600, and PKR 750 for UAV services like spraying or surveying. The willingness to pay decreased as the price increased, with families of size 4 to 6 showing the highest desire at all price points. The second heatmap shows the percentage of respondents who believed UAVs may, do not, or do reduce environmental impacts. The majority believed that UAVs help reduce environmental impact, especially in families with 4 to 6 members. The drone usage increases with moderate family sizes, possibly due to labour availability and operational efficiency. The larger families are more likely to report higher cost savings if there is a common cost-saving band and if there are gaps or white/light areas suggesting no responses in some combinations. This can guide future outreach and subsidy programmes targeting medium-sized agricultural households for drone adoption.

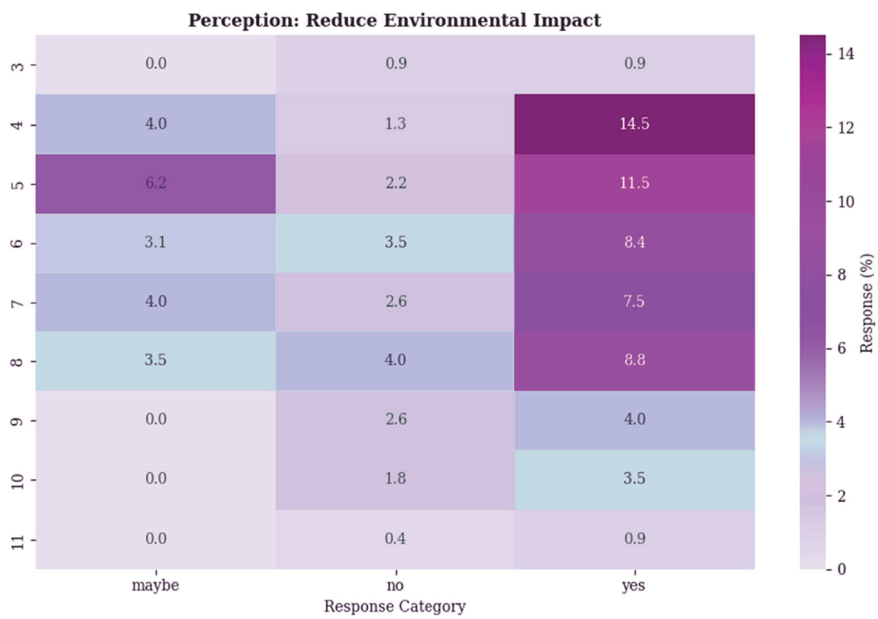
Figure 19: Family Size and Drone Usage





Source: Authors' calculations.

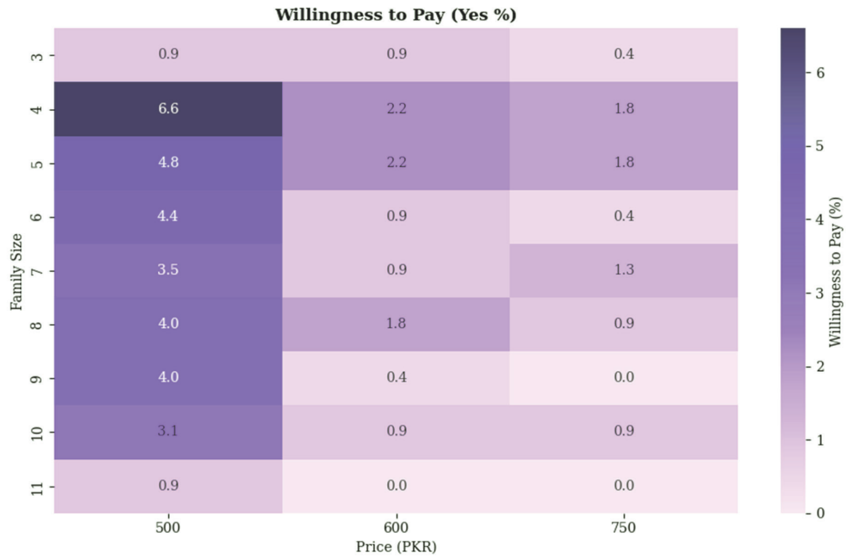
Figure 20: Reduction in Environmental Impacts



Source: Authors' calculations.

Willingness to Adopt UAVs: A heatmap in Figure 21 shows the willingness of respondents from different family sizes to pay PKR 500, PKR 600, and PKR 750. The colour intensity increases with higher willingness, revealing trends such as middle-sized families (4-8 members) showing higher willingness across all price points. As the price increases from 500 to 750, willingness to pay generally declines, especially among larger families. Very small and very large families show less willingness to pay higher amounts.

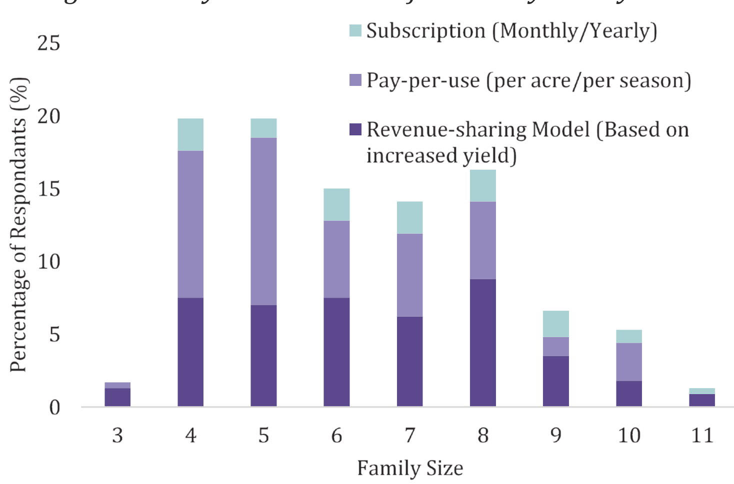
Figure 21: Willingness to Pay and Family Size.



Source: Authors' calculation.

Payment Models for UAV Services: Figure 22 shows the distribution of payment models for different family sizes. Families having smaller or very large sizes showed minimal willingness for any model, suggesting either limited need or affordability constraints. The revenue-sharing model was the most preferred, especially for medium-sized families (6-8), followed by the pay-per-use model among families of size 4 and 5. The subscription model received the least preference across all family sizes, but still had notable acceptance among families of size 6-8. The figure provides a visual representation of the preferred payment models across different family sizes.

Figure 22: Payment Model Preferences by Family Size

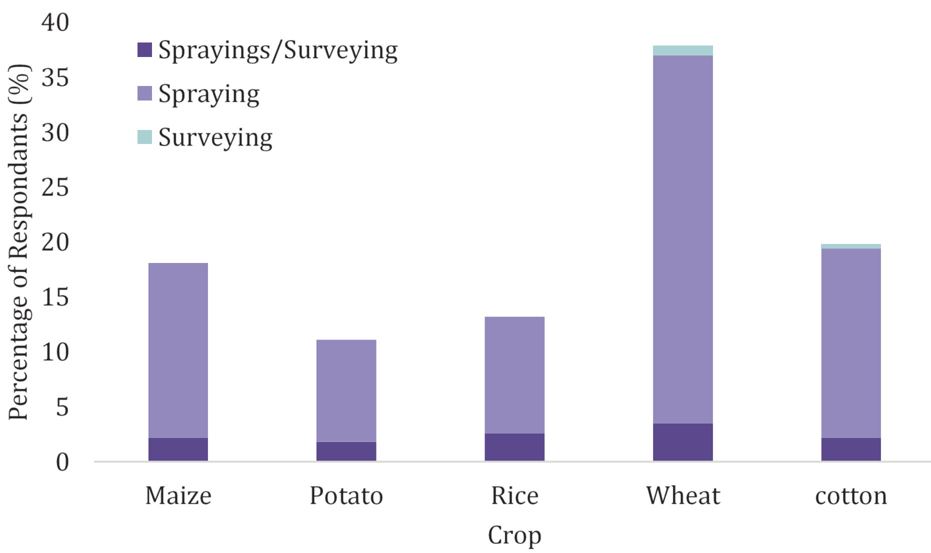


Source: Authors' calculations.

Crop Preferences and UAV Adoption

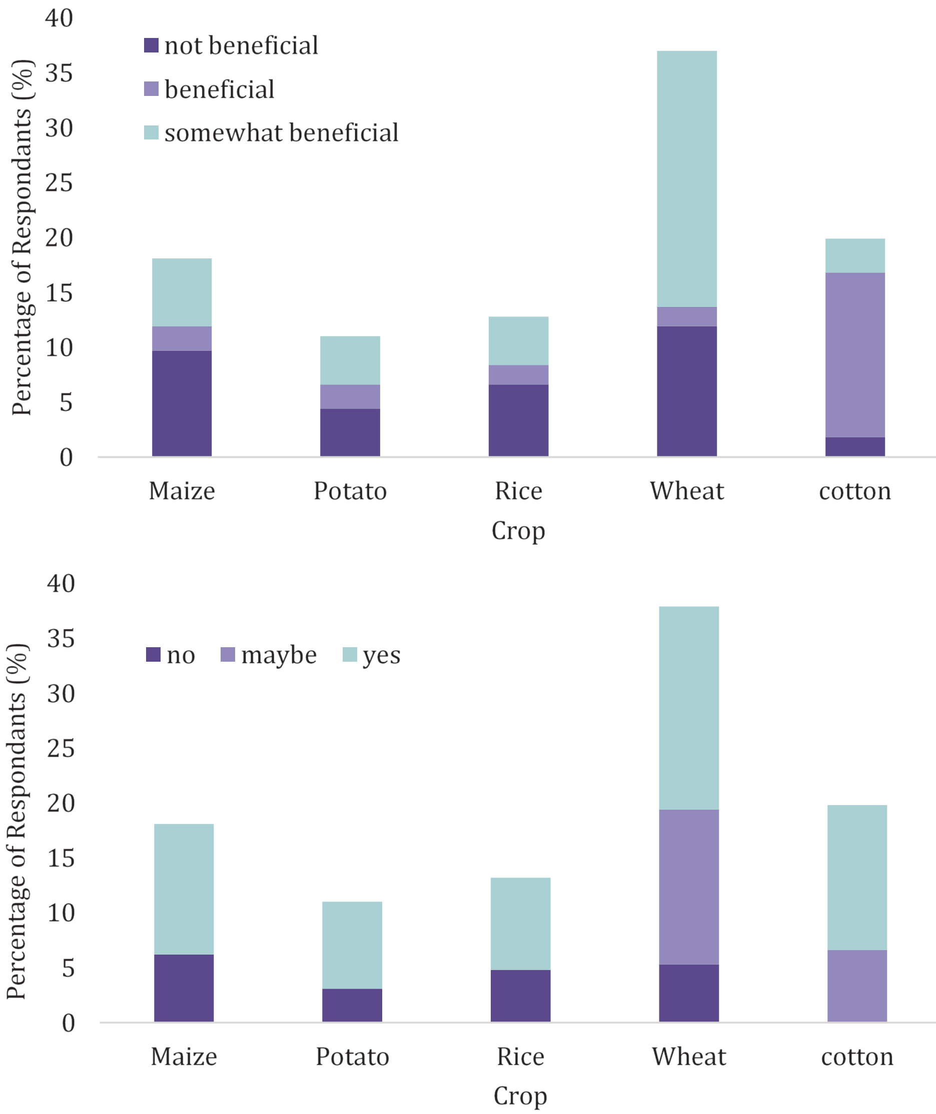
Effects of Different Crop Preferences on UAV Usage and Adoption: Figure 23 shows that wheat, maize, and rice are the most drone-intensive crops, accounting for 37.9% of the total. Wheat growers use spraying (12.3%), surveying (0.9% and 0.4% respectively), and drones in general. Cotton growers are the second-largest group, with 3.5% using drones. Maize and rice farmers are the most prominent, with 15.9% using spraying and 2.2% using combined use. Potato growers are the smallest, using a mix of spraying, surveying, and surveying. Overall, drone use is 15.4%, with 28.6% of non-users. The percentage distribution of perceived cost reductions achieved through UAV use across different crops is shown in Figure 24. Most wheat and cotton growers reported no cost reduction, while maize, potato, and rice growers often claimed 30% or more cost savings, indicating crop-specific variability in drone cost-effectiveness.

Figure 23: UAV Usage and Adoption Preferences for Different Crops



Source: Authors' calculations.

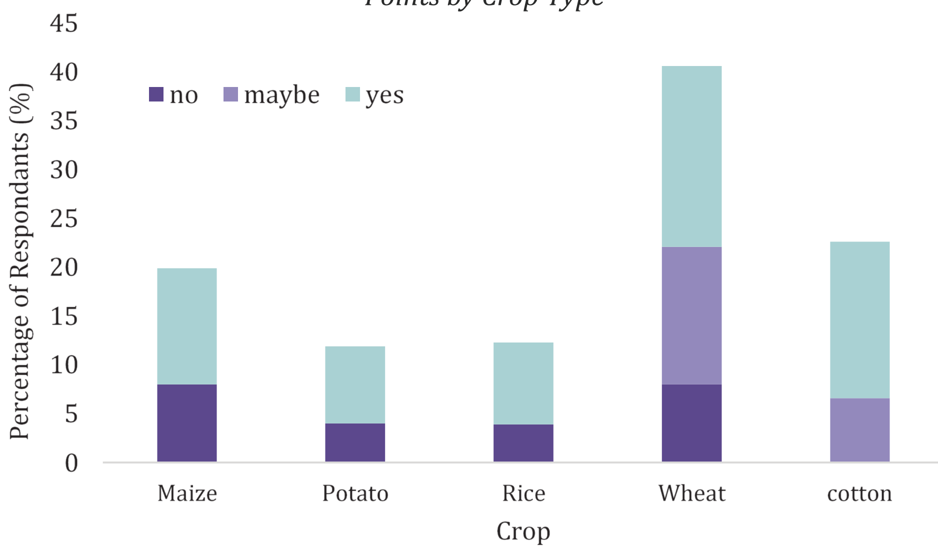
Figure 24: Cost Reduction by Crop due to UAV Usage (%)



Source: Authors' calculations.

Willingness to Adopt UAVs: Figure 25 shows that farmers' willingness to pay for UAV services at three price points (PKR 500, PKR 600, and PKR 750) is influenced by crop type. As the cost increased to PKR 600, only 10.1% remained willing, and at PKR 750, willingness declined further to 7.5%, indicating strong price sensitivity. Cotton farmers showed the least interest, with 0% willingness across all price points. At PKR 500, 32.2% of respondents were willing to pay, with maize, wheat, and rice growers being the most willing. Wheat has the highest likelihood of adopting UAV technology, accounting for 37.9% of total responses. Cotton and maize farmers followed closely, with 19.8% and 18.1% respectively. However, 37.4% of farmers found UAV adoption unlikely, possibly due to cost, knowledge gaps, or perceived ineffectiveness. Only 13.2% expressed a moderate to low enthusiasm for UAV adoption, indicating a need for financial or awareness barriers to be addressed, as shown in Figure 26.

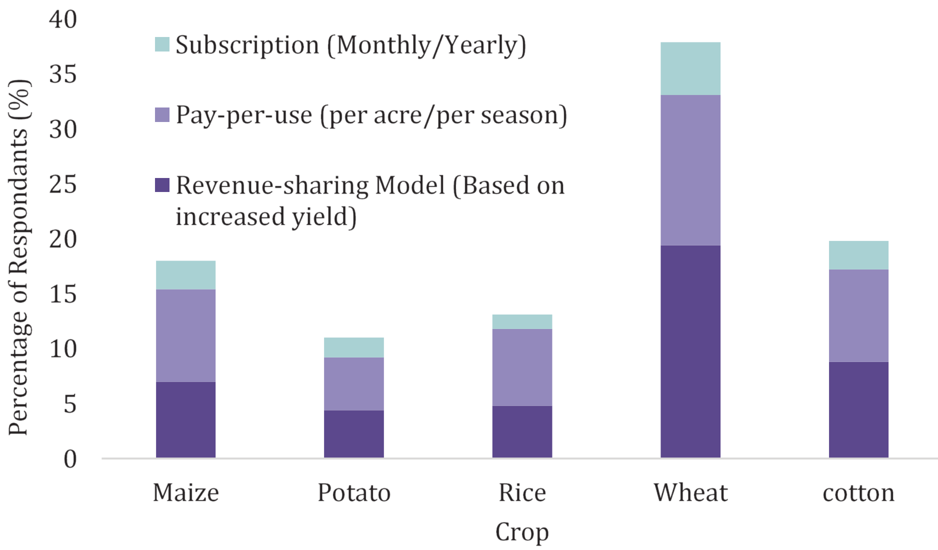
Figure 25: Farmers' Willingness to Pay for UAV Services at Different Price Points by Crop Type



Source: Authors' calculations.

Payment Models for UAV Services: The farmers preferred different payment models for UAV-based services for major crop types. The subscription model was the most preferred, with 34.5% of respondents choosing it, especially the wheat farmers. The pay-per-use model was preferred by growers of wheat, cotton, and maize crops. The subscription model was the least popular, with support, indicating limited willingness to commit to ongoing UAV service contracts. Wheat farmers showed the highest preference across all models shown in Figure 26.

Figure 26: Preferred Payment Models for UAV Services by Crop Type



Source: Authors' calculations.

4. CONCLUSIONS

The focus of the conducted study was on both opportunities and challenges associated with the adoption of UAVs in Pakistan's agricultural sector among small to large landholding farmers. The results of KIIs indicated that although UAVs offer promising solutions for precision agriculture in terms of reducing costs, enhancing efficiency, and minimising environmental impact, their adoption remains limited due to various types of constraints. The major constraint identified during KIIs with private service providers, agrochemical companies, and government institutions turned out to be the absence of a national drone policy.

The absence of structured mechanisms and regulations has complicated the import process, an approval process that ultimately results in lower adoption rates. The survey revealed that 59.9% of respondents believe that the use of drones reduces environmental impact, with 41.4% finding it beneficial. Farmers are willing to pay PKR 500, with larger families showing higher willingness. Revenue-sharing and pay-per-use are preferred payment models, while subscription-based models are the least popular. Drone usage is dominated by spraying, with minimal surveying, indicating potential for awareness and capacity building.

Moreover, the lack of technical awareness and lower availability of UAVs at research institutions are also contributing to low propagation rates of UAV spraying in Pakistan. Results of farmer surveys revealed that awareness of UAV technology is growing, especially among young and more educated farmers. However, actual adoption remains low due to high initial costs, high spraying costs, limited access to service providers, and a lack of training programmes. Smallholder farmers are more inclined towards government subsidies or pay-per-use models.

The study also highlighted that farmers in areas with better exposure to technology showed a higher inclination toward adoption, while others showed their reliance on traditional methods. The major solutions to the highlighted challenges are the formulation of a national UAV policy for agricultural use, introducing service provider models, and integrating UAV training into educational programmes. Addressing these barriers will ensure the successful wide-scale adoption of UAV technologies in Pakistan's agricultural industry, which will ultimately improve farm productivity and food security.

5. POLICY RECOMMENDATIONS

The following policy actions are recommended for the adoption of UAVs in agriculture among small to large landholding farmers based on KIIs and farmer surveys.

1. The government should act like a facilitator and develop a well-structured regulatory and policy framework. With the help of such frameworks, agricultural institutes, research think tanks, and engineering universities can collaborate effectively and promote the local production of UAVs.

2. In the short term, the government should digitise the import licensing and NOC procedure to import UAVs and their spare parts.

3. In Universities, compulsory courses should be included for technical and practical knowledge about agricultural technology, so they have both scientific and technical knowledge.

4. Like the solarisation project of the tubewell, a subsidised or low-interest scheme needs to be introduced for UAVs to cover the huge investment and maintenance costs.

5. Increase awareness and knowledge about UAVs by conducting awareness sessions and advertising testimonials videos of farmers who have already adopted UAVs.

6. One of the major constraints in UAV adoption is access to UAVs in the local regions. Development of private or governmental UAV service hubs in key agricultural regions can increase the use of UAVs for spraying among small-scale farmers.

7. The agriculture extension department can play a pivotal role in conducting targeted awareness campaigns through demonstration events to educate farmers on the economic and environmental benefits of agricultural UAVs.

8. Establishing local workshops for repairing and assembling UAVs is necessary to provide timely maintenance services and reduce reliance on expensive imports.

Implementation of these policy recommendations will boost the adoption rates of UAVs in Pakistan and overall precision agriculture technologies. Pakistan needs to incorporate these technologies to ensure sustainable crop production and food security.

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APPENDIX: KEY FINDINGS FROM THE INTERVIEWS WITH KEY STAKEHOLDERS

1. Constraints in Purchasing/Importing UAVs:

- What challenges do you face when purchasing or importing UAVs?

a. No availability of policy document for guidelines on importing, purchasing, and usage of drones.

b. Lack of clear guidelines and organisations to contact for obtaining NOCs to operate and import a drone.

c. Lengthy and repetitive documentation.

d. Unnecessary delays in various national and local administrative offices for the application of purchase licensing.

e. No clear background check mechanism.

f. High purchase cost of UAVs.

g. Absence of competing markets to purchase drones at reasonable prices.

h. Importation of parts is easier compared to a complete UAV.

i. Absence of after-sales markets to purchase parts to repair drones.

j. The use of private channels to import undocumented drones is due to the large demand.

k. Currently, the Ministry of Defense and the Interior Ministry are issuing NOCs for the importation of drones to some large groups.

2. Service Delivery and Pricing Mechanism:

- How is your current service delivery structured?

a. Service delivery model.

i. Traditional In-Person Model: Agrochemical companies are providing the in-person model by providing information to farmers at their distribution centres. Mainly agrochemical companies (Star Group (Pvt) Limited). They have private drone operators in their contacts.

ii. eCommerce Model: Companies rely on e-commerce, such as Facebook (GrowTech (Pvt) Limited). Sapphire, Concave Agri, and AeroVision (Pvt) Limited are also relying on their web platform for the acquisition of services.

iii. Pier to Pier Model: FACE is using the platform of FFC to provide drone services to its customers. RaviEngineering (Alkaram AgroTech Services) is using the leads generated by the Syngenta distribution network for the acquisition of a drone for spraying by the farmers in their localities.

- What is your pricing model?

i. Usage-Based Model: Usage-based models are adopted by GrowTech, Sapphire Group, FACE, and Ravi Engineering. Their pricing structure varies from USD 700 per acre to USD 2,400 per acre. The conditions are minimum landholdings (ranging between 5 acres and 500 acres) and average distance from distribution centres.

ii. Per-Added-Module Model: Star Group (Pvt) Limited is offering its customers discounted rates for drone spraying with the purchase of agrochemicals from their distribution centres.

iii. Per-User Model: GrowTech is also relying on a per-user model to execute their spraying for small landholding farmers by managing the leads generated in the same vicinity on the same day. However, their minimum acreage is 5 acres/farmer.

- What are the main factors driving the current pricing mechanism?

a. Availability of drones in the vicinity.

b. Minimum acreage.

c. Fuel and other commodities prices.

d. Distance from the service provider base.

3. Operational Constraints and Skill Requirements:

- What operational challenges do you encounter?

a. Skilled labour shortage to operate a drone.

b. Technology integration and propagation at the farmer's level

c. Regulatory compliance in some areas is restricted by the local administrations.

- What skills are necessary to effectively operate UAVs?

a. Crop knowledge, diseases, and pests' knowledge.

b. Drone operating skills, safety measures, and technical education.

c. Climatic conditions awareness, such as temperature and wind

- What is your opinion regarding the skillset of UAV operators? Should he/she be certified by any national institute, such as TEVTA/NAVTCC?

a. Proper courses on drone usage.

b. Crop identification and classification knowledge as modules.

c. Certification and background clearance to operate drones.

d. Training courses should be offered as per market demand, as it is a very specialised field.

4. Market Constraints and Limitations:

- What is the general response of farmers regarding willingness to adopt UAVs in agriculture?

a. Overwhelming positive response among farmers.

b. Less interest by older farmers.

c. More interest by young farmers.

d. A few concerns regarding availability during the field season.

- What are the current market limitations for UAVs?

a. Small landholdings of farmers.

b. Lack of infrastructure to provide services at the village level

c. Economic conditions of farmers.

d. Less demand due to the limited availability of drones.

- How do you see market expansion if the UAV policy is launched?

  a. Local purchase will be easier.

  b. Establishment of service stations.

  c. More market competition.

  d. Easy procedure for drone imports.

  e. Policy must be service provider-friendly and farmer-friendly, as stringent policies will discourage service providers.

- How do you see the role of commercial banks in the widespread use of UAVs in agriculture?

  a. Rapid expansion is possible as the initial price is very high.

  b. Inclusion in the subsidised packages offered by the Government through banks.

  c. Depends on the market demand, as banks might be reluctant to include UAVs in their loanable items.

5. Required Changes:

- What changes do you believe are necessary for improvement?

  a. Easy access to drone service providers for farmers

  b. More literature availability for extension staff to aware among farmers about the benefits of drone usage

  c. Trained UAV operators with a basic agriculture background

6. Governmental Support:

- What kind of support is required, especially from the government?

  a. The formulation of the policy to use drones.

  b. Subsidy on drone purchase.

  c. Better training of farmers and drone service providers.

Government Institutions

- Ministry:

- What is the current policy regarding UAVs?

    a. No policy is in the implementation stage.

    b. Drone use policy for agricultural purposes is being devised in the final stages by the Interior Ministry and the Ministry of Defense.

    c. The Punjab Government have developed SOPs for the use of drones through the Home Department and the DC office.

- What role does your department play concerning UAVs?

    a. MoST has devised the initial policy with the cooperation of all stakeholders.

    b. Provide technical feedback on issues regarding the safe use of drones.

- What should be done about UAVs?

    a. Regularisation of existing use.

    b. Better background checks.

    c. Development of safe zones for agricultural usage.

- What are the current regulations concerning UAVs?

    a. No current official regulations. NOCs can be issued by the Ministry of Interior and the Ministry of Defense for the importation of drones.

- Are there any commercial companies approaching to get NOCs for drone importation?

    a. Yes, AlKaram Agroctech has obtained NOC to import XAG drones in Pakistan.

    b. A few other companies have also contacted us to obtain licenses to operate drones.

- Is there any kind of demand from farmers regarding drone importations/implementation in agriculture?

a. Few corporate farmers have been contacted to allow drone purchase.

b. Feedback from the field office of the agriculture department informed the ministry that farmers are interested in drone purchase.

- What is the current procedure, such as the number of NOCs required, the time required for the complete procedure, and when allowing someone to buy/use UAVs?

a. NOCs of the Ministry of Interior, the Ministry of Defense, the Ministry of Agriculture, and the DC office are required to operate drones. However, the proper procedure has not been devised to date.

- How many drones are allowed to date, or for what purposes can you share data?

a. There is not much information about it.

b. A few centres received as a gift from China, while FACE –Rahim Yar Khan announced the availability of 50 UAVs for the farmers' service. Some startups are providing private services as well.

- How many companies are registered to provide UAV services to farmers?

a. No company is officially registered to date. However, some companies are providing services locally.

National Agricultural Research Center, Atomic Energy Commission, Ayyub Agricultural Research Center, and Agricultural Universities in Punjab (University of Agriculture, Faisalabad, MANSUA, Multan)

1. Use of UAVs in Operations:

- What do you say about the potential of UAVs in agriculture?

a. UAVs play a very important role in agriculture.

b. In plant protection, when there is pest control for disease, sometimes it is not possible to do it manually or with a tractor or any big machine.

c. A drone is a very good equipment that can spray uniformly.

d. Weed and disease management in tall crops, such as maize or sugarcane.

e. Orchard spraying

f. Time savings and timely spraying

g. Cost effectiveness

- Are you currently utilising UAVs in your operations?

a. Drones donated by different countries are operational in NARC, UAF, and ARID.

b. Some drones are locally purchased as well.

c. Used to conduct limited-scale studies basically for R&D purposes.

2. Experience with UAVs:

- What has been your experience using UAVs?

a. Effective time management and less laborious

b. Better and uniform spray coverage compared to other methods.

c. Non-destructive method of spraying

d. Proper training is required to operate drones.

e. Proper agricultural knowledge is necessary in terms of agrochemicals and crop types.

- What are the impacts of using UAVs on plant growth and productivity?

a. Preliminary studies conducted at ARID, UAF, and NARC have shown positive results in different cropping systems.

b. Saving of agrochemicals between 5 to 20%.

c. Large-scale testing is required for proper insights.

3. Cost-Benefit Analysis:

- Have you conducted a cost-benefit analysis of using UAVs?

a. Only a few studies have been conducted on cost-benefit analysis.

b. ROI of 2 to 5 years for more than 500-acre farms.

c. Benefits in terms of labour savings and time savings between 10 to

40% depending on the sprayed acreage (large acreage results in more savings).

4. Constraints:

- What legal, technical, and operational challenges do you face?
    a. Not been allowed by the Government of Pakistan yet.
    b. No large-scale implementation due to the unavailability of commercial drones
    c. Publications are not easy due to the above-mentioned reasons.
    d. Lack of properly trained staff to operate drones.
    e. Lack of data for drone testing in each crop.
    f. Data interpretation skills for UAV-related data.
    g. Proper maintenance training to repair and maintain drones
    h. Safety training and SOPs for operating UAVs
- What is the role or potential role of NARC in developing/implementing UAV policy?
    a. PARC is a federal institution.
    b. Provide feedback to MoST on drone policy development and implementation in agriculture.
    c. Safety guidelines.
    d. Feasibility studies on drone use for cost-effective crop management.

Agriculture Department, Punjab (Extension Department, Engineering Department

1. Role in UAV Deployment:

- What is your department's role concerning UAVs?
    a. Conduct feasibility studies for agricultural land management.
    b. 3D modelling of soils.

   c. Demonstration plots for farmers in different districts of Punjab.

   d. Provide technical and awareness documentation to farmers.

   e. No current use due to the unavailability of the drones' policy

2. Limitations:

- What are the limitations regarding UAVs, including skill sets and the availability of trained experts?

   a. The biggest limitation is the unavailability of skilled workers. All the people working in the field areas are agronomists.

   b. Lack of basic engineering knowledge

   c. No training program for developing skill sets to operate drones.

- What are the limitations of staff regarding highlighting the importance of UAVs among farmers?

   a. Lack of trust in adopting innovative technologies

   b. All the field workers who are working in the field are given drone training.

3. Market Development Potential:

- If your department were to lead the development of the UAV market, what potential do you see?

   a. There is a lot of potential. There are 28 offices across Punjab. From Potohar to Rajanpur, the network is very strong. There are 15 to 20 staff members in each office. Whether they are assistant directors, deputy directors, or at the director level, they are all further distributed.

   b. The engineering and extension departments should play a role where there is a lot of potential to cover a large area and rapid technology transfer.

   c. Rental spaces for service providers.

   d. Proper training of service providers at the department's regional offices.

   e. A large network of farmers allows better knowledge sharing.

CENTRAL BANK DIGITAL CURRENCY, FINANCIAL COMPETITION, AND GROWTH: IDENTIFYING CHALLENGES, OPPORTUNITIES, AND APPLICATIONS

Abdul Rashid[1] , Zainab Jehan[2] and Saira Tufail[3]

ABSTRACT

Central banks worldwide are actively pursuing the successful implementation of Central Bank Digital Currency (CBDC) with perceived benefits such as enhanced financial inclusion, a more efficient and secure payment system, increased transaction transparency, stable prices, and a robust framework for effective monetary policy. This report had five main objectives encompassing the global and national dimensions related to CBDC, employing qualitative and quantitative methodologies. The analysis revealed that Pakistan's economic and technological indicators are comparable with those of countries at the advanced stages of CBDC exploration. Moreover, Pakistan's adoption of digital payment systems positions it favorably for CBDC implementation. Regional competitors like India and China are progressing rapidly, reinforcing the urgency for Pakistan to act. Based on the primary data, it is revealed that digital illiteracy, particularly among women, is perceived as a significant barrier to CBDC adoption and the risk of excluding marginalised groups unless targeted interventions are implemented. Financial institutions reported inadequate communication and a lack of coordination regarding CBDC awareness, highlighting the need for improved stakeholder engagement. Trust in digital ecosystems and concerns about data privacy are significant barriers. The report emphasises that addressing these issues is vital to fostering public confidence in digital currencies. Investments in cybersecurity measures and public education on safe digital practices are perceived as prerequisites for realising the professed benefits of CBDC. CBDC

[1] Professor of Economics/Director General, International Institute of Islamic Economics (IIIE), International Islamic University, Islamabad.

[2] Associate Professor/Chairperson, Department of Economics, Fatima Jinnah Women University, Rawalpindi.

[3] Assistant Professor, Department of Economics, Fatima Jinnah Women University, Rawalpindi.

presents a transformative opportunity for Pakistan to modernise its financial system, enhance financial and digital inclusion, and foster economic growth. However, realising this potential requires addressing critical gaps in literacy, infrastructure, and trust. With strategic investments, stakeholder engagement, and alignment with global practices, Pakistan can position itself as a leader in digital financial innovation.

1. INTRODUCTION

Background

The contemporary era of digitalisation, characterised by rapid advancements in big technologies (BigTech) and financial technologies (FinTech), is reshaping our perception and management of currency. The paradigm shift in financial payment systems is inextricably linked to the emergence of the internet, digitalisation, and Fintech. Internet banking, a gateway to digital innovations, provides a convenient alternative to traditional banking by enabling individual and corporate clients to manage their finances and other financial transactions remotely and more effectively. The advent of plastic money enhanced transaction convenience while also improving payment security, records, and fraud protection. As technology advanced, mobile wallets and payment apps became the forefront of digital finance. These apps leverage smartphone capabilities for contactless payments, streamlining transactions and enhancing security through features like biometric authentication and tokenisation (Uwaleke, 2022).

The emergence of decentralised finance (DeFi) based on blockchain technology, exemplified by cryptocurrencies like Bitcoin and Ethereum, has brought to the forefront the challenges and risks associated with digital currencies. Nevertheless, central banks and financial institutions (FIs) all over the world are grappling with challenges such as regulatory concerns, price volatility, and security issues, among others, associated with this innovative form of money. A vast range of policies has been implemented by the central banks of different countries to guarantee that individuals and businesses continue to have access to more secure and efficient payment systems. Several central banks are considering central bank digital currencies (CBDCs) as a regulated and secure alternative to DeFi, with perceived benefits including but not limited to financial inclusion, an efficient and secure payment system, transparency in transactions, price stability, and effective monetary policy.

Features and Models of CBDC

The 2018 report by the Committee on Payments and Market Infrastructures - Markets Committee (CPMI-MC) defines CBDC as a new form of central bank money, distinct from physical cash or central bank reserve/settlement accounts. The classification of CBDCs into different types is based on factors such as intended users, use cases (Retail and Wholesale CBDC), technical implementations, and issuance methods (account-based and token-based CBDC). A concise summary of differences in different types of CBDCs is presented in Figures 1.1 and 1.2.

Figure 1.1: Retail vs wholesale CBDC

Target Users

R-CBDC - General public, individual, and business

W-CBDC -Financial instituions, banks and other market participants

Use Cases

R-CBDC - Everyday transactions

W-CBDC - Interbank transactions

Motivation

R-CBDC -Central bank fiat currency, Financial inclusion, competetion and innovation

W-CBDC -Efficient and secure managment of wholesale markets

Benefits

R-CBDC -Security, reliability, resilience and, combating Defi

W-CBDC -Effecient settlements, collateral and liquidity

Challenges

R-CBDC - Privacy concerns, disintermediation, technology development, and legal framework

W-CBDC -Monetray and financial stablity and competetion

Current Status

R-CBDC -Pilot phase, a few launch

W-CBDC -Not Launch but actively explored

Figure 1.2: Account vs Token Based CBDC

Representation

T-CBDC - Digital tokens, claims on central bank

A-CBDC - Account Balances, ownership of monetary balances

Ownership

T-CBDC -Bearer instrument

A-CBDC - Sccount Hoder Identity

Verification

T-CBDC - Recipient

A-CBDC -Intermediary

Record

T-CBDC -Ledger records ownership chain

A-CBDC -Transaction History

Security

T-CBDC -Token authenticated to prevent counterfiet

A-CBDC -Account security ensures authorized transactions

Transaction Verification

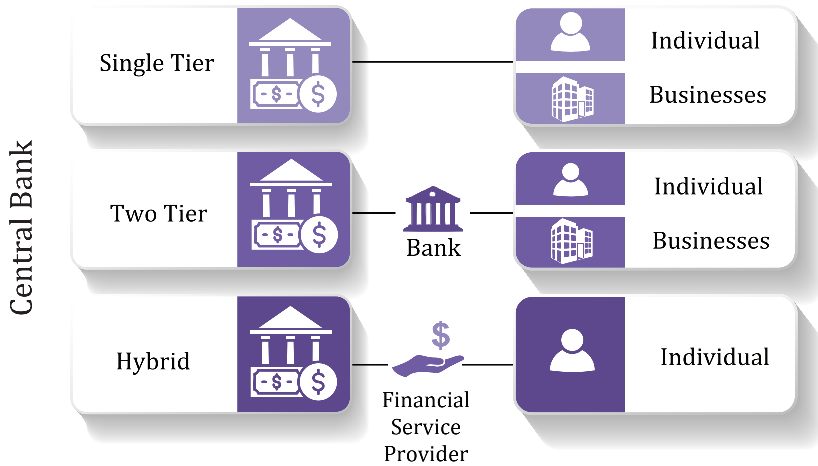
T-CBDC -Verification of token authenticity

A-CBDC - Verification of account holder authority

Source: Authors' Construction.

There are three distinct modes for the issuance and administration of CBDCs (see Figure 1.3). These are single-tier, two-tier, and hybrid modes. For the single-tier or direct mode, the central bank assumes full responsibility for overseeing all aspects of the CBDC framework, including issuance, account management, and transaction validation. The two-tier, or indirect, mode involves a collaborative approach where central banks manage CBDC through financial intermediaries. In the hybrid mode, intermediaries deliver retail services to end users, while the central bank maintains a record of retail transactions (Chortareas et al., 2024).

Figure 1.3: Modes of CBDC



Source: Authors' construction.

Central Bank Digital Currency: Global Facts

A total of approximately 134 countries and currency unions, representing 88% of global GDP, are currently exploring CBDCs. Currently, about 68 countries are in advanced stages of exploration, including development, pilot testing, or launch. However, it is also shown that the CBDC exploration phase of 134 countries of the world, with most countries in the research phase of CBDC development.

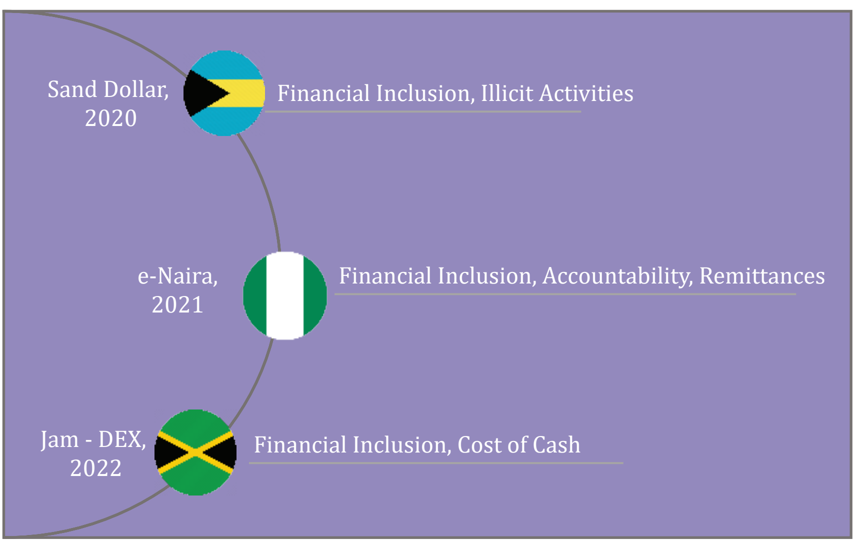
Along with a significant increase in the number of countries piloting and developing CBDC projects, some countries have also cancelled CBDC after its launch or have disabled it for the time being. For instance, both Ecuador and Senegal have permanently terminated their retail CBDC project after the launch. The Ecuadorian Central Bank launched its digital currency, but due to a low level of trust in the central bank, the project was eventually cancelled. In November 2016, a regional Senegalese Bank, Banque Régionalede Marchés (BRM), announced the launch of a digital currency called the eCFA. Importantly, the eCFA in Senegal was not declared legal tender, but an experiment that the central bank could observe and learn from. However, the eCFA was soon criticised due to a lack of compliance with e-money regulations and, therefore, was cancelled instantly.

The number of countries where CBDC became inactive after initial initiatives has also increased over time. Currently, 17 countries have abandoned their CBDC projects. A noteworthy case is Kuwait, which has shown no progress since its first announcement in 2018. Last year, Kuwait's capital market authority banned all crypto and virtual transactions, and the Central Bank of Kuwait introduced a new interbank payment system. Similarly, the Central Bank of Uruguay completed a retail and intermediated digital currency pilot programme. The pilot ended in 2018 and has been at a standstill since then.

About 60% of countries are running retail-CBDC development projects. The highest percentage is of those projects that are at the pilot testing phase of CBDC development. Almost 44 countries are actively pursuing the exploration of wholesale CBDC. Countries like India, China, Russia, Australia, and Brazil, among others, are exploring both types of CBDC. Similarly, North American countries, along with the UK, Norway, and a few Southeast Asian countries, which are largely at the development stage of CBDC projects, have announced to launch of both types of CBDCs. Another important feature, which is unanimous in all the mentioned countries, is that their CBDC is planned to be a two-tier CBDC.

The data from the Atlantic Council reports also highlights the motivation to launch CBDC. Figure 1.4 depicts financial inclusion as a uniform motivation of countries where CBDC is fully operative. The Central Bank of Nigeria claimed that e-Naira can increase financial inclusion from 85% which currently stands at 60%. It is also expected that a well-managed eNaira could add twenty-nine billion dollars to the GDP of the country over the next ten years. JAM-DEX is projected to save about seven million US dollars per year, which Jamaica currently spends on replacing, storing, and handling cash.

Figure 1.4: CBDC Status Launched



Source: Authors' construction.

Advanced economies such as the USA, Canada, and Norway are primarily researching cross-border operable CBDCs. In contrast, Asian countries like Indonesia, the Philippines, Taiwan, and South American Countries like Colombia are exploring the potential benefits of retail or wholesale CBDCs, focusing on financial inclusion, reduction in tax evasion, and payment efficiency. Some South American countries, such as Peru, view the launch of a CBDC as essential for fiscal and monetary stability. In contrast, Argentina does not see an urgent need to issue a CBDC and is focusing on improving its current payment systems. European countries such as Hungary and the Czech Republic have also stated that they are not considering the launch of a CBDC shortly. African countries have recently begun researching CBDCs, with African central banks exploring the possibility of a common CBDC with the member states. South Asia has a similar situation; Bangladesh is cautiously exploring the feasibility of a CBDC, influenced by unsuccessful examples of other countries and widespread digital illiteracy. The progress of research on CBDCs in Pakistan and Nepal is also negligible.

CBDC in Pakistan: Gap Identification and Problem Statement

Pakistan's plans for a CBDC trace back to 2018, when the State Bank of Pakistan (SBP) proposed a bill to the legislature, setting the groundwork for the development of a CBDC. A that time, the central bank's objective was to launch a digital form of the national currency to address the proliferation of unregulated digital currencies and counter the perceived threat of dollarisation in the economy. The former Governor of the SBP elucidated that the primary motives behind the potential issuance of CBDC were to enhance financial inclusion and to strengthen efforts in combating money laundering, countering the financing of terrorism, and bringing the vast informal economy into a formal setup (Baqir, 2022b).

According to one strand of views, Pakistan is already transitioning to a digital payment system, and thus, prospects for CBDC to achieve its primary objectives are very bright. Given the rising levels of technological literacy and the demographic composition, where the youth constitute a substantial majority of the population, there is an immense potential for digitalisation. It is also manifested in the impressive growth of digital transactions as compared to cash transactions, specifically, in recent years. According to some statistics, there was an increase of 100-150% in digital transactions in 2020. Moreover, while addressing the Pakistan Fintech Forum (2022), the Governor of the SBP mentioned that the SBP has issued a licensing and regulatory framework for the establishment of digital banks in Pakistan, which depicts the country's preparedness to adopt the technology (Baqir, 2022a). The successful launch of RAAST Bulk Payment and RAAST Person-to-Person (RAASTP2P), and RAAST Person-to-Merchants (RAASTP2M) by the SBP has added further confidence about the successful launch of CBDC in Pakistan.

An alternative perspective raises concerns regarding the usefulness of CBDC in Pakistan. For instance, while digital transactions in Pakistan are on the rise, over 80% of payments are still paper-based. Though the rise of e-banking is considered an improvement in the digital payments landscape, within e-banking, over 70% of the transactions are paper-based. Similarly, while real-time online branches (RTOB) are by definition online, they include transactions that occur between branches where cash is either deposited, withdrawn, or transferred between the same bank branches. A survey of emerging affluent Pakistanis by Standard Chartered showed that 50% of the total population saves money by storing cash at home. In other surveyed countries, the highest ratio was in India, where only 15% of the population saved by storing cash at home. This reflects a lack of trust in FIs in Pakistan, along with the motive to avoid coming under the tax net. Additionally, high costs and poor end-user experience in digital services have made cash a natural means of payment and savings. The resistance may be exacerbated, given the religious sentiments of the Pakistani populace regarding the Sharia legitimacy of financial services in Pakistan.

Moreover, the role of CBDC in the effectiveness of monetary policy transmission and its strength to achieve mandated macroeconomic objectives (e.g. price and financial stability, sustainable economic growth, and stable exchange rates) is still ambiguous. Interest rate pass-through is found to be very weak in Pakistan, undermining the SBP's effort to achieve price stability and other monetary policy objectives (Munir et al., 2023). With increased bank competition, if CBDC is implemented appropriately, the interest rate margins may reduce and the interest rate channel for monetary transmission may become more potent (Drechsler et al., 2017). Moreover, the bank lending channel may become stronger with an increase in wholesale funding, and the asset price channel may become effective with more financial inclusion.

As per the CBDC Dashboard, Pakistan is positioned among the countries that have conducted initial explanatory research on CBDC. However, beyond the SBP's former governors' speeches and interviews, and only a handful of newspaper articles and blog content, there is a lack of publicly available information regarding the explanatory research conducted by the SBP on the issue of CBDC (CBDC Tracker, n.d.).

Also, there is a dearth of institutional and academic research on Pakistan on the need assessment, potential benefits, and challenges associated with the launch and implementation of CBDC. Moreover, the evaluation and assessment of the existing legal framework of the SBP has not yet been conducted to understand its compatibility with the launch and management of CBDC and the mechanism for redressal of issues related to its monitoring and accountability. Furthermore, there is no comprehensive study to identify the macroeconomic, financial, and technological factors that are considered a prerequisite for a successful launch of CBDC. Finally, very little is known about the opinion of key stakeholders, including the general public, FIs, and merchants, about the preparedness for the adoption of CBDC, leveraging the benefits of CBDC and addressing the challenges associated with it. Given these gaps in the existing literature on Pakistan, the objective of this research is to discern the opportunities and challenges in launching CBDC in Pakistan.

Objectives and Research Questions

This study has the following objectives.

- To conduct a comprehensive literature review on CBDC using systematic review, bibliographic mapping techniques, and synthesis analysis.
- To identify the macroeconomic, financial, technological, and other factors influencing the adoption and implementation of CBDCs in various countries classified based on CBDC development stages, income groups, and geographical regions.
- To compare the financial ecosystem and macroeconomic environment of Pakistan with countries with different stages of CBDC development.
- To critically assess the compatibility of the existing regularity framework to launch and implement CBDC.
- To assess the level of awareness, readiness, acceptability, and perception about the benefits, challenges, opportunities, and implications of CBDC at all tiers of the financial ecosystem, comprising FIs, merchants and the general public.

Based on the study objectives, the following research questions are explored in this study.

- What are the predominant themes and trends in the existing literature on CBDCs, and how has the body of research on CBDCs evolved over time and across different regions?
- How do macroeconomic conditions, financial developments, and technological setup vary in countries at different stages of CBDC development, income groups, and regional characteristics?
- Does the regulatory framework of the SBP require amendments for the launch and effective implementation, and monitoring of CBDC?
- What are the perceptions of FIs regarding the preparedness of the financial ecosystem and challenges for the adoption of CBDC in Pakistan, and the benefits and opportunities associated with it?
- What opinions do commercial and personal users have regarding the perceived advantages and risk exposures in the adoption of CBDC in Pakistan?
- What strategies can the SBP adopt to effectively address the challenges and leverage the opportunities associated with CBDCs?

2. METHODOLOGY

The chapter presents methodologies adopted to achieve the research objectives.

Methodology: Objective 1

Regarding the first objective, an extensive literature review was conducted using various conventional and advanced techniques.

Conventional Literature Review

For the conventional literature review, the existing literature was divided into three overlapping groups:

- Issuance and adoption of CBDC
- The potential and realised benefits of CBDC
- Implications of CBDC

We further categorised the literature based on institutional and academic research. Institutional research includes reports and working papers published by different organisations such as the International Monetary Fund (IMF), Bank of International Settlements (BIS), and central banks from various countries. Academic research, on the other hand, focuses on scientific research published in well-reputed journals. We also identified key aspects within each category and presented their occurrence percentages using treemaps.

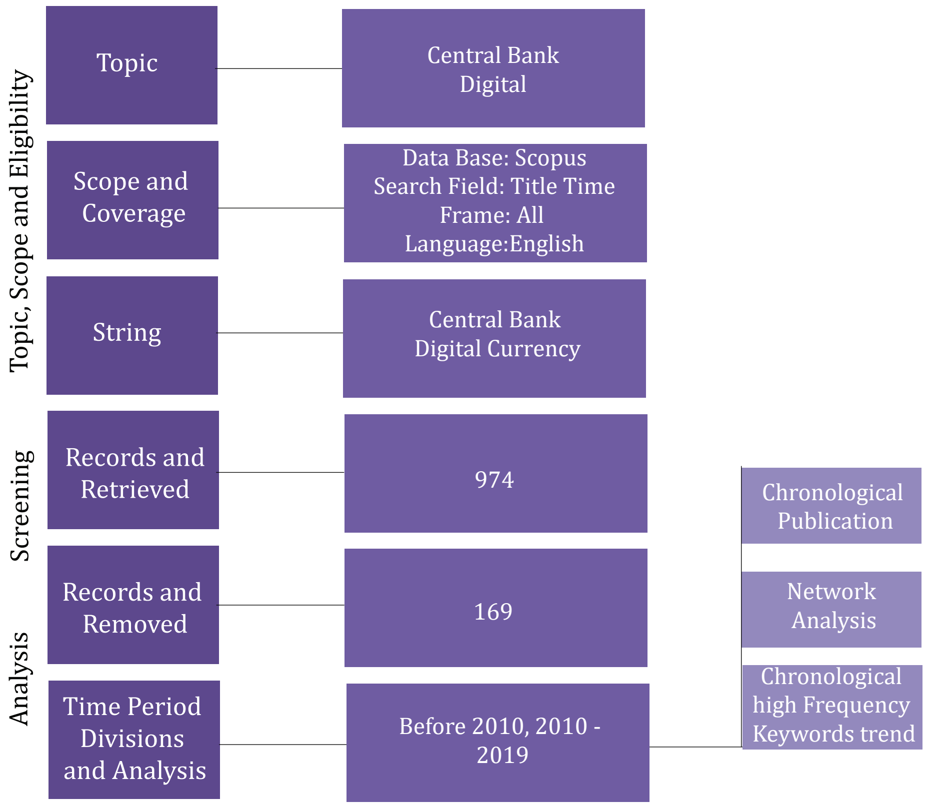
Bibliographic Mapping

We employed bibliographic mapping techniques. Our search began with targeted keywords, specifically, "central bank digital currency" or "CBDC," in the Scopus database. We chose Scopus due to its extensive coverage of scholarly articles across diverse disciplines, ensuring a comprehensive collection of relevant literature.

The initial search yielded 874 documents, including articles, book chapters, conference papers, reviews, books, short surveys, and notes. To refine this database, we implemented a rigorous selection process. We restricted our review to articles published in English to ensure linguistic consistency and the accessibility of findings to the international research community. We selected 805 articles, which were then sorted into different time periods. All articles published before 2010 were grouped, and the second group ranges from 2011 to 2018. After 2018, the analysis was conducted on an annual basis till 2024.

For the analysis of the selected articles, we employed a combination of software tools, including Vosviewer and Excel. These tools provided a versatile and powerful framework for data organisation, analysis and visualisation. We analysed publication trends, network analysis, and keyword frequency analysis to delve deeper understanding of the issue. Figure 2.1 contains the strategy for conducting bibliographic mapping.

Figure 2.1: Data Collection Strategy for Bibliographic Mapping



Source: Author's construction.

Systematic Literature Review

The study was further extended to include a systematic literature review (SLR). For this, 100 working papers and reports were sourced from the IMF, BIS, and central banks of various countries. Two hundred academic research articles retrieved from Scopus were also reviewed. NVivo software was used to create a word cloud highlighting the most frequently used terms in literature related to CBDC. Additionally, the information was organised into treemaps and mind maps to identify areas rich or lacking in the literature. Figure 2.2 contains the strategy for SLR.

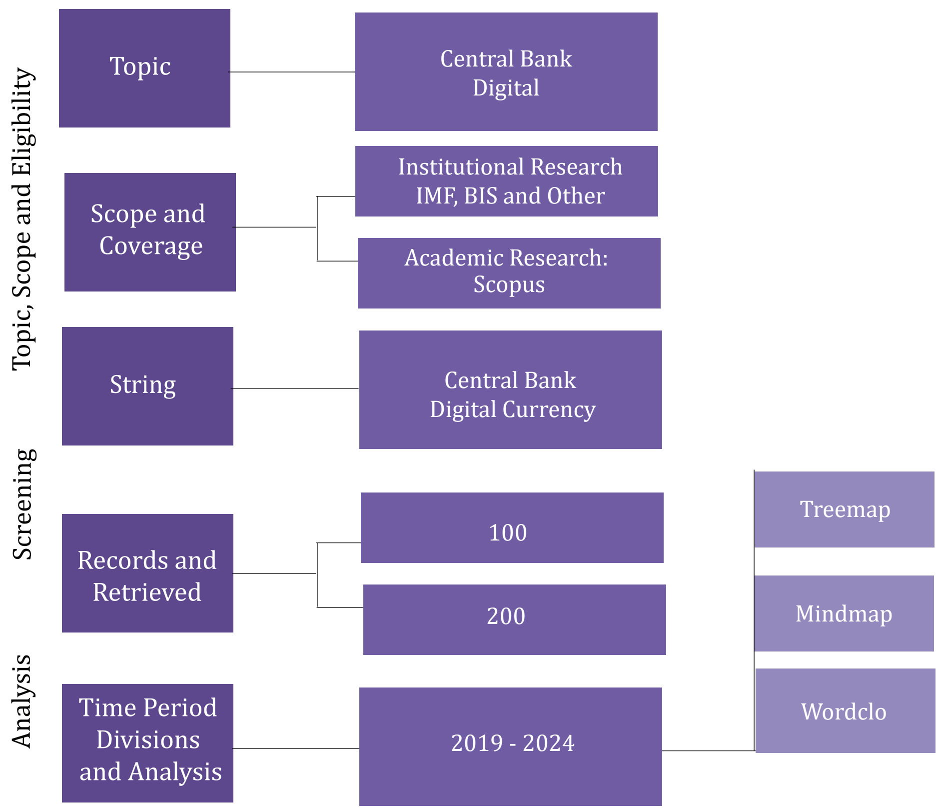
Methodology: Objectives 2 and 3

Distribution Analysis:

Many macroeconomic variables were explored for their potential connection with the development of CBDC. Variables were classified into five categories:

- Monetary policy indicators
- Financial sector indicators
- Technological adequacy indicators
- Macroeconomic indicators

Figure 2.2: Data Collection Strategy for Bibliographic Mapping



Source: Author's construction.

The research used choropleth mapping to assess countries concerning the above-mentioned variables in the following three categories.

- Stages of CBDC development
- Income groups
- Regional groups

Methodology: Objective 4

To examine the readiness of the financial architecture and regulatory framework for CBDC launch and intermediation in Pakistan, we employed a comprehensive, evidence-based approach. This involved data from secondary sources, including academic research and institutional reports, and analysing international case studies such as those of China and India.

Methodology: Objectives 5

For objectives 4 and 5, a comprehensive survey analysis was conducted. The survey was structured around three main stakeholders in the twin cities of Pakistan. The three main stakeholders are:

- General public
- Merchants
- Financial institutions

These three pillars collectively provided an all-inclusive view of CBDC readiness and awareness across different sectors of society, laying the groundwork for analysing the diverse factors that influence the adoption and implementation of digital currency in Pakistan.

Questionnaire Design

For the general public, the questionnaire aimed to assess their awareness and potential acceptance of CBDC. The questionnaire for merchants was structured to understand their readiness to adopt CBDC in business operations. Both questionnaires included the following sections based on the technology adoption model.

1. Demographics
2. Awareness/knowledge about CBDC
3. Relative advantages (only for merchants)
4. Perceived usefulness
5. Perceived ease of use/benefits of CBDC

6. Challenges
7. Compatibility
8. Personal innovativeness with digital technology and CBDC
9. Future considerations

For FIs, the questionnaire was designed to capture the strategic and operational perspectives of banks and fintech companies. It included the following sections:

1. Bank/institution's profile
2. Demographic profile of the respondent
3. Perception of FinTech and CBDC
4. Potential financial and economic benefits of CBDC.
5. Potential financial and economic costs/risks
6. Technical adequacy
7. Public perception and acceptance
8. Challenges and remedies
9. Design of CBDC

Geographical Area of the Study

The study was conducted in Islamabad and Rawalpindi, chosen because of their diverse and dynamic population, as well as the concentration of business and financial activities.

Sampling Frame

The sampling frame was determined based on the availability and accessibility of respondents within the selected areas. The study included 270 respondents from the general public, 200 merchants from various business sectors, and 50 representatives from FIs, such as banks and fintech companies.

Training of Enumerators

A two-day training was organised for enumerators to ensure the quality and reliability of the data collected. During the training, enumerators were briefed on specific terminologies and concepts used in each questionnaire, as well as the importance of understanding the context of CBDC. They were also instructed on the sensitivity of certain questions, how to handle them appropriately, and the protocols for maintaining respondent confidentiality and data integrity. The training emphasised the ethical and professional standards required for conducting the survey, ensuring that enumerators were well-prepared to engage with participants respectfully and effectively.

Ethical Considerations

The study followed the ethical guidelines established by the International Islamic University Islamabad (IIUI). All ethical considerations, including informed consent, voluntary participation, confidentiality, and the right to withdraw from the survey at any time, were strictly observed. Participants were assured that their responses would be kept anonymous and used solely for research purposes, in line with IIUI's ethical standards and research protocols.

Data Analysis

The data were analysed using stacked bar graphs for each item. Moreover, the comprehensive indices for each aspect of CBDC are also constructed and presented in the form of bar charts.

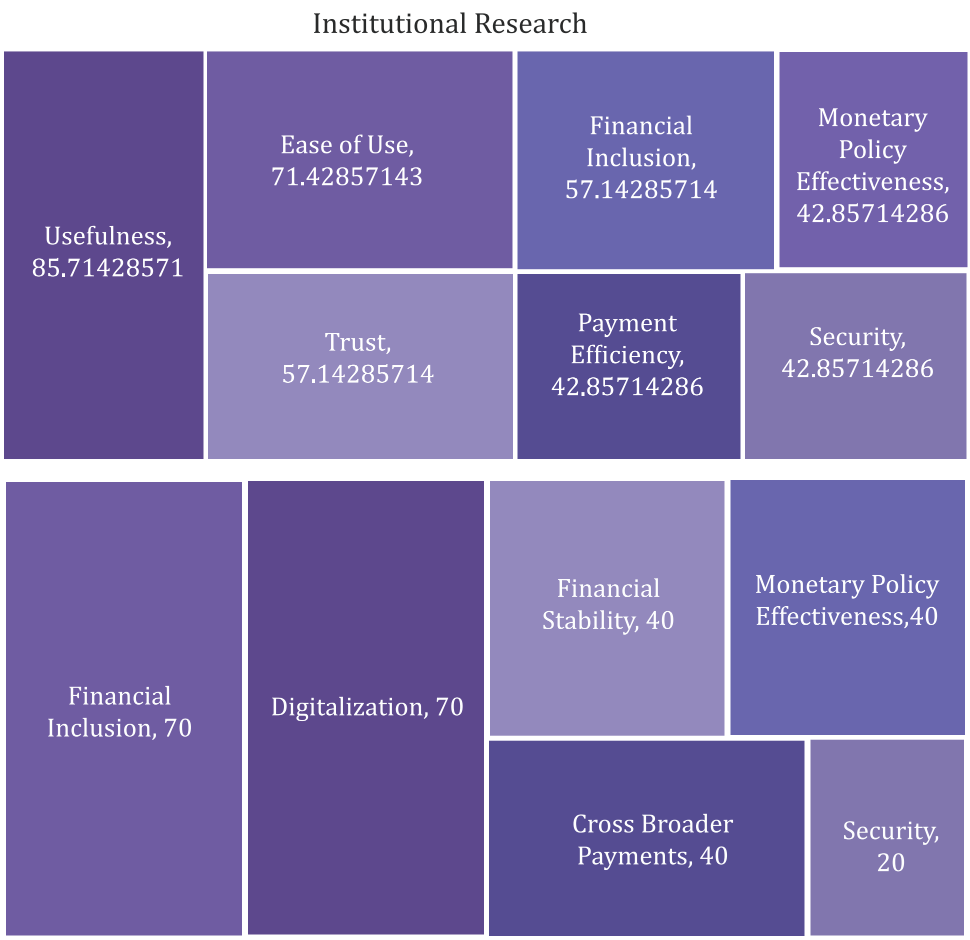
3. LITERATURE REVIEW

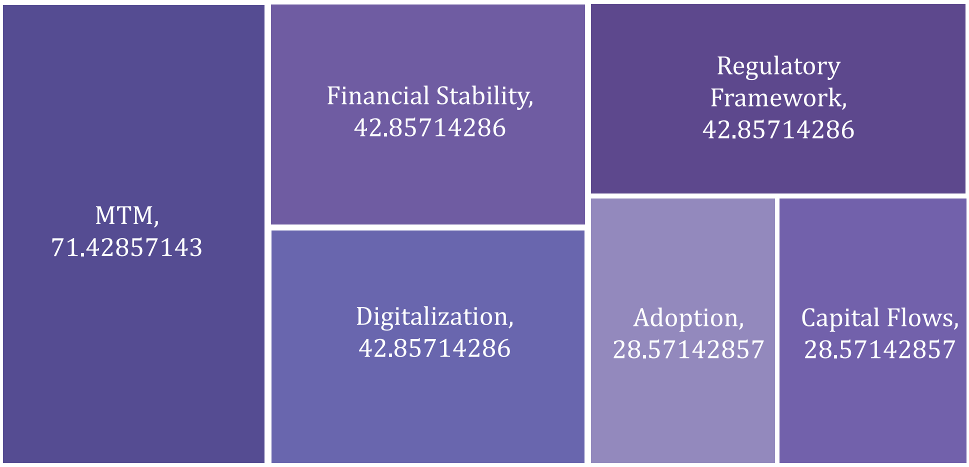
Literature Review and Synthesis Analysis

This section reviews institutional and academic research on factors determining the adoption, implications, benefits, and challenges of CBDC. The concise summary of the literature review of each dimension specified is presented in the respective tables. The synthesis analysis is also presented in the form of treemaps, with each dimension of the literature reviewed. Tables 3.1B-3.12B contain the summary of institutional, academic and research, including Pakistan, undertaken to examine the factors affecting the adoption, cost/benefits and implications of CBDC.

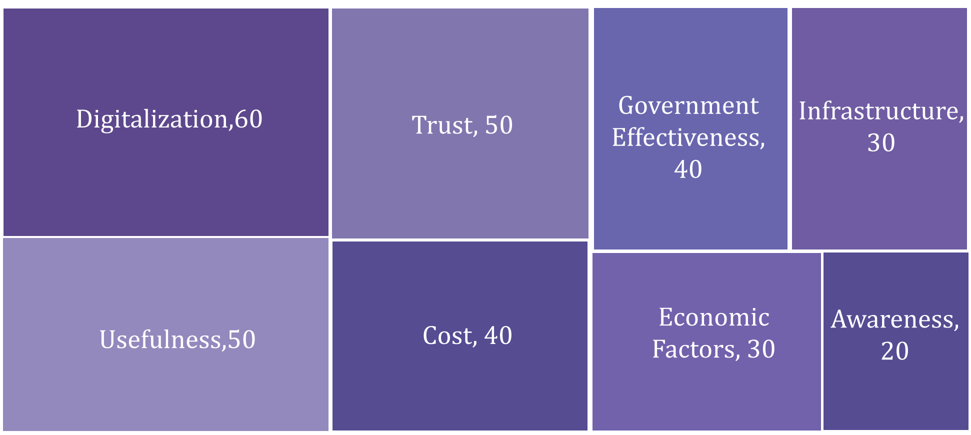
Overall, the research highlighted the usefulness as the most important factor in the adoption of CBDC, followed by ease of use. Academic research also places ease of use and the level of digitalisation encompassing digital literacy as important factors for CBDC adoption all over the world. Trust in the existing financial system and security concerns are also important factors in inducing or hindering the adoption of CBDC. The literature review also highlights that improvement in digitalisation and financial inclusion, increase in payment efficiency, and effectiveness of monetary policy are the most frequently reported benefits of CBDC. Research, including in Pakistan, has also reported enhanced security as one of the most prominent benefits of CBDC. Moreover, CBDC has substantial implications for the monetary transmission mechanism. The synthesis analysis for all the above-mentioned dimensions is presented in Figure 3.1

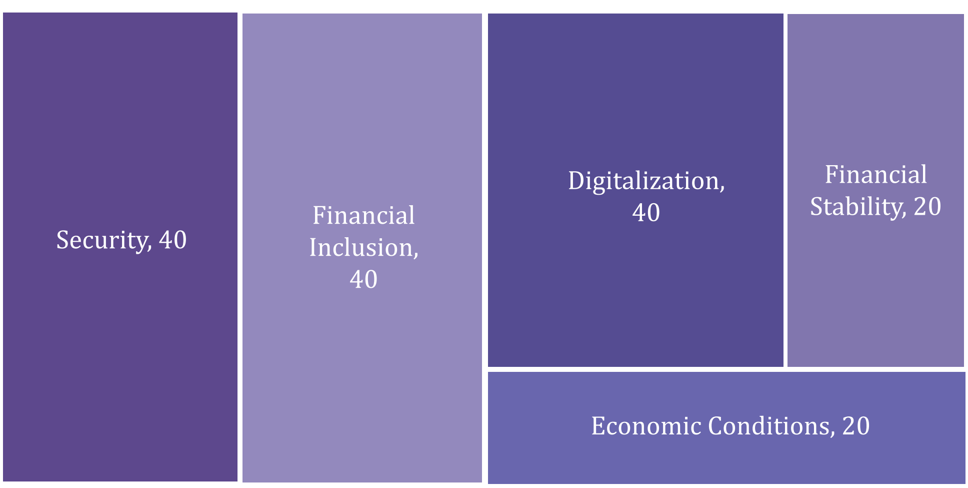
Figure 3.1: Synthesis Analysis

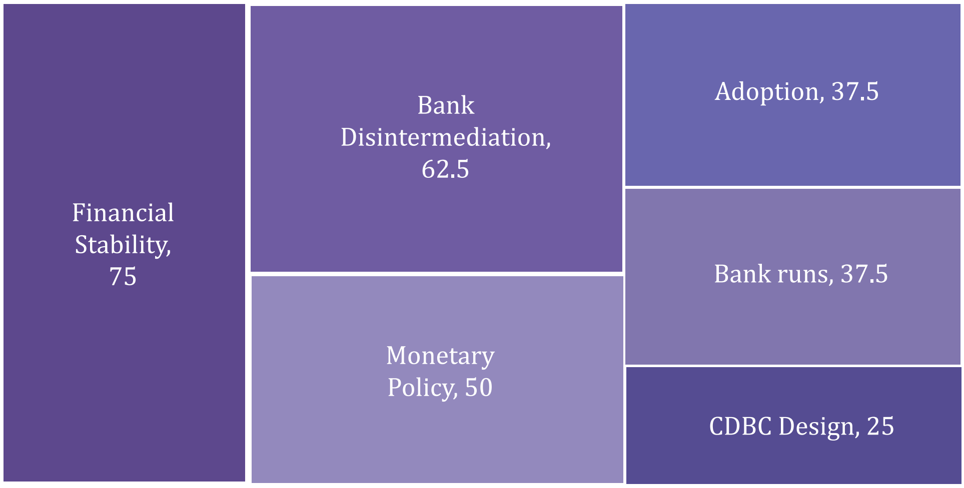




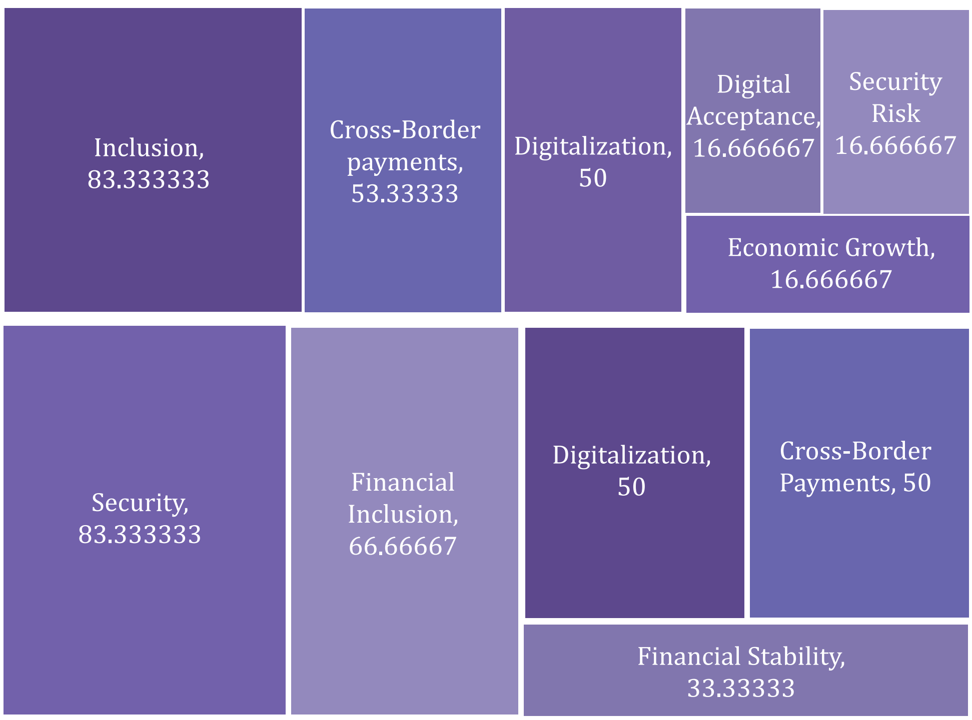
Academic Research







Research Including Pakistan



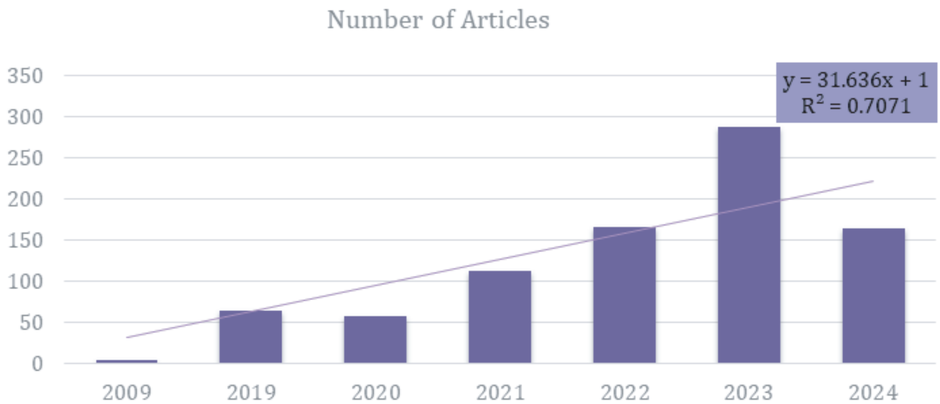
Source: Author's construction.

Bibliographic Mapping

The study employed bibliometric and content analysis to examine the landscape of existing knowledge related to CBDC by using the Scopus database and organising it into periods.

For content analysis, the study adopted a narrative synthesis approach, where the actual content of each research study was used for literature classification. Through network analysis, several frequently occurring keywords in research on CBDC were grouped into clusters. The analysis is presented for 2010–2018 and the most recent years only. Figure 3.2 depicts the number of articles published over time. A trend line is fitted, and the R-squared value is reported to determine the significance of the trend over time. The estimated value indicates that there was about a 71 % increase in publications each year.

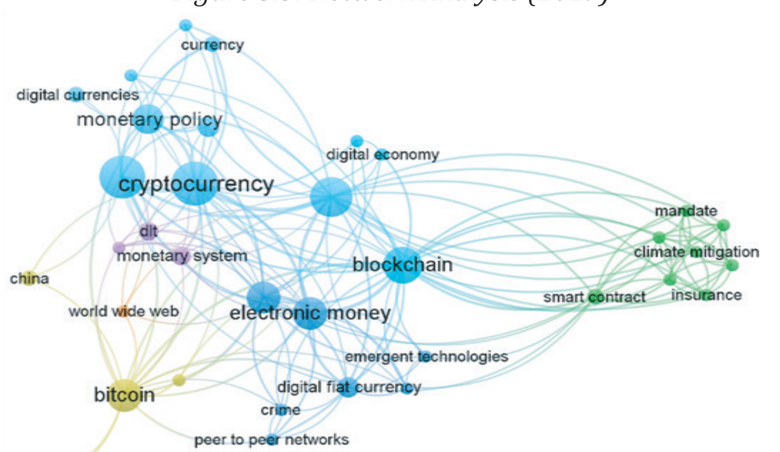
Figure 3.2: Publication Trend



Source: Authors' construction based on Scopus data.

The extent of research is depicted in Figure 3.3 for the period 2010-2018. CBDC, cryptocurrency, digital currency, and monetary policy are the keywords with substantial strength, manifesting the evolution and direction of research undertaken in the field. Moreover, the discussion on use cases and design aspects of CBDC was also initiated during the same period.

Figure 3.3: Network Analysis (2019)



Source: Authors' construction.

Data provide evidence that in 2024, countries reached the advanced phases of exploration (launch, pilot, or development). As of May 2024, functioning CBDCs existed in the Bahamas, Jamaica, and Nigeria. Nevertheless, several countries have pilots, and eight G20 nations are developing CBDC programmes. Prior research has explored various dimensions, emphasising the impact of CBDCs on financial stability and the effectiveness of the monetary policy (Figures 3.4 and 3.5).

Figure 3.4: Network Analysis (2023)

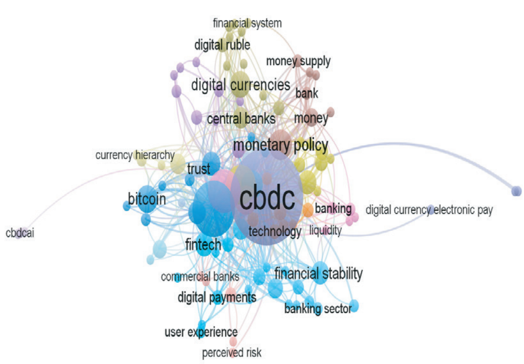
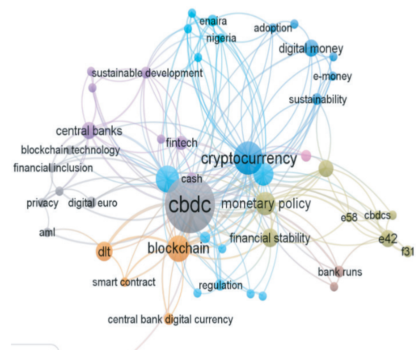


Figure 3.5: Network Analysis (2024)



Source: Authors' Construction.

Systematic Literature Review

The systematic literature review synthesises the findings from previous studies to guide future research paths and policy discussions. It is organised into two distinct sections (institutional research and academic research), each focusing on a specific category of research on CBDCs. We collected studies published in Scopus between 2018 and 2024.

Word Cloud

Institutional Research

The word cloud highlights the most frequently used keywords in banks'/institutional research. The first one is "CBDC". Other words are "cross-border payments", "digital", and 'currency', underlining the importance of international transactions and digital financial systems. The phrases "central", "bank", and "payments" emphasise the role of central banks in CBDC development and execution. Additional prominent terms include interoperability, wholesale, retail, and ledger, which indicate a broad spectrum of uses and considerations in the practical application of digital currencies, from retail transactions to large-scale wholesale activities.

Academic Research

The word cloud represents the theme of central bank digital currency, with the largest and most prominent terms such as “CBDC”, “central”, “bank”, “financial”, “payments”, and “cross-border”, highlighting the fundamental premise of central bank-issued digital currencies and their main function in allowing payments.

The terms digital, infrastructure, services, and system represent CBDC's scientific and service-oriented qualities, implying their capacity to upgrade the financial system and deliver digital financial services. The phrases inclusion and efficiency refer to the advantages of CBDC in terms of payment efficiency and financial inclusion, whereas market, policy, and legal words refer to the regulatory and policy concerns involved in adopting CBDC (Figures 3.6 and 3.7).

Figure 3.6: Word Cloud of Institutional Research

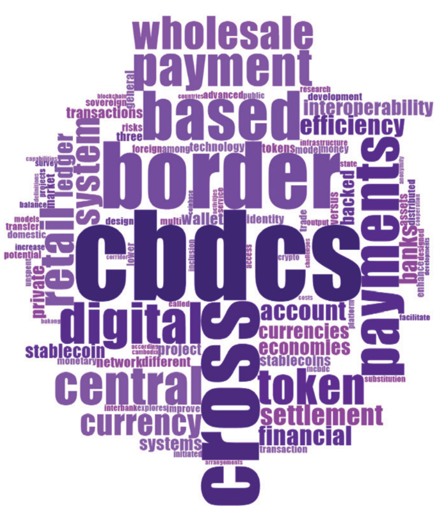
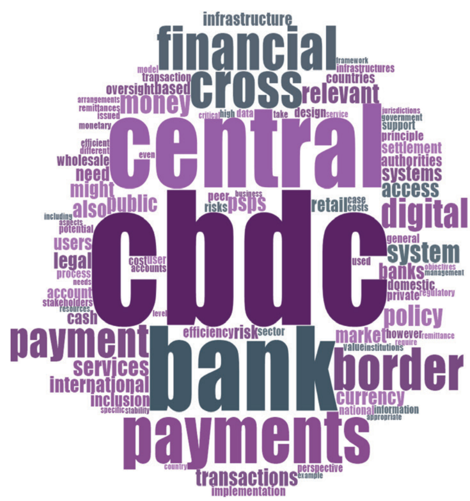


Figure 3.7: Word Cloud of Academic Research

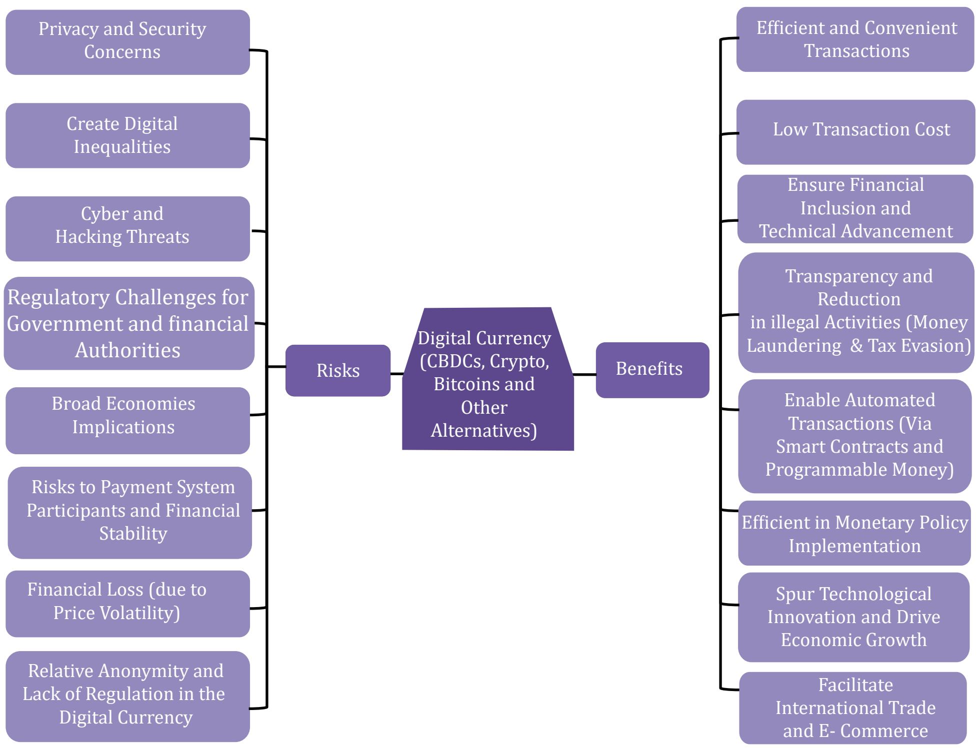


Source: Authors’ construction.

Mind Map

Figure 3.8 presents the mind map of digital currency, which is divided into CBDCs and cryptocurrencies, along with their respective risks/challenges and benefits/opportunities.

Figure 3.8: Mind Map of Digital Currency (2023-2024)



Source: Authors' construction.

4. REGULATORY FRAMEWORK OF PAKISTAN

Following the global trend, the SBP seeks to develop a digital currency with the aim of improving financial inclusion, lowering transaction costs, and offering a more effective and safe payment system by learning from the experiences of other nations. The SBP has stated its intention to create a thorough legal and regulatory framework for CBDCs (GOP, 2022). The existing regulatory framework and amendments required in the framework to launch and manage CBDC are explained in this chapter.

Existing Regulatory Framework of Pakistan

The launch of a CBDC in Pakistan requires a careful evaluation of the SBP's existing legal framework. The State Bank of Pakistan Act of 1856 grants the SBP the authority to issue and regulate physical currency, but this legal framework may not encompass digital forms of currency like CBDCs. According to a comparative analysis of CBDC in different countries, most of the countries that have pursued CBDC have had to amend their central banking laws to account for the unique characteristics of digital currencies. Similarly, Pakistan may need to amend its definition of the "currency" to explicitly include digital forms, as current laws primarily focus on physical currency.

Pakistan's existing laws only recognise cash and bank deposits as legal tender. Therefore, giving the legal tender status to CBDC in Pakistan would also need amendments, as noted in various international studies on CBDC frameworks. For instance, Allen et al., (2022) emphasise that legal recognition of a CBDC as tender is crucial to ensure its universal acceptance for transactions. In addition, while the SBP regulates electronic payment systems under laws like the Payment Systems and Electronic Fund Transfers Act, 2007, this does not fully cover the specific dynamics of CBDCs.

Moreover, CBDCs could influence monetary policy and financial stability. Studies by Auer & Böhme (2021) highlight how CBDCs could alter monetary transmission mechanisms, necessitating revisions to central banks' tools for managing interest rates and money supply. Finally, aligning with international best practices is critical. Countries like China and Sweden have either amended their legal structures or are in the process of doing so to remove legal ambiguities.

Routes to Amending Regulatory Framework

There are two possible routes that the SBP may adopt for amending its regulatory framework to introduce a CBDC. The legislative route, involving amendments to the SBP Act, 1856, would ensure comprehensive legal backing and avoid potential challenges, as suggested by De Gregorio (2021). Alternatively, the ordinance route could be pursued for faster enactment, though it would still require eventual parliamentary approval. These legal adjustments are critical to provide the SBP with the legal authority to issue and regulate a CBDC, ensuring stability in the financial system and resilience in the face of digital currency adoption.

Key Regulatory Authorities for CBDC Conversion in Pakistan

The launch and management of CBDC require coordination between different regulatory authorities.

- State Bank of Pakistan
- Ministry of Finance

- Securities and Exchange Commission of Pakistan (SECP)
- Federal Board of Revenue (FBR)
- National Assembly
- Financial Monitoring Unit (FMU)
- Pakistan Telecommunication Authority (PTA)
- Anti-Corruption Authorities
- International Institutions (IMF, World Bank)

These entities would ensure the legal, economic, technological, and operational aspects of currency conversion are managed in compliance with national and global standards.

5. CBDC AND MACRO-FINANCIAL-TECHNOLOGICAL FACTORS: GLOBAL ANALYSIS AND PAKISTAN'S POSITION

The chapter discusses the first two objectives of the study and provides a qualitative and quantitative scoping review of the global state of CBDC development.

Monetary Indicators and CBDC: Global Analysis

The analysis appraises the status of various monetary indicators, including central bank independence (CBI), monetary policy independence (MPI), exchange rate stability (ERS), and money supply (M2). Figure 5.1 reveals that ERS may be an important predictor of CBDC adoption. It illustrates that countries with fully launched CBDCs exhibit moderate to high ERS (0.52-0.87). In contrast, countries from the proof-of-concept, research, and pilot testing stages show a wide variation in ERS with values ranging from 0.05 to 1.00.

Panels A and B of Figure 5.1 demonstrate that countries that have fully launched CBDCs primarily belong to low and middle-income regions. It includes countries like Nigeria, the Bahamas, and Jamaica. These countries have a moderate level of CBI (0.46-0.58). In contrast, the majority of countries that are in the pilot-testing stage show a broader CBI range (0.28-0.81). Those in the proof-of-concept stage predominantly have moderate CBI scores (0.52

and 0.58). Lastly, the research-stage countries display the highest variation in CBI scores (0.24-0.82). What is striking is that countries with fully-launched CBDCs have the lowest MPI, yet their CBI scores are moderate. Countries in the pilot-testing and research stages have higher CBI, while the proof-of-concept stage countries have the highest MPI.

Overall, the mapping depicts that all groups maintain an average MPI below 0.50, indicating limited MPI across different CBDC stages. The mapping illustrates that higher CBI (MPI) does not predict the CBDC adoption, as countries with higher scores remain in the research or proof-of-concept stages. CBDCs may enhance MPI but could also reduce reliance on commercial banks to improve transmission effectiveness. However, CBDCs may temper the MPI and sovereignty of the central bank if they lead to dollarisation, causing unwanted exchange rate fluctuations.

Additionally, countries that have launched CBDCs fully have the lowest M2/GDP ratio, while countries at the research stage have the highest value, showing CBDCs may affect M2 through various channels, like digital currency substitution and cross-border payments.

Monetary Indicators and CBDC: Case of Pakistan

As per the CBDC Atlantic Trace, Pakistan's goal of issuing a CBDC is to promote financial inclusion and reduce corruption and inefficiency. Pakistan is at the research stage of CBDC development. Figure 5.2 shows that Pakistan's CBI and MPI scores are 0.37 and 0.13, respectively. It is pertinent to note that for CBI, the average score of Pakistan is higher than the minimum average score of countries in the proof-of-concept and pilot-testing stages. Similarly, the average values of M2 (14.8) and the ERS index (0.48) are almost near the research group's average score for these indicators. Therefore, Pakistan's performance in the monetary indicators is moderate and satisfactory.

Financial Indicators and CBDC: Global Analysis

The financial variables for the analysis include financial markets (FM) and FIs' access, depth, efficiency, financial openness index, and financial development index. Figure 5.3. explains that the financial development index of the fully-launched group has the lowest scores, less than 50%, followed by the research group. Notably, the research group attains scores above 50% despite comprising low and middle-income countries. However, countries in proof-of-concept and pilot testing illustrate the strongest financial sectors with index values crossing 80%. These observations indicate that the countries with higher/improved financial sector performance in terms of efficiency, access, depth and openness are still working on the CBDC. On the other hand, the countries where the financial sector is yet to mature have launched CBDC.

Countries with fully launched CBDCs show a wide variation in financial market access (efficiency), ranging between 0.06 and 0.48. The highest score of FM and FI's depth is attained by proof-of-concept and pilot-testing countries, with notable variations due to diverse income levels. Financial openness stays moderate for fully-launched CBDC countries.

Financial Indicators and CBDC: Case of Pakistan

Figure 5.4 demonstrates that Pakistan's performance is relatively better in terms of institutions. In terms of depth, FMs are performing relatively better than FIs. Specifically, financial market efficiency appears encouraging with an average score of 0.62. Similarly, the Financial Development Index (FDI) stands at 0.26. The financial sector of Pakistan, among the research group of CBDC, is among the low-performing countries, as indicated by its average values, except for the FM efficiency. Thus, it may be inferred that CBDC presents an opportunity for Pakistan to bring further improvements in financial infrastructure and architecture, enhance financial inclusion, and improve financial sector efficiency.

Illicit Financial Outflows, Cyber Security, and CBDC: Global Analysis

Figure 5.5 shows that the countries with fully-launched CBDCs have the lowest illicit financial flows, while countries in the research stage have the highest illicit flows, highlighting the benefits attached to CBDCs. Moreover, pilot-testing countries show the highest security levels, while fully launched countries have the lowest. The research group shows relatively better cybersecurity. Due to the sensitivity of CBDCs to cyber threats, central banks must address infrastructural, operational, and user privacy challenges for a smooth adoption of CBDCs.

Illicit Financial Outflows and Cyber Security: Case of Pakistan

Figure 5.6 explains that the average illicit financial flows as a percentage of total flows appear quite low for Pakistan compared to the research group countries. However, it is higher than the average of the pilot-testing and fully-launched groups.

Banking Sector Indicators: Global Analysis

Figure 5.7 shows that the majority of countries are at the lower end of the bank assets, as shown by the lighter shade of the area in Figure 5.7. The bank ratio is lowest in fully launched countries, while it is the highest among pilot-testing countries. CBDC may influence the banking sector in different ways. It may adversely affect the deposit base by introducing an alternative to physical currency and through currency substitution. The bank concentration index is highest for the research-stage countries and lowest for the fully-launched stage countries. Pilot testing and proof-of-concept groups show similar results.

Banking Sector Indicators and CBDC: Case of Pakistan

Figure 5.8 indicates that Pakistan's performance in the banking sector is quite low compared to the average of the research group. Specifically, the situation with the bank assets is quite dismal. Thus, CBDC may provide an opportunity for Pakistan to improve banking sector performance.

Technology Indicator and CBDC: Global Analysis

Digital infrastructure, including mobile cellular subscriptions, fixed broadband subscriptions, mobile services, debit cards, and ATMs, greatly influences the launch and adoption of CBDCs. As depicted in Figure 5.9, mobile phone subscriptions are the highest in the pilot-testing stage countries, followed by research and proof-of-concept groups, while the launched stage countries have the lowest mobile phone subscriptions. A consistent pattern is seen for fixed broadband and mobile service subscriptions. It implies that although having a greater number of mobile users may help in the introduction of digital transaction systems, it is not essential for the CBDC launch. The pilot testing stage has the highest number of debit cards, while most ATMs are in the research-stage countries.

Technology Indicators: Case of Pakistan

Figure 5.10 explains that Pakistan has performed reasonably well in terms of mobile subscriptions and mobile services. The average value of mobile subscriptions is higher than the average value of the research group and equal to the pilot testing group's average value. On the other hand, he average value of mobile services is almost equal to the research group's average. The average value of the number of debit cards is considerably below the average of the research group, but it is above the minimum value of the group. The least-performing areas are the number of ATMs and broadband subscriptions.

Macroeconomic Indicators and CBDC: Global Analysis

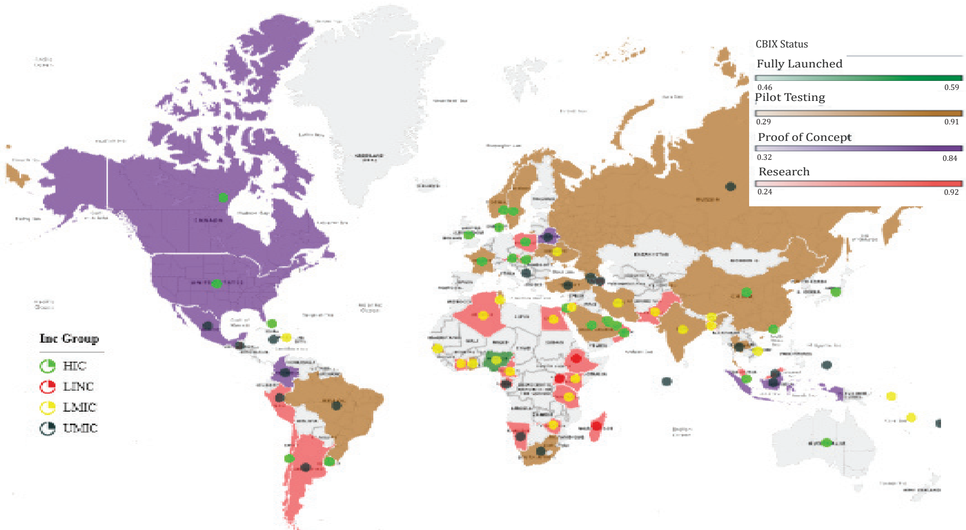
Macroeconomic indicators are categorised into internal and external sectors. The internal sector consists of the consumer price index (CPI), government expenditures, informal economy size, per-capita income (PCI), ease of doing business (EODB), human capital, and literacy rate. Mapping reveals that the research group has the highest PCI growth, but shows a notable decline in this growth. Figure 5.11 explains that the launched group has the lowest PCI growth and inflation rates. Government expenditures and EoDB are highest in the pilot testing group, followed by research, proof-of-concept, and launch stages. Human capital is highest in the proof-of-concept group, with the launched stage having the lowest levels. EODB is the lowest in the fully launched group. The informal economy is seen to be highest in pilot testing countries and smallest in the proof-of-concept stage. There is an unclear relationship between internal sector indicators and CBDC.

External sector indicators are trade openness, foreign direct investment (FDI), and exchange rate stability. Choropleth mapping reveals that the value of FDI and trade openness is highest in the pilot-testing group, followed by the research group, proof-of-concept group, and, lastly, the launched group. External sector performance could be enhanced using CBDCs through more transparent cross-border payments.

Macroeconomic Indicators: Pakistan vs Research Group

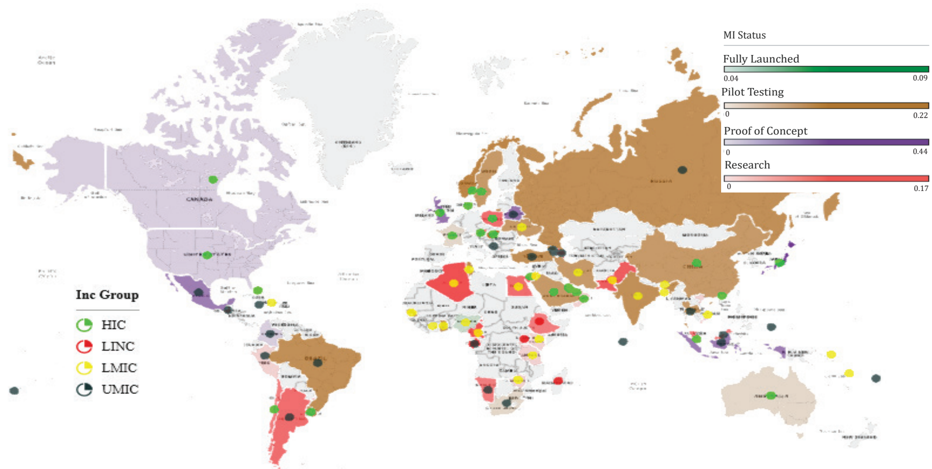
As shown in Figure 5.12, the macroeconomic conditions of Pakistan present a mixed picture, as some of the indicators show a promising trend, whereas the areas direly need substantial improvement. For instance, literacy rate, informal output growth, and per-capita income growth are near the research group's average. Notably, EODB in Pakistan appears near the group average. The average performance of Pakistan in terms of human capital, GE, FDI, and TO is well below the research group, with TO being the least-performing indicator compared to the whole group.

Figure 5.1: Monetary Indicators: Panel A-Exchange Rate Stability Index



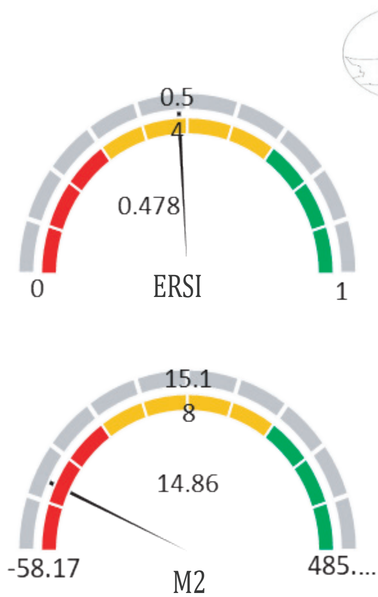
Source: Author's construction.

Figure 5.1: Monetary Indicators: Panel B-Monetary Policy Independence Index



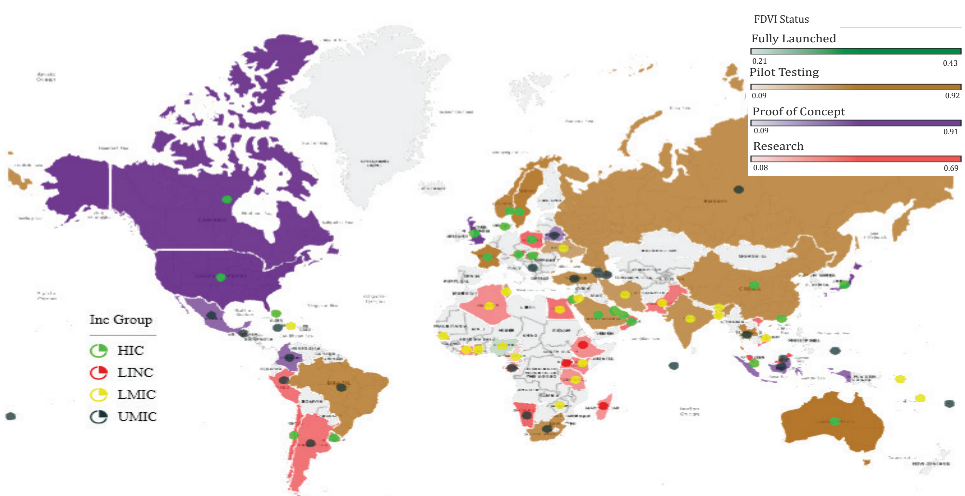
Source: Author's construction.

Figure 5.2: Monetary indicators in Pakistan



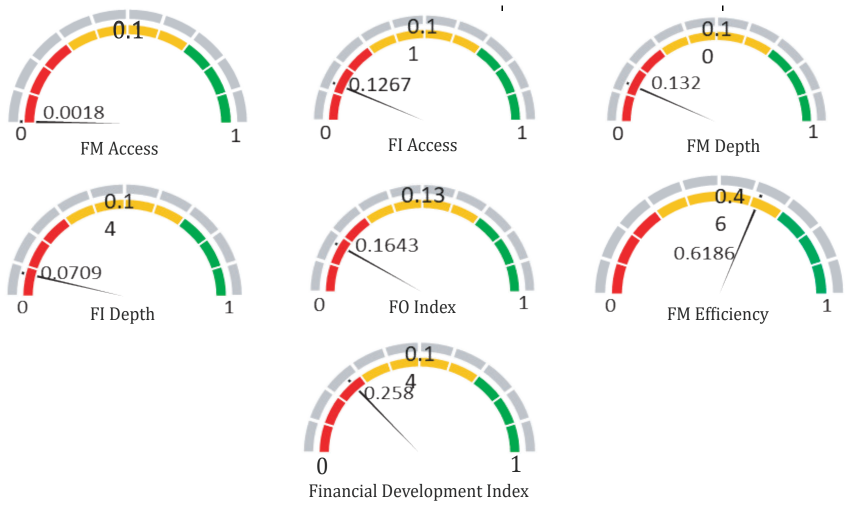
Source: Author's construction.

Figure 5.3: Financial Sector Indicators: Financial Development Index



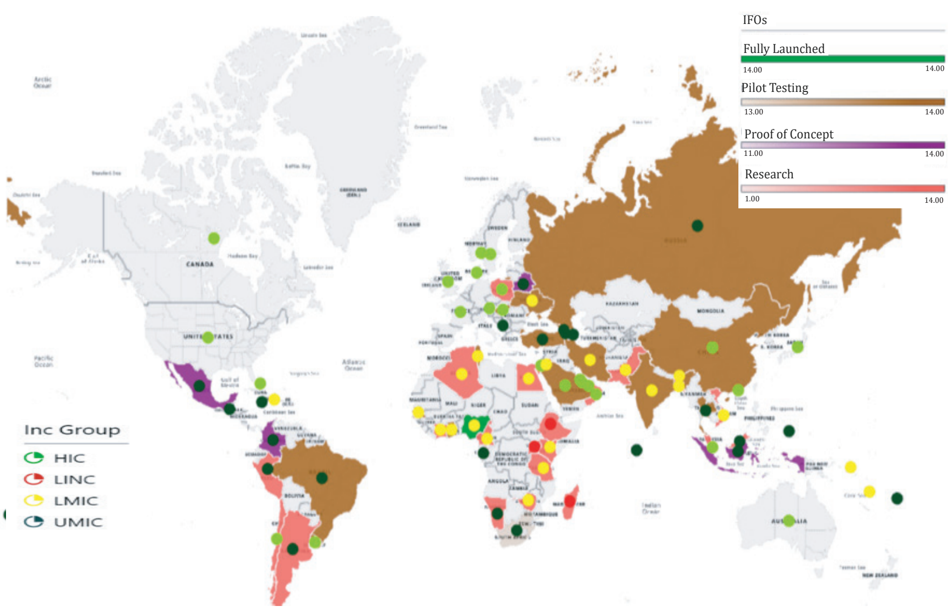
Source: Author's construction.

Figure 5.4: Financial Indicators in Pakistan



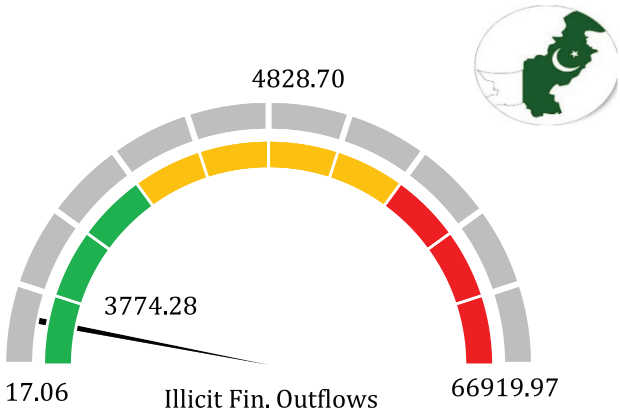
Source: Author's construction.

Figure 5.5: Illicit Financial Outflows



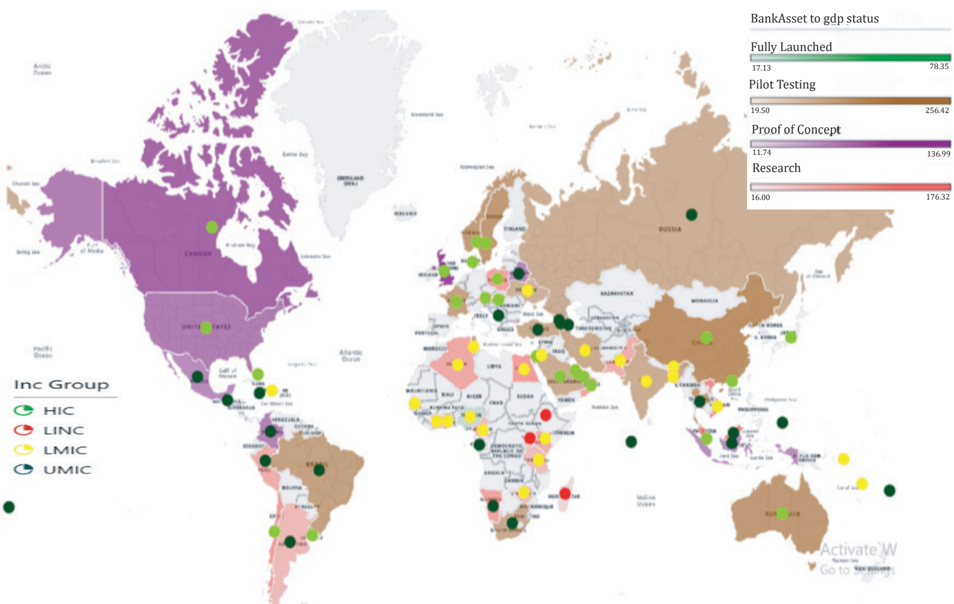
Source: Author's construction.

Figure 5.6: Illicit Financial flows in Pakistan



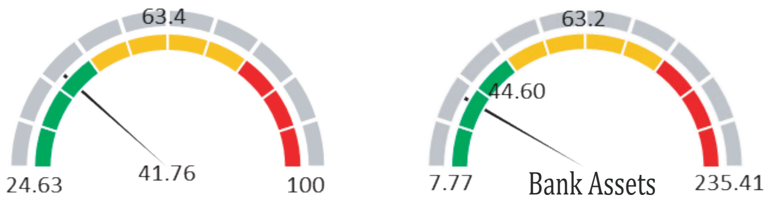
Source: Author's construction.

Figure 5.7: Banking Sector indicators: Panel B. Bank assets to GDP ratio



Source: Author's construction.

Figure 5.8: Bank Indicators in Pakistan

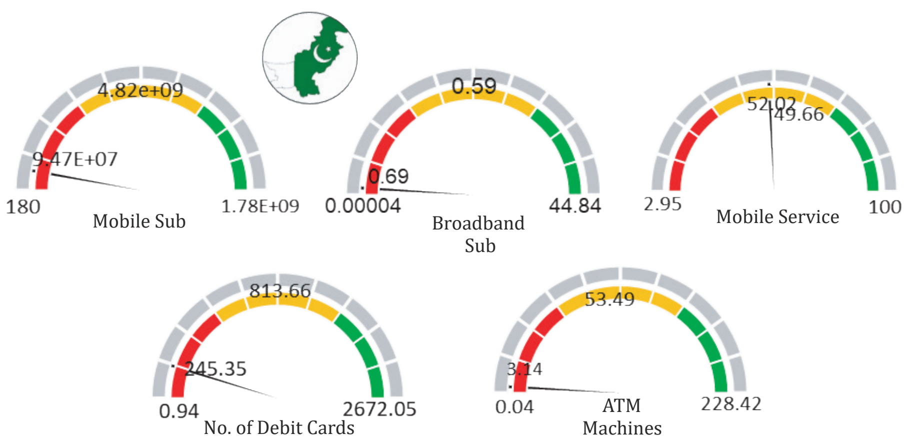


Source: Author's construction.

Figure 5.9: Technology Indicators

Source: Author's construction.

Figure 5.10: Technology Indicators in Pakistan

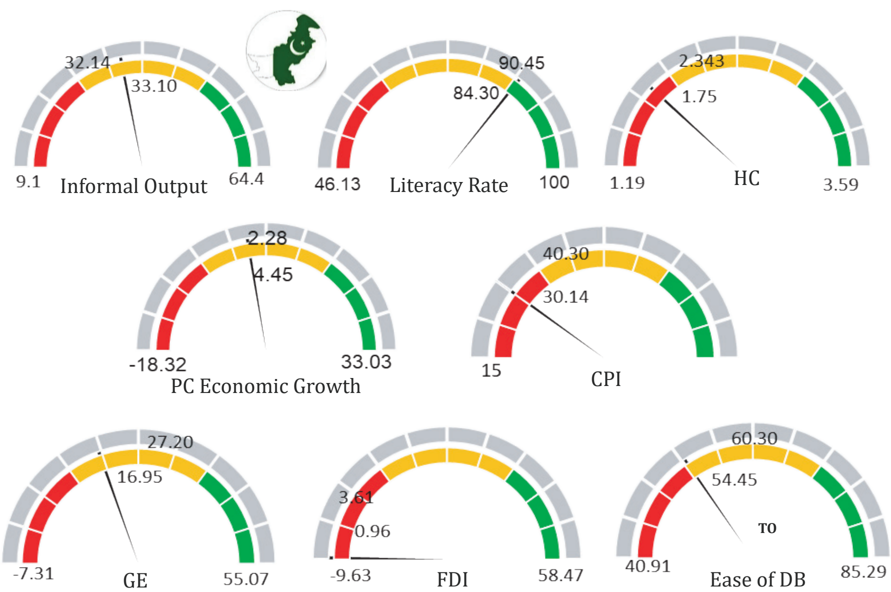


Source: Author's construction.

Figure 5.11: Macroeconomic Indicators: Per capital Income Growth

Source: Author's construction.

Figure 5.12: Macroeconomic Indicators in Pakistan



Source: Author's construction.

6. RESULTS AND DISCUSSIONS: ANALYSIS OF SURVEY DATA

Analyses from the Survey of the General Public

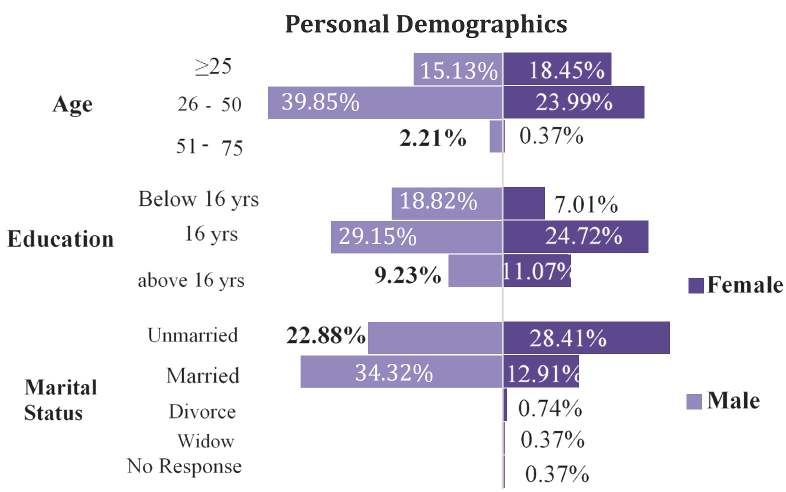
Introduction

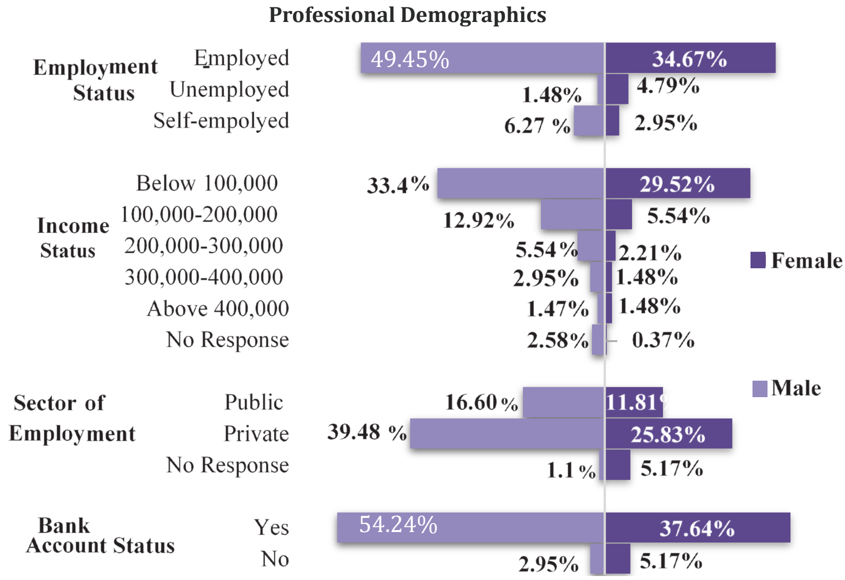
This section presents the analysis and findings from the survey data of 271 general public respondents (155 males and 116 females) from the twin cities of Rawalpindi and Islamabad. The primary objective was to assess the preparedness and acceptability of the general public for the expected implementation of CBDC in Pakistan. The results are presented based on six different dimensions, including (a) perceived benefits, (b) perceived ease of usefulness, (c) challenges and compatibility, (d) the personal innovativeness of the individuals, (e) trust level in the central bank or other banks, and (f) the future considerations of the digital currency.

Demographic Profile of Participants

The demographic profile of the respondents is presented in Figure 6.1. The data shows that the 26-50 age group represented the largest share of both male (38.85%) and female (23.88%) respondents, while males had higher educational attainment. The sample comprised a higher percentage of employed males (48.45%) compared to employed females (34.67%), and they fell in higher income brackets. The majority of participants (62.82%) had an income below PKR 100,000, and the majority were employed in the private sector, while 28.41% were employed in the public sector. A higher percentage of males had a bank account compared to females.

Figure 6.1: Respondents' Demographics



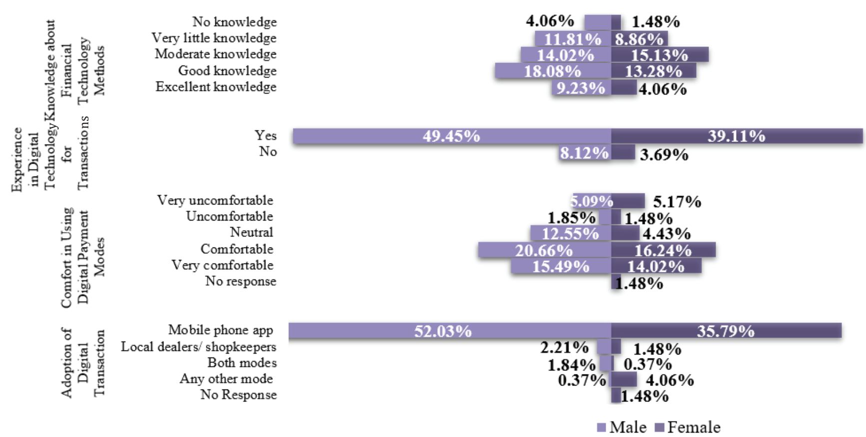


Source: Author's construction.

Knowledge of Digital and Financial Technology

The data on digital knowledge and transaction behaviour of the respondents by gender reveals significant disparities in financial technology usage. A greater percentage of males demonstrated superior knowledge of financial technology, with 35.46% having moderate–to–good knowledge, compared to 26.73% of females. Additionally, 48.64% (30.11%) of males (females) reported prior digital transaction experience, suggesting that gender differences in digital literacy and access to financial services may hinder women's engagement in formal financial systems.

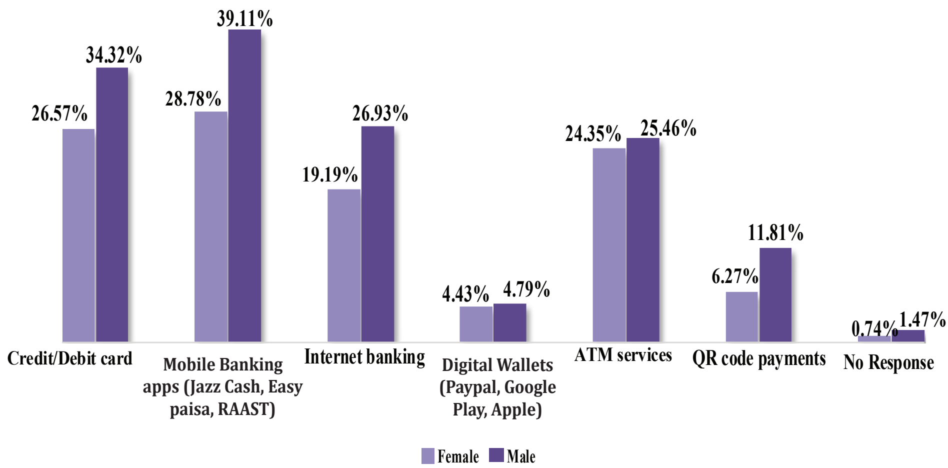
Figure 6.2: Digital and Fintech Knowledge



Source: Author's construction.

A higher percentage of males (36.0 %) expressed greater comfort with digital payment methods as compared to females (30.0%), which likely influences their adoption of various digital transaction tools. Specifically, among various types of digital payment modes, males showed a higher proportion of usage compared to their female counterparts. Notably, the gender gap is widest for the use of mobile banking apps, digital wallets (such as PayPal, Google Pay, and Apple Pay), followed by credit/debit cards and internet banking, while the gap was the narrowest in digital payments and ATM services.

Figure 6.3: Current Mode of Financial Transactions



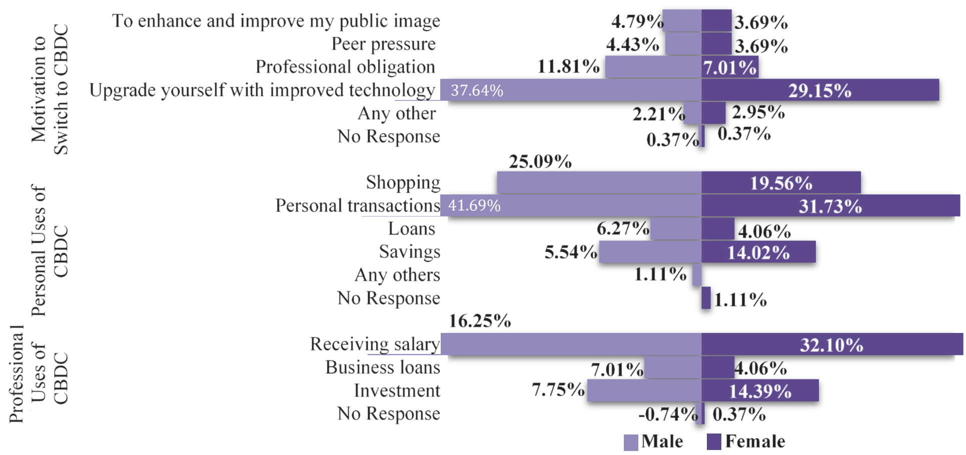
Source: Author's construction.

Awareness/Knowledge about CBDC

Figure 6.4 provides the extent of awareness, knowledge, and readiness to adopt CBDC across genders. A higher percentage of male (32.47) showed familiarity with CBDC as compared to their female counterparts. Both genders primarily turn to social media as their main source of information regarding CBDC, although men showed slightly more interaction with FIs, such as banks, for obtaining CBDC knowledge. Both genders showed equal likelihood of adopting the CBDC.

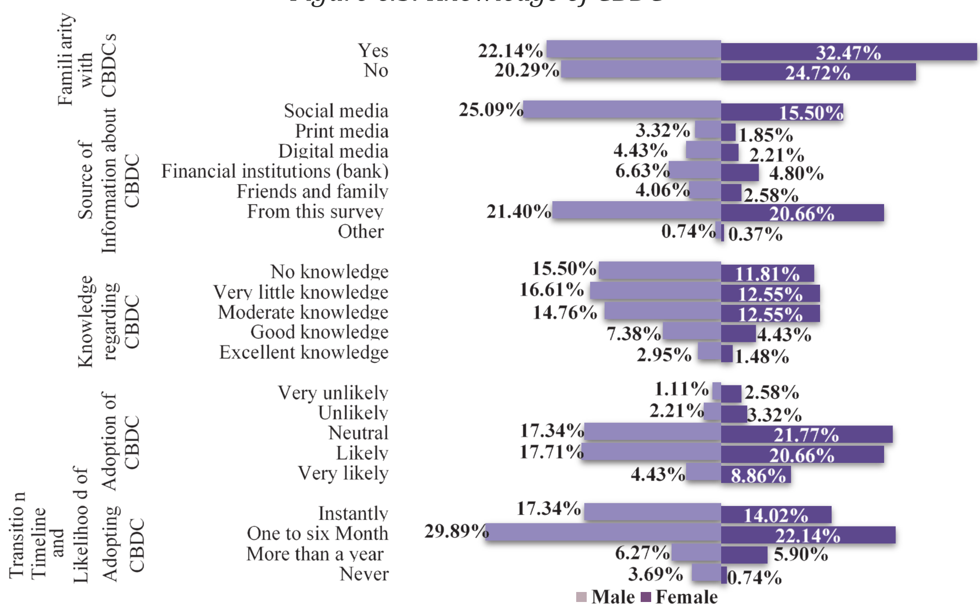
In terms of motivation, both genders stated that they would shift to adopt CBDC to upgrade to improved technology. In terms of personal usage, both males and females (41.68% and 31.73%) prefer CBDC for personal transactions, although females (14.02%) are more inclined to use it for savings than males (5.54%). For professional use, both genders have a comparable interest in receiving a salary through CBDC. Males, however, are more likely than females to use CBDC for business loans (5.27%) and investments (7.57%).

Figure 6.4: Adoption of CBDC



Source: Author's construction.

Figure 6.5: Knowledge of CBDC

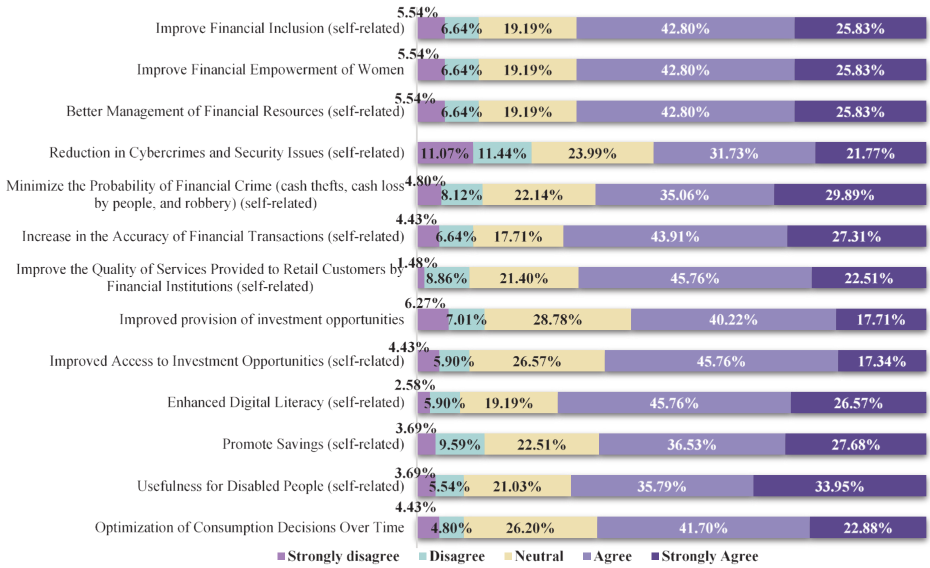


Source: Author's construction.

Relative Advantages and Perceived Usefulness

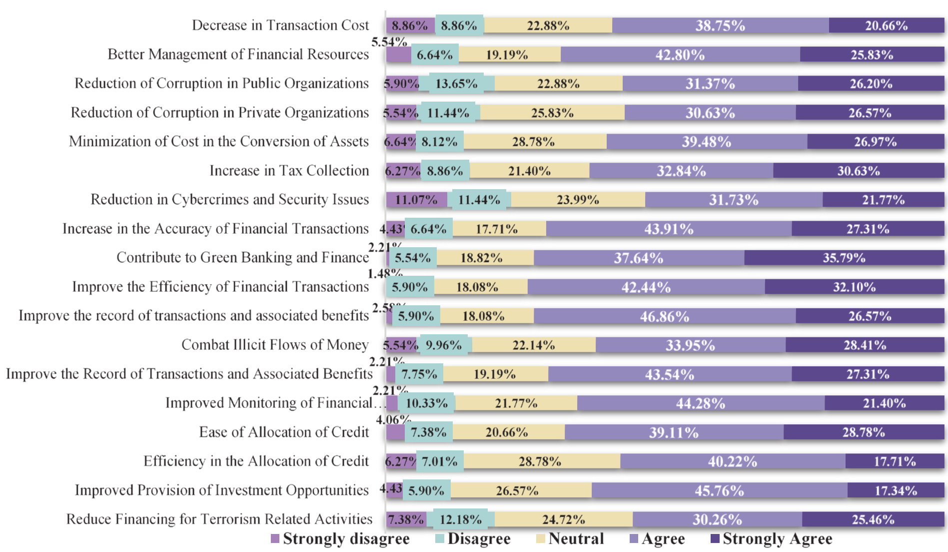
Figure 6.6a depicts that the respondents agreed that CBDC will accrue a range of economic and social benefits. Specifically, at the individual level, the highest percentage of respondents (71%) agreed that CBDC will enhance the accuracy of financial transactions and digital literacy. At the economy-wide level (Figure 6.6b), efficiency in the transaction of credit, green banking, and avoidance of tax are the most alleged benefits of CBDC by the general public. Notably, a reduction in cybercrimes, security, and corruption was considered the least expected advantage of CBDC in Pakistan.

Figure 6.6a: Benefits and Usefulness of CBDC at Individual Level



Source: Author's construction.

Figure 6.6b: Benefits and Usefulness of CBDC at Economy Level

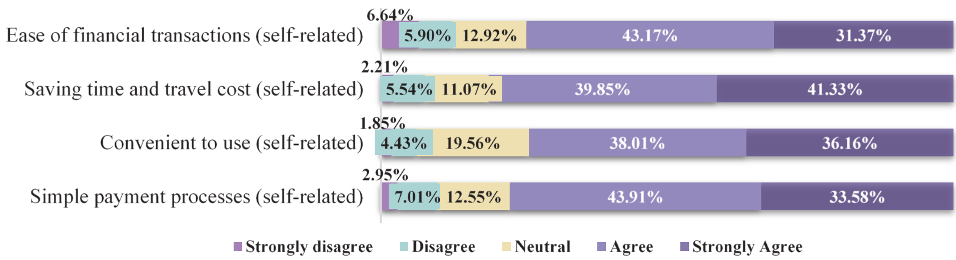


Source: Author's construction.

Perceived Ease of Use

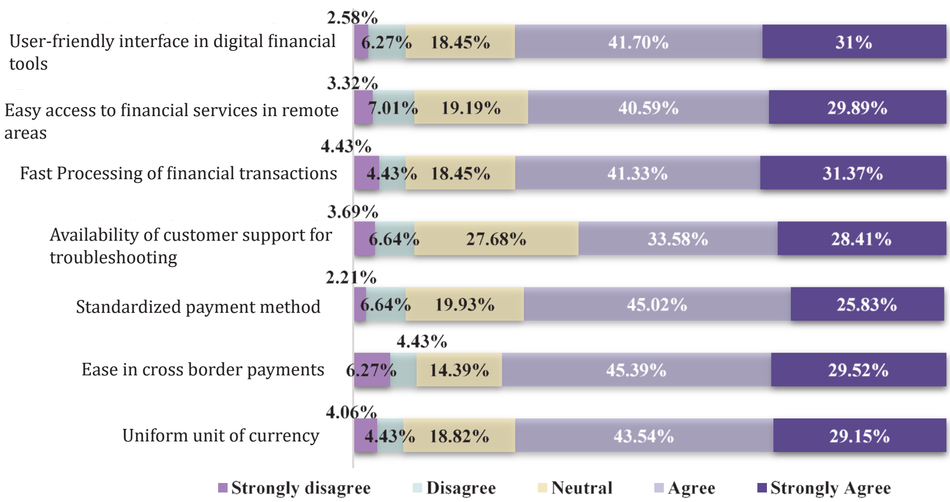
Figures 6.7a and 6.7b represent the perceived ease of use of CBDC at the individual and economy-wide levels. At both individual and economy-wide levels, there is a high perception among respondents (74%) that CBDC will simplify and improve the ease of financial transactions. Similarly, there is a high agreement that CBDC would potentially reduce travel costs and save time (81%). At the individual level, there is a high agreement regarding the simplicity of the payment process (77%, agree and strongly agree combined). The lowest-ranked use of CBDC is customer support for troubleshooting, as reported by the majority of the respondents from the general public.

Figure 6.7a: Perceived Ease of Use at Individual Level



Source: Author's construction.

Figure 6.7b: Perceived Ease of Use at Economy Level

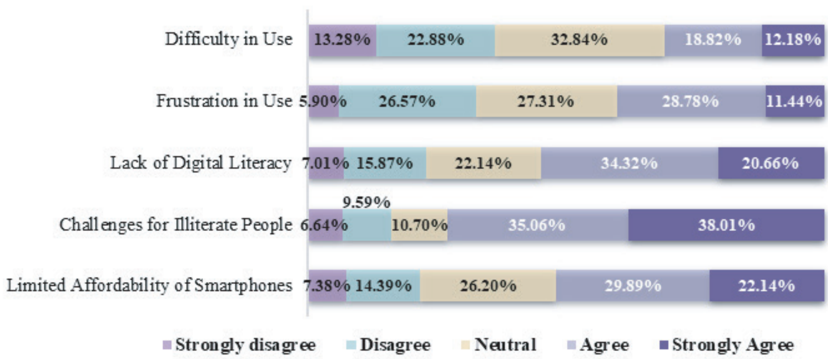


Source: Author's construction.

Challenges/ Complexity

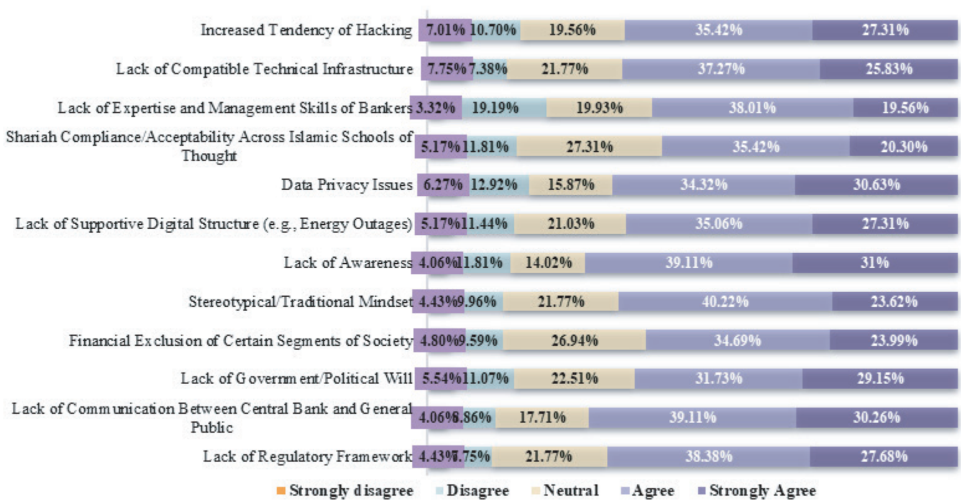
This section offers insights into the perceived challenges regarding the adoption of CBDC. Figures 6.8a and 6.8b present the perceived challenges regarding the use of CBDC at the individual and economy levels. At the individual level, the population with low literacy, lack of digital literacy, and affordability of smartphones pose serious challenges in the implementation of CBDC in Pakistan. At the economy-wide level, lack of awareness and communication between the central bank and the general public, lack of a regulatory framework, and data privacy issues appear as serious obstacles in implementing CBDC in Pakistan. Notably, respondents do not see financial exclusion, political will, and Shariah compliance as serious challenges for the implementation of CBDC in Pakistan.

Figure 6.8a: Perceived Challenges of CBDC at Individual Level



Source: Author's construction.

Figure 6.8b: Perceived Challenges of CBDC at the Economy Level

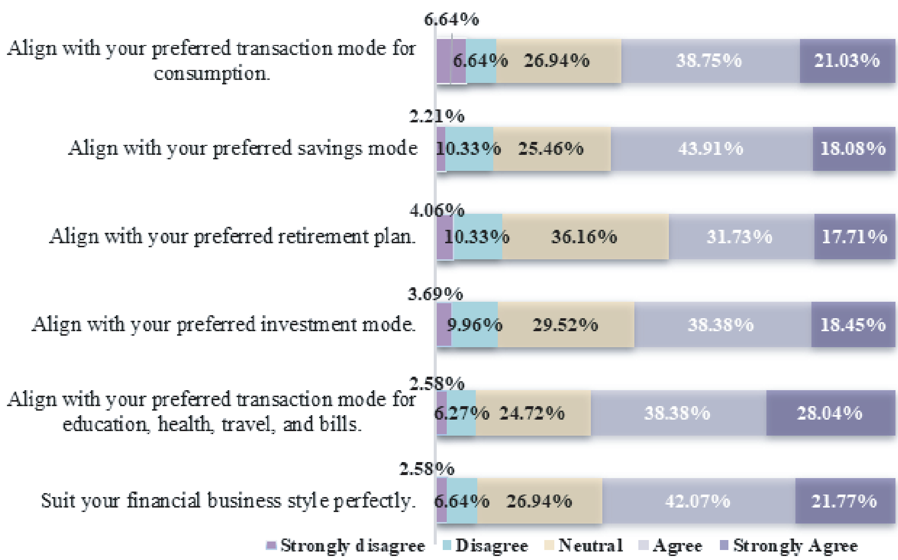


Source: Author's construction.

Compatibility

This section provides how well CBDC aligns with the existing financial management practices and preferences across various aspects. Figure 6.9 presents the compatibility of CBDC with the existing financial modes of transactions. The majority of the respondents believe that CBDC is highly compatible with their preferred mode of transaction used for education, health, and travel-related payments. Similarly, they also agree that CBDC is compatible with their current business styles and mode of savings. However, respondents disagree that CBDC would align with their preferred retirement plans.

Figure 6.9: Compatibility of CBDC

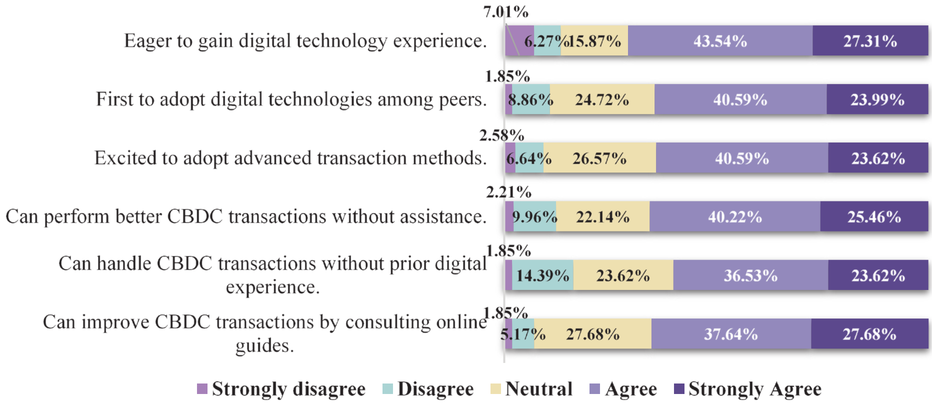


Source: Author's construction.

Personal Innovativeness with digital technology and Digital Self-Efficacy

Figure 6.10 shows the respondents' opinion about the innovativeness of CBDC. About 70% of respondents agreed that they are willing to adopt CBDC because they are eager to gain digital technology experience. They also believed that they could master CBDC-based transactions only by consulting online guides without any further assistance. However, people also showed their concern that the adoption of CBDC would not be easy without any prior digital experience.

Figure 6.10: Personal Innovativeness

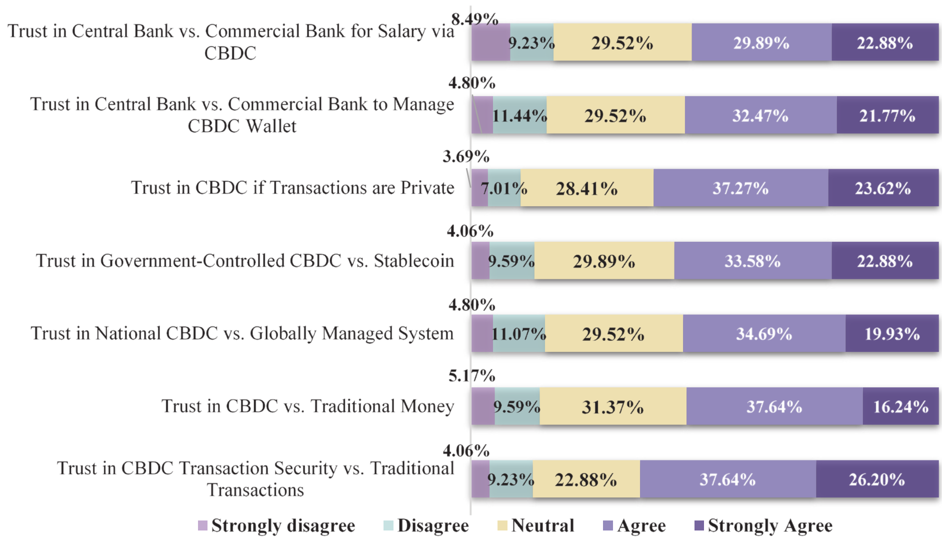


Source: Author's construction.

Level of Trust in CBDC

Figure 6.11 illustrates various dimensions of trust in CBDC compared to traditional financial systems, institutions, and transactions. The perceived trust of the general public will be high if CBDC can offer high transaction security (64%) and privacy (61%) as compared to traditional modes. However, 54% of respondents stated that they were unsure about their trust in CBDC compared to traditional money.

Figure 6.11: Trust Level

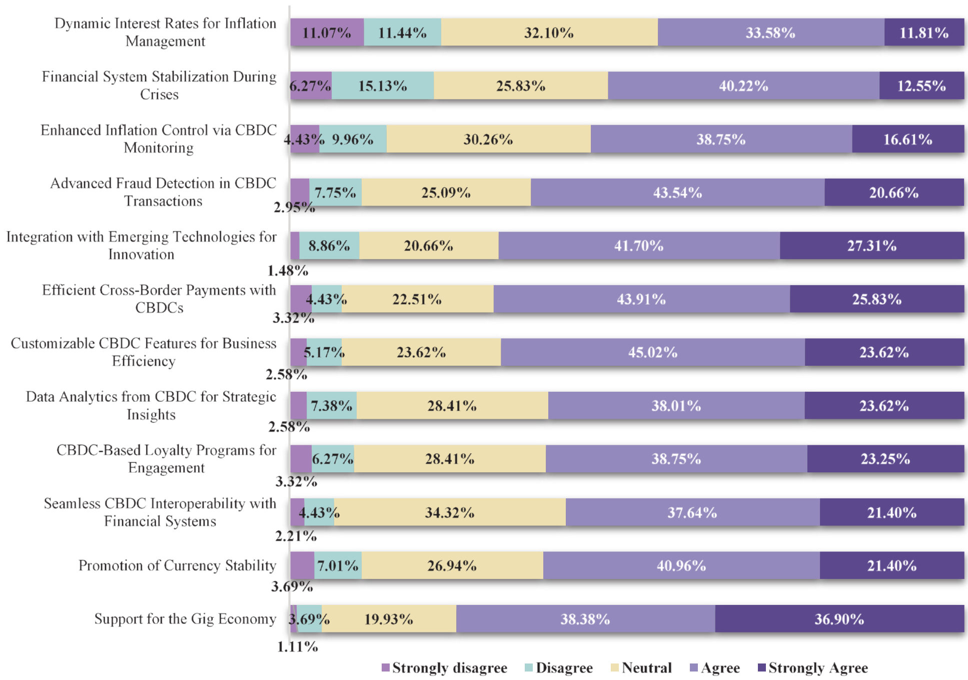


Source: Author's construction .

Future Considerations

Figure 6.22 presents merchants' views on the potential future impact of CBDC. Approximately 88% of the merchants viewed CBDC as pivotal for supporting the gig economy. For the effectiveness of CBDC in countering fraud and enhancing security, promoting emerging technologies for business innovations, increasing efficiency of cross-border payments, increasing business efficiency, and maintaining currency stability in the future, a reasonably high percentage of merchants agreed on the role of CBDC. Merchants, however, disagreed that CBDC could be used for better inflation management.

Figure 6.12: Future Considerations regarding CBDC



Source: Author's construction.

Analysis of the Survey of Merchants/Businesses

Introduction

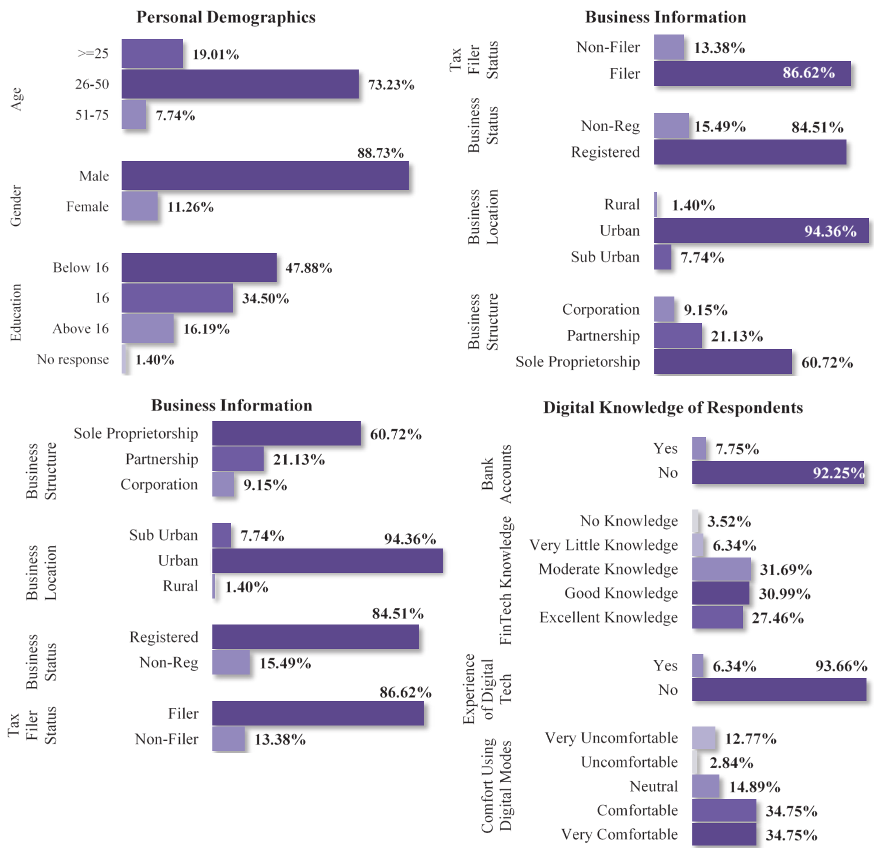
This section presents the findings and insights derived from data collected from businesses and merchants to evaluate their preparedness and acceptance of CBDC. The results are organised around six key themes, namely, (i) benefits of CBDC, (ii) perceived ease of use and utility, (iii) challenges and compatibility with existing practices, (iv) merchants' innovativeness, (v) trust in the central bank and other FIs, and (vi) future outlook on digital currency. The analysis is based on the survey of 142 merchants in Rawalpindi and Islamabad. These merchants are categorised into four groups: wholesalers, retailers, service providers, and manufacturers.

Demographic Profile of Merchants

Figures 6.13 and 6.14 present the demographic profile of merchants. The data shows that the 26-50 age group represents the largest proportion of merchants for both males (88.73%) and females (11.26%). Notably, 52% of the merchants had 16 years of education or higher. The majority of merchants had been doing business for over 10 years, retail business owners dominated the market (44.36%), and about 15% of the merchants were also involved in international dealings. About 61% of the merchants operated under sole proprietorships, while a small proportion (8%) ran corporations. Most of the businesses were registered (84.51%), and 86.62% of merchants were tax filers. Regarding current payment modes that merchants use, ATMs were the most utilised, with 76.80% of merchants, indicating familiarity with digital tools, and also depicting strong inclusion in the financial sector.

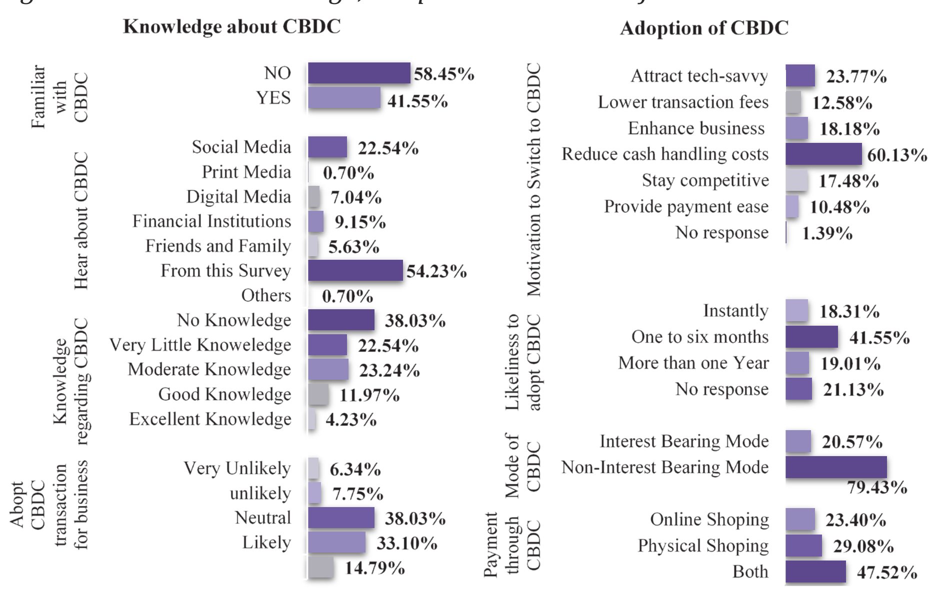
In terms of fintech knowledge, most of the respondents (58%) rated themselves as having good-to-excellent knowledge. 83.66% of merchants had prior experience in dealing with digital transactions. Moreover, 70% of the respondents demonstrated comfort in using digital technology. 76% showed reliance on the traditional mode of payment, i.e., cash/physical currency. Nonetheless, more than 65% were also using mobile banking apps and internet banking for financial transactions. As far as the current mode of payment for personal transactions is concerned, merchants relied mostly on ATMs (76.8%) and mobile banking apps (78.2%). 32% of the merchants had already shifted 40-60% of their transactions to online modes. As far as the adoption of CBDC for business transactions is concerned, almost 50% of merchants found it very likely to happen. About 60% of the respondents had little or no knowledge of CBDC. For the rest, the main source of information on CBDC remained social media. The primary motivation for adopting CBDC cited was to reduce the cost of cash handling, followed by the desire to satisfy tax-savvy customers, lower transaction fees, and maintain competitiveness. About 42% of the merchants showed willingness to adopt CBDC within 1-6 months, while others said they might take more than one year. Notably, 18.31% intended to shift to CBDC instantly. The majority of the respondents (78.40 %) preferred a non-interest-bearing CBDC, while 50% said that they would like to use CBDC for online and physical shopping.

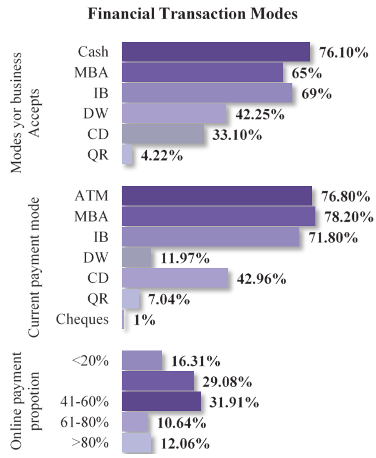
Figure 6.13: Respondents' Demographics and Digital Information



Source: Author's construction.

Figure 6.14: CBDC Knowledge, Adoption and Modes of Financial Transactions



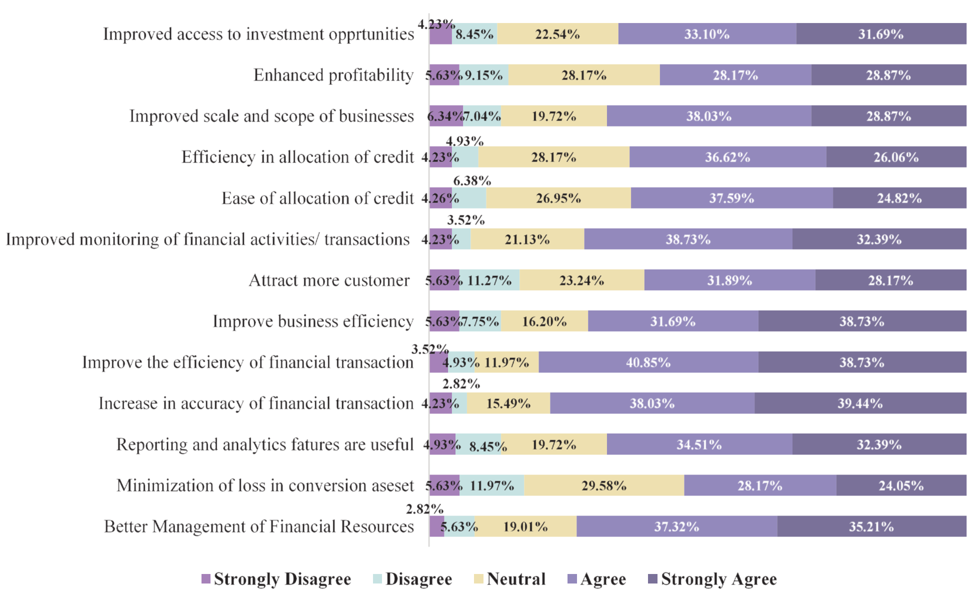


Source: Author's construction.

Relative Advantages and Perceived Usefulness

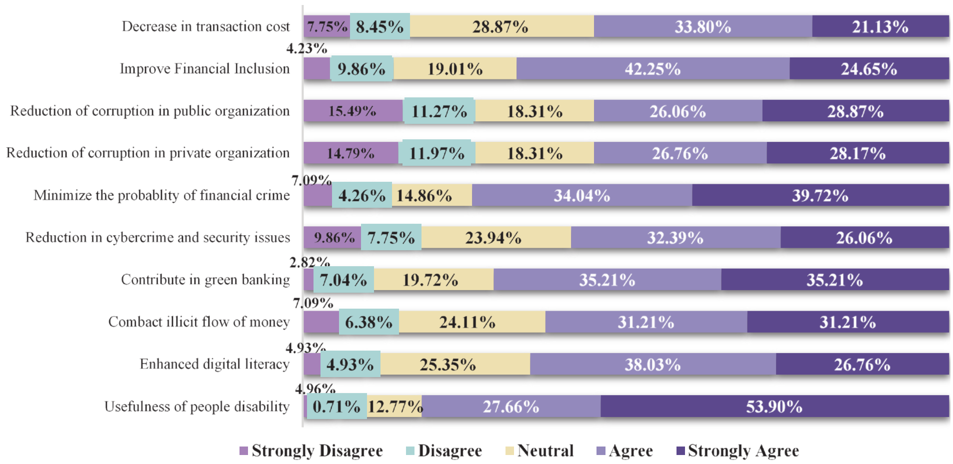
Figure 6.15 explains the perception of merchants of the potential advantages of CBDC over traditional banking systems. The analysis of relative advantages has been further broken down into two dimensions, namely, benefits at the economy-wide level and benefits at the business level. Accuracy and efficiency of financial transactions, along with better management of financial resources, appeared to be the most promising benefits of CBDC. However, respondents did not consider CBDC useful for the minimisation of loss in asset conversion, attracting more customers and increasing the profitability of the business as potential benefits of CBDC.

Figure 6.15: Benefits and Usefulness of CBDC at Business Level



Source: Author's construction.

Figure 6.16: Benefits and Usefulness of CBDC at Economy Level



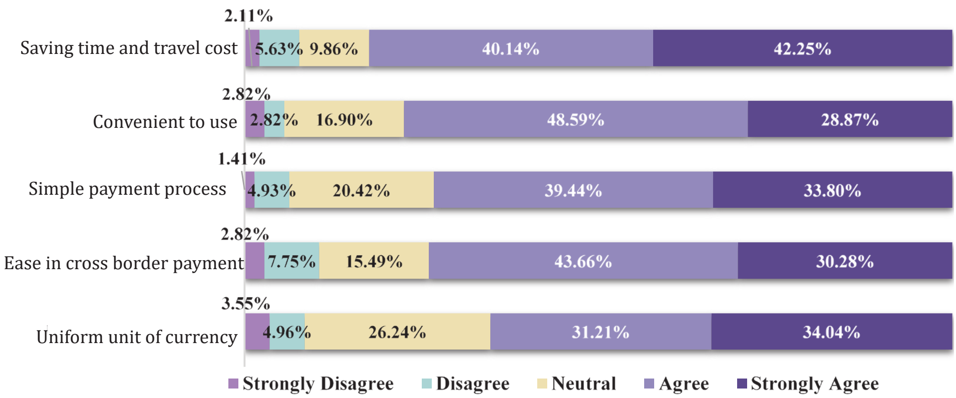
Source: Author's construction.

At the economy-wide level, minimising the probability of financial crimes, improving financial inclusion, and green banking were cited by merchants as the most likely potential benefits of CBDC. On the other hand, merchants did not consider CBDC to be useful for people with disabilities. Moreover, a decrease in transaction costs and a reduction in corruption in public and private organisations could not earn substantial agreement from the merchants.

Perceived Ease of Use

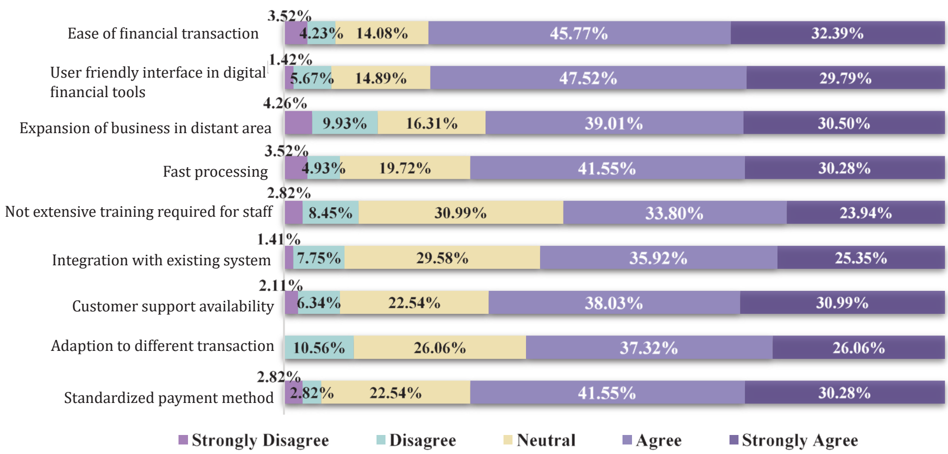
Figure 6.17 provides a breakdown of respondents' opinions on the perceived ease of use of CBDC at the individual and macro levels. At both the individual and the economy-wide levels, approximately 82% of merchants agreed that CBDC would save time and reduce travel costs due to the ease of remote digital transactions. Moreover, CBDC was also perceived by a vast majority of merchants (74%)to create ease in cross-border payment. At the economy-wide level, a substantial proportion of merchants cited ease in financial transactions (78%), user-friendly interface (77%), fast processing in financial transactions (72%), and standardised payment methods (71.8%) as the potential benefits of introducing CBDC.

Figure 6.17a: Perceived Ease of Use at Individual Level



Source: Author's construction.

Figure 6.17b: Perceived Ease of Use at Economy Level

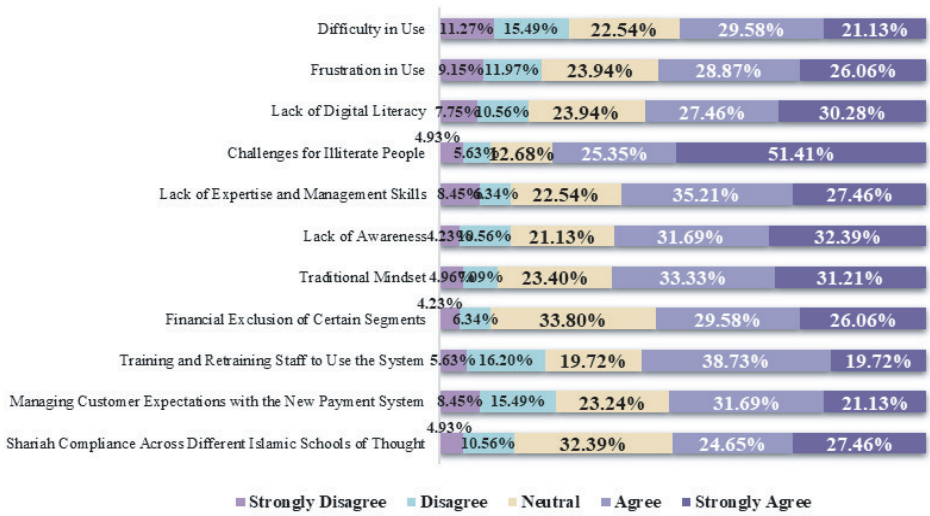


Source: Author's construction.

Challenges/Complexity

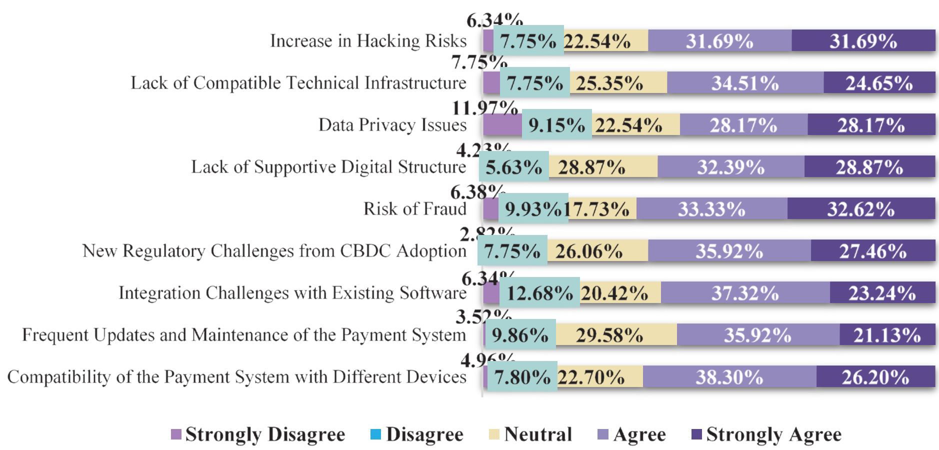
Figures 6.18a and 6.18b present merchants' insights related to the perceived challenges posed by adopting CBDC in Pakistan. At the individual level, illiteracy (77%), traditional mindset (64%), lack of awareness (63%), lack of expertise and management skills (63%), and lack of awareness (63%) appeared as important factors that can pose a challenge to the implementation of CBDC. At the economy-wide level, the risk of fraud (66%), compatibility of the payment system (65%), and risk of hacking (64%) appeared as crucial factors that can threaten the implementation of CBDC.

Figure 6.18a: Challenges of CBDC at the Individual Level



Source: Author's construction.

Figure 6.18b: Challenges of CBDC at the Economy Level

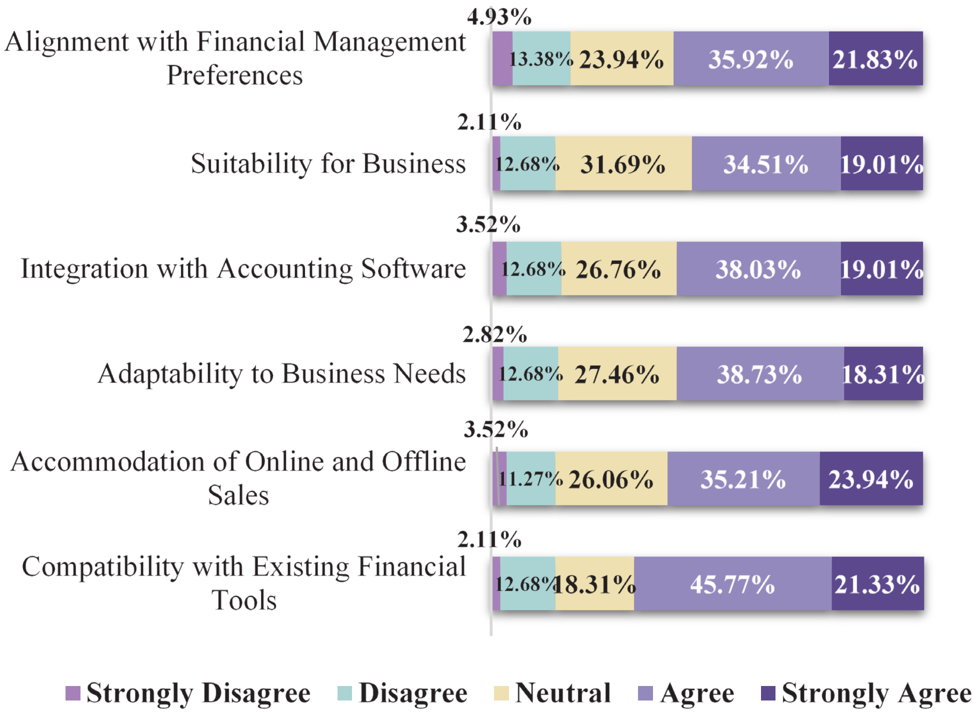


Source: Author's construction.

Compatibility

Figure 6.19 explains merchants' perspectives on the compatibility of CBDC in businesses in Pakistan. About 67% of merchants perceived CBDC as compatible with existing financial tools. They also saw CBDC as well aligned with financial management preferences and highly adaptable to business needs. Merchants also reported that CBDC can accommodate both online and offline sales and can be integrated with existing accounting software.

Figure 6.19: Compatibility of CBDC

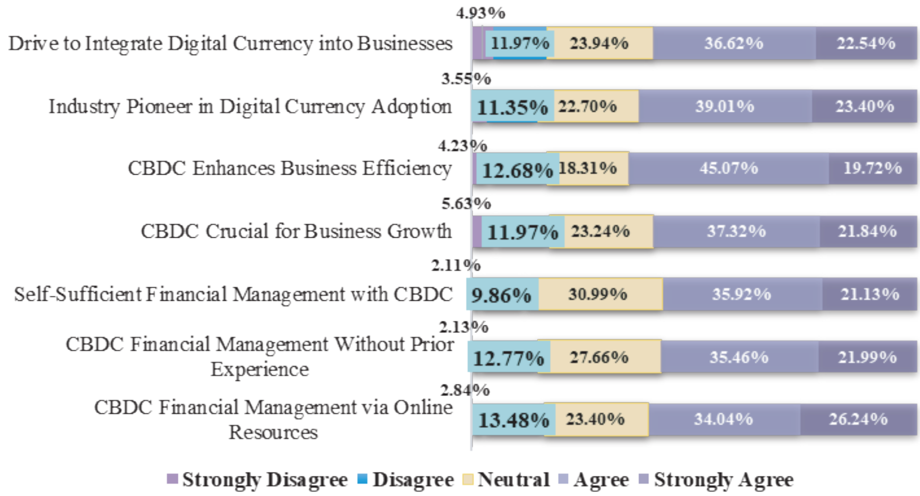


Source: Author's construction.

Personal Innovativeness with Digital Technology and Digital Self-Efficacy

Figure 6.20 shows the role of personal innovativeness in the adoption of CBDC. Approximately 65% of merchants expressed their belief that CBDC will enhance business efficiency, and 61% of the merchants showed interest in the adoption of CBDC to become pioneers in the use of digital currency. CBDC's financial management for online resources and the drive to integrate digital currency into businesses also appeared as highly agreed-upon factors.

Figure 6.20: Personal Innovativeness of CBDC at Businesses

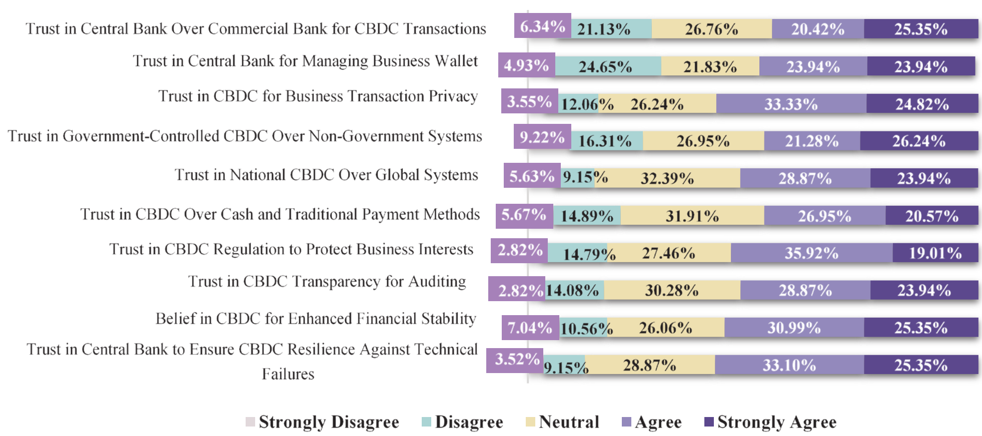


Source: Author's construction.

Level of Trust in CBDC

Figure 6.21 shows the trust of merchants in the management and operation of CBDC. Business transaction privacy, as well as trust in the central bank to ensure CBDC resilience towards technical failure, were viewed as the most important trust factors. However, people did not show their trust in government-controlled CBDC compared to non-government systems, nor did they show substantial trust in CBDC over cash and traditional payment methods.

Figure 6.21: Trust Level on Banks regarding CBDC

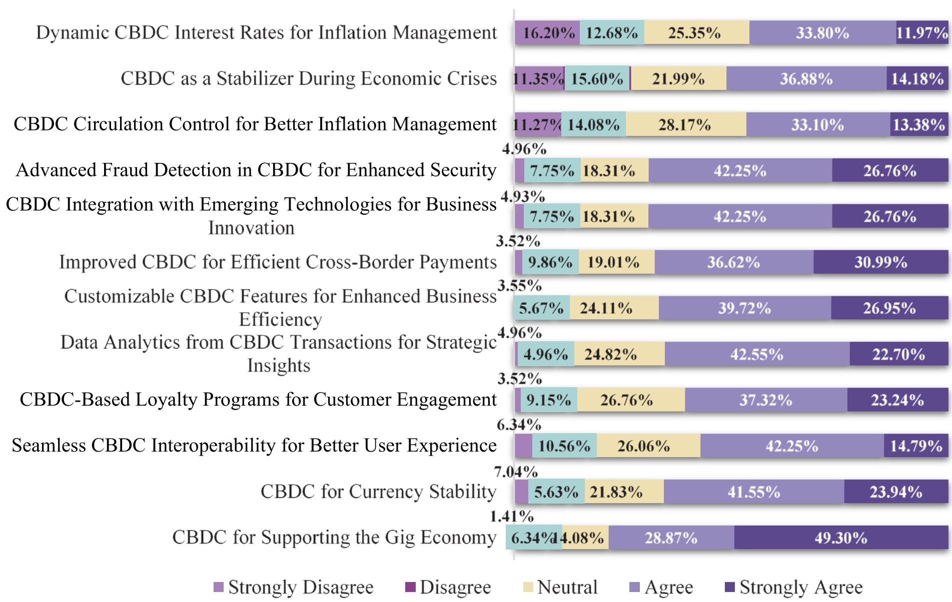


Source: Author's construction.

Future Considerations

Figure 6.22 presents merchants' views on the potential future impact of CBDC. Approximately 88% of the merchants viewed CBDC as pivotal for supporting the gig economy. For the effectiveness of CBDC in countering fraud and enhancing security, promoting emerging technologies for business innovations, increasing efficiency of cross-border payments, increasing business efficiency, and maintaining currency stability in the future, a reasonably high percentage of merchants agreed on the role of CBDC. Merchants, however, disagreed that CBDC could be used for better inflation management.

Figure 6.22: Future Considerations of CBDC



Source: Author's construction.

Analysis of the Survey of the Financial Institutions

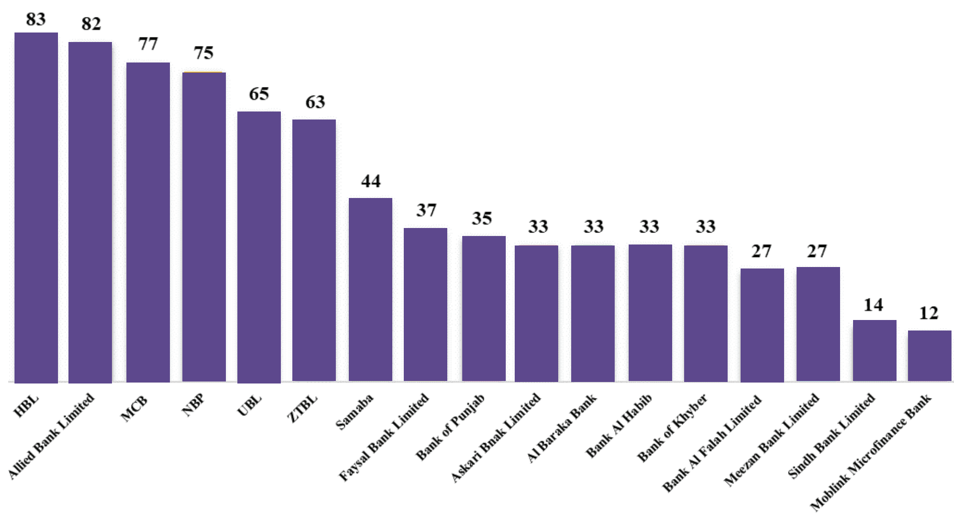
Introduction

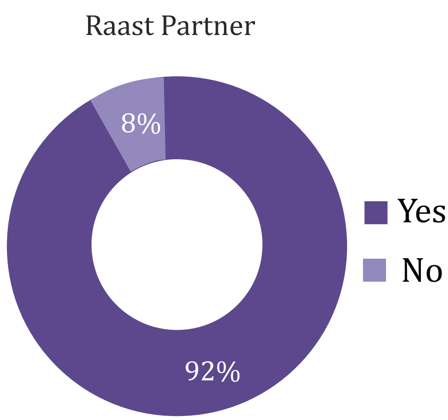
The survey included 38 banks and non-bank financial institutions in Rawalpindi and Islamabad to gain insights into the level of experience in the digital finance sector, as the State Bank of Pakistan moves towards the introduction of CBDC.

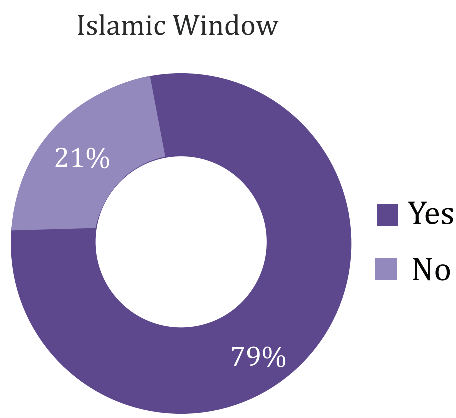
Profile of Financial Institutions

Figure 6.23-6.25 shows the profile of FIs. Of the total 38 financial institutions surveyed, the oldest FIs are HBL and Allied Bank Limited, whereas Mobilink Individual Finance Bank is the youngest at 12 years old. 82% of these FIs are RAAST partners, and 78% operate in both conventional and Islamic modes. Under both modes, conventional FI provides a diverse range of digital products, including mobile and internet banking, credit/debit cards, ATMs, digital wallets, and other apps. 32% of the FIs reported having received training on digital financial services, and only 27% had attended seminars conducted by the SBP. 32% of the FIs had the experience of dealing in digital currency.

Figure 6.23: Age of Financial Institutions

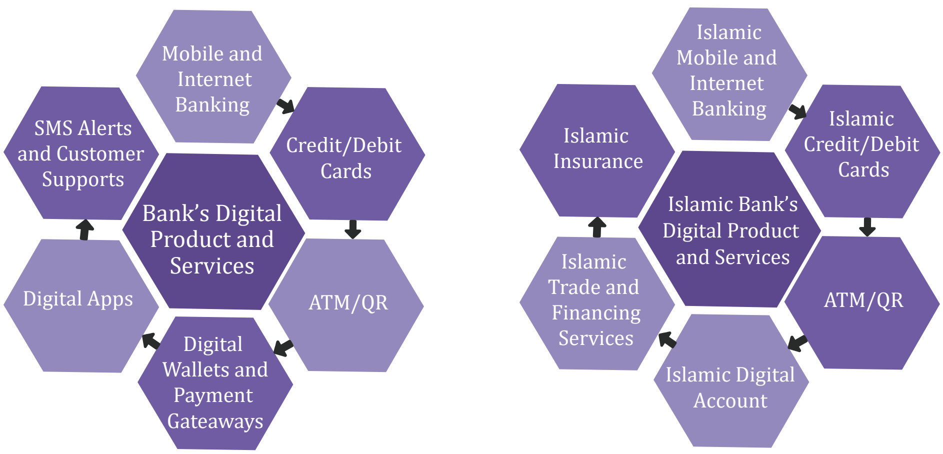






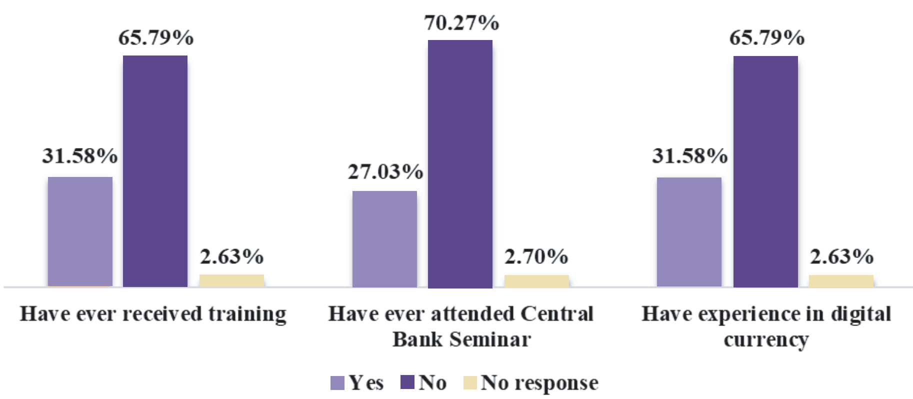
Source: Author's construction.

Figure 6.24: Digital Products and Services of Banks



Source: Author's construction.

Figure 6.25: Bank's Experiences Regarding Digital/Financial Technology

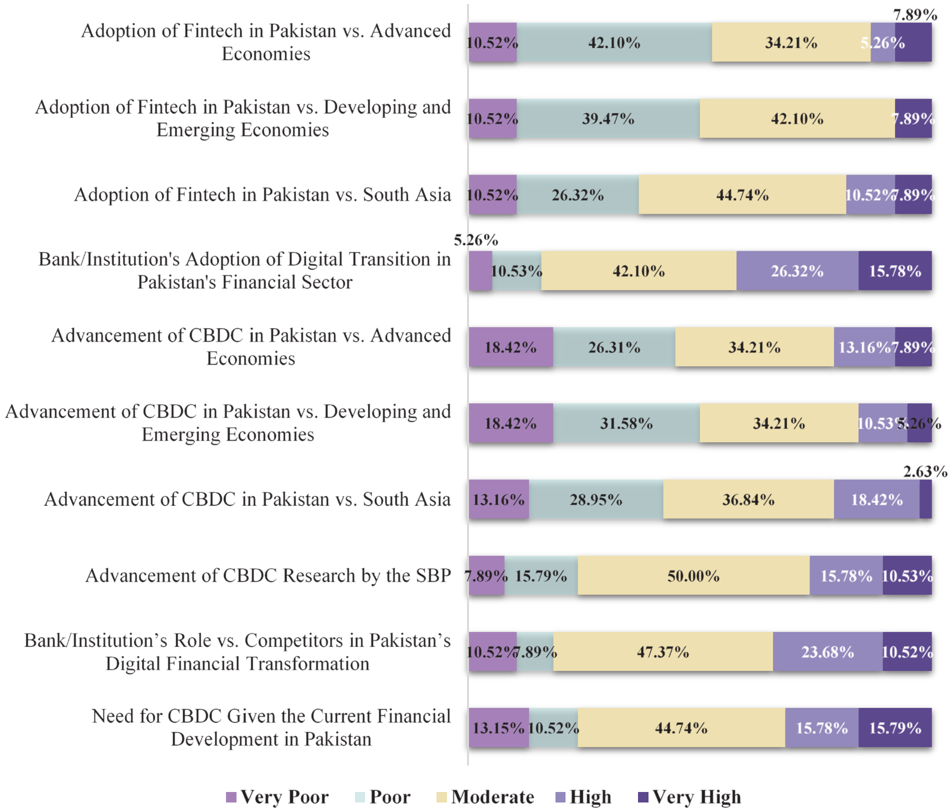


Source: Author's construction.

Perception of Fintech and CBDC

Figure 6.26 presents the perception of FIs about financial technology. About 14% (8%) of the respondents considered the adoption of fintech in Pakistan comparable to other advanced (emerging) economies around the globe. Most of the responses in this regard revealed moderate adoption of fintech in Pakistan. Similarly, the advancement of CBDC in Pakistan compared to other countries, specifically South Asian countries, was deemed significantly low (20%). Only a small proportion of the respondents (26%) considered a moderate level of research by the SBP on the advancement of CBDC. Similarly, 32% of the respondents viewed CBDC as essential for financial development

Figure 6.26: Respondents' Perceptions of Fintech and CBDC



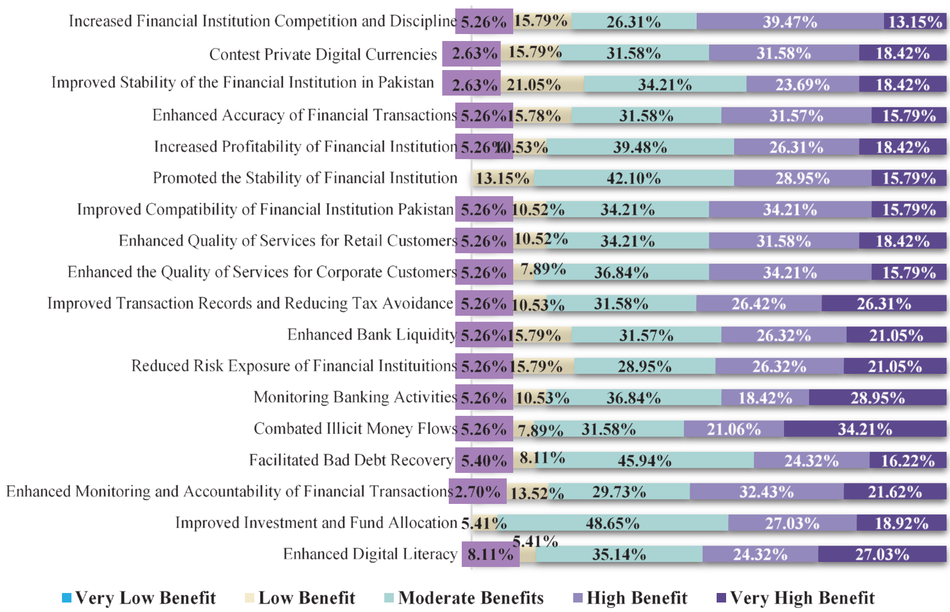
Source: Author's construction.

Potential Benefits of CBDC

Figure 6.30a displays the potential benefits of CBDC at the bank level, from FIs' perspective. The majority of the respondents (more than 50%) considered CBDC as an effective tool for countering illicit financial flows, increasing bank competition and discipline, enhancing monitoring and accountability of financial transactions, reducing tax avoidance, and increasing digital literacy. Nonetheless, recovery of bad debt, improving financial stability, improvement in investment and funds allocation, profitability, and stability of banking sectors were not viewed as potential benefits of CBDC by the majority.

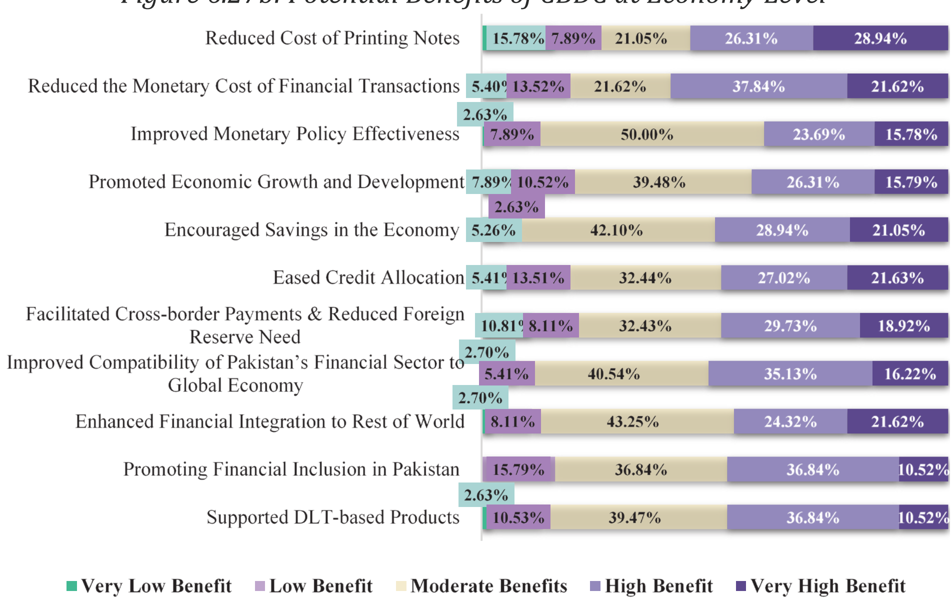
At the economy-wide level (Figure 6.30b), reducing the monetary cost of financial transactions and improving the compatibility of Pakistan's financial sector with the global economy received the majority of responses. A vast majority (60%) believed that CBDC does not have the potential to increase the efficacy of monetary policy, nor can it be a significant driver of economic growth and development.

Figure 6.27a: Potential Benefits of CBDC at Financial Institutions Level



Source: Author's construction.

Figure 6.27b: Potential Benefits of CBDC at Economy Level

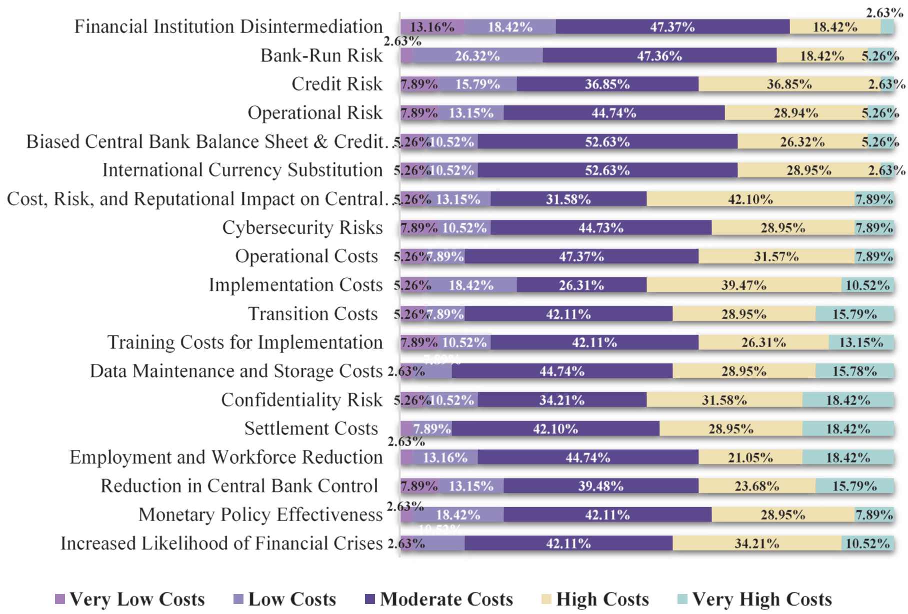


Source: Author's construction.

Potential Financial and Economic Costs/Risks

Figure 6.28 shows the survey responses regarding the financial and economic costs of CBDC. The most important cost of CBDC was considered to be the implementation cost, risk, and reputational impact of CBDC, confidentiality risk, increase in the likelihood of a financial crisis. On the other hand, respondents are of the view that bank disintermediation and bank run risk may not appear as adverse implications of CBDC.

Figure 6.28: Potential Costs and Risks Associated with CBDC



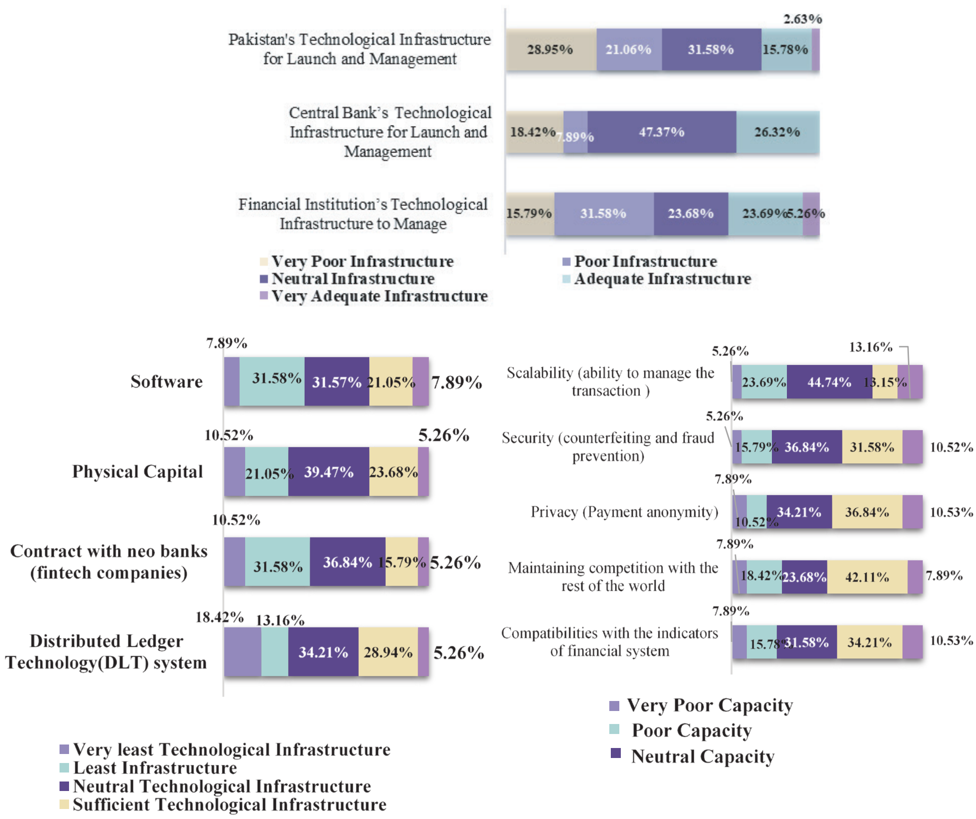
Source: Author's construction.

Technical Adequacy

Figure 6.29 represents the opinions of the representatives of FIs about the technical adequacy of FIs. Approximately 26.32% of the respondents considered the technological infrastructure of Pakistan adequate for the launch and management of CBDC, while about 16% viewed the State Bank of Pakistan's infrastructure as suitable for CBDC. 23% of the respondents agreed that their particular FI was technologically ready for the management and launch of CBDC.

The figure also describes the financial sector's views on various aspects of technological infrastructure and capacity building. On software capabilities, responses had moderate confidence (31.57%), while 38.47% of the respondents had confidence in the FI's physical capital. Overall, these results suggest that although there is a steady improvement, it is not enough for modernisation due to the inadequacy of infrastructure. For instance, the respondents expressed dissatisfaction with the state of distributed ledger technology (DLT) evaluation, scalability challenges, and security for the prevention of fraud. Furthermore, privacy remains a concern and implies that the bank must improve payment anonymity. In conclusion, a significant investment in both hardware and software to ensure security is required for the successful implementation of CBDC in Pakistan.

Figure 6.29: Technical Adequacy and Implementation Concerns regarding CBDC

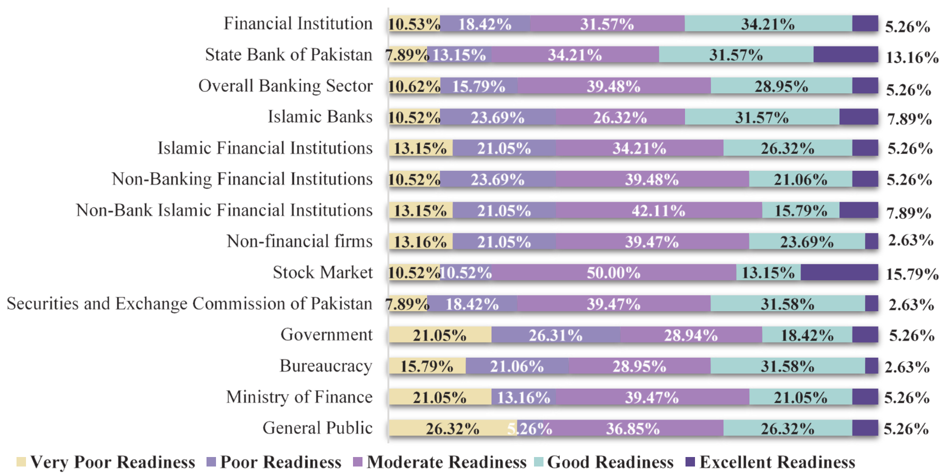


Source: Author's construction.

Preparedness and Acceptance of CBDC from the Financial Institutions Perspective

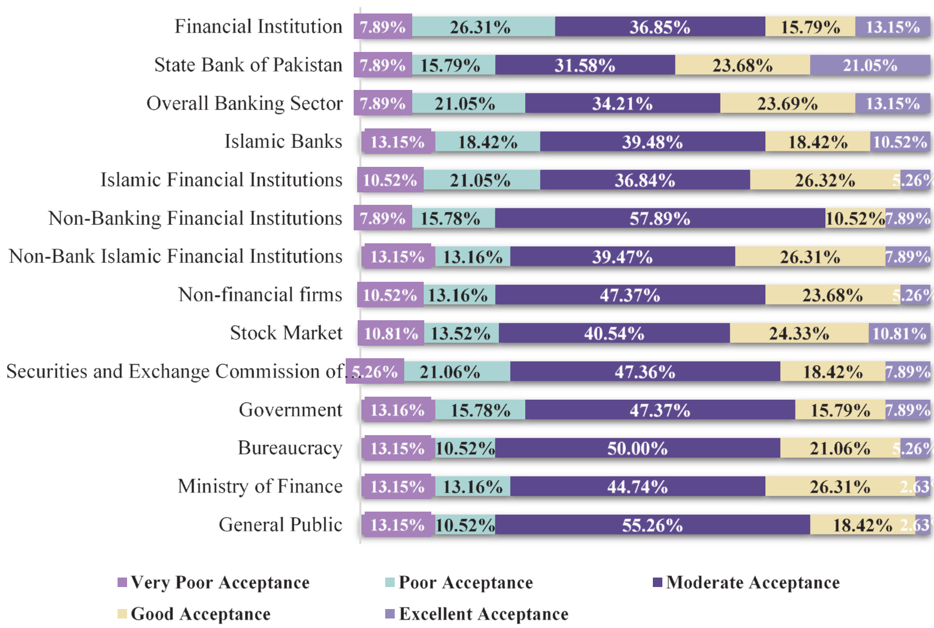
Figures 6.30a and 6.30b show the preparedness and acceptance of CBDC by FIs. Approximately 44% of participants thought that SBP is prepared to launch CBDC. Similarly, 40% of the respondents opined that banks and non-bank FIs, along with Islamic branches, are ready for the CBDC in Pakistan. Preparedness and acceptance by the government and non-bank Islamic FIs, and the Ministry of Finance were reported as low.

Figure 6.30a: Readiness of the Financial Institutions/Stakeholders/Public/Government



Source: Author's construction.

Figure 6.30b: Acceptance of CBDC

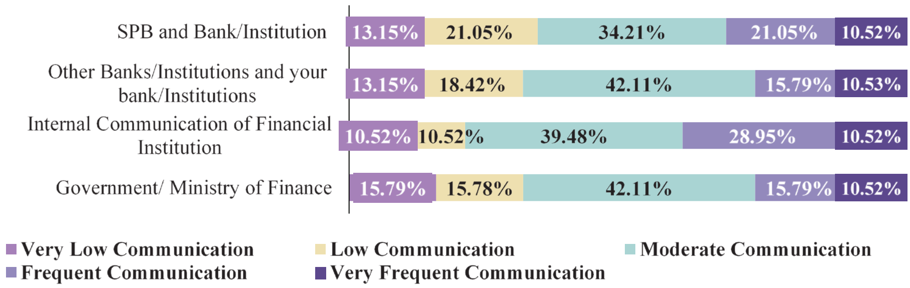


Source: Author's construction.

Frequency of Communication regarding CBDC

Figure 6.31 describes the frequency of communication regarding CBDC between different stakeholders. Only 31% of the respondents reported that SBP and their respective institutions have a high level of communication regarding the CBDC. Similarly, quite a low percentage of respondents reported a high frequency of communication between different banks and within the government. Similarly, the frequency of training held by different FIs on fintech was highlighted by 31% of respondents.

Figure 6.31: Communication Frequency regarding CBDC

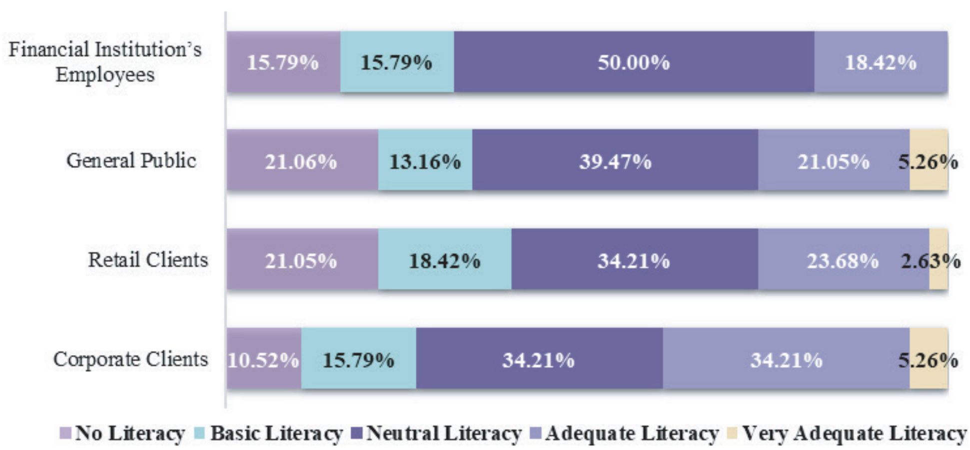


Source: Author's construction.

Digital and Fintech Literacy regarding CBDC

Figure 6.32 describes the level of digital and fintech literacy of different stakeholders as perceived by the representatives of FIs. Almost 40% of the respondents agreed that corporate clients possess a higher level of digital and fintech literacy, while employees of FIs got the lowest score on digital and fintech literacy, even lower than the general public and retail clients.

Figure 6.32: Digital and FinTech Literacy of the Respondents regarding CBDC

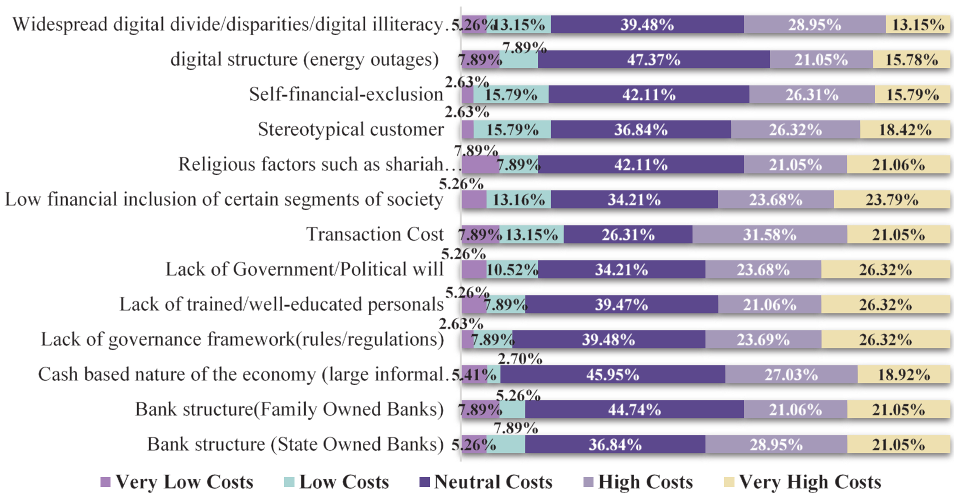


Source: Author's construction.

Potential Challenges for CBDC

Figure 6.33 describes several challenges regarding the implementation of CBDC in Pakistan. 52% of the respondents considered the transaction cost as the most pressing challenge associated with CBDC. Moreover, a lack of political will, regulatory framework, and state-owned structure of banks were also considered critical factors by the majority of the respondents. However, energy outages, family-owned bank structures, and Shariah compatibility were viewed as relatively less critical challenges.

Figure 6.33: Potential Challenges related to the CBDC

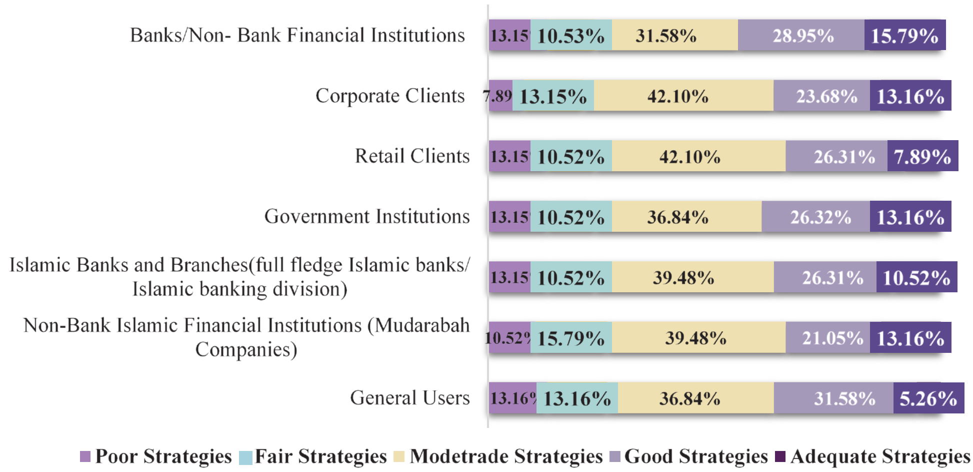


Source: Author's construction.

SBP and Financial Institutions Strategies to Enhance CBDC

Figure 6.34 explains the strategies devised by the SBP to increase awareness about CBDC, preparedness, and acceptance across various sectors. 45% of respondents considered that SBP is taking effective strategies to enhance CDBC preparedness, acceptance, and awareness of banks and non-bank FIs, governmental institutions, and the general public. However, for retail clients, SBP's strategies were deemed less effective in increasing awareness about CBDC, preparedness, and acceptance.

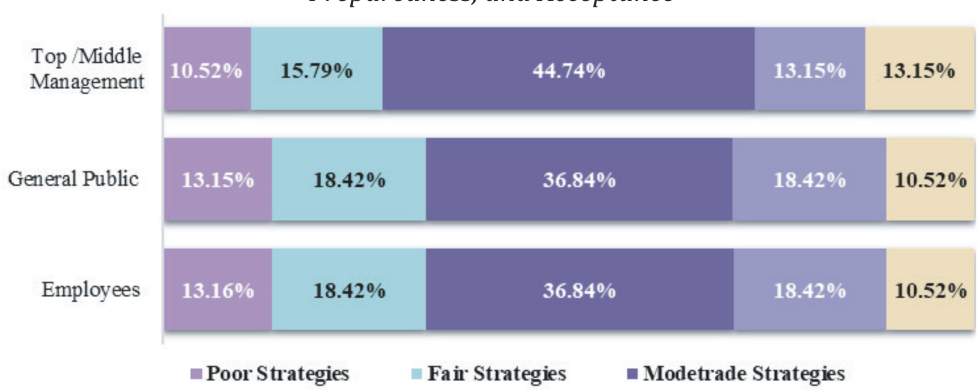
Figure 6.34: SBP's Strategies to Enhance CBDC Awareness, Preparedness, and Acceptance



Source: Author's construction.

Figure 6.35 presents the banks and non-bank FIs' strategies to enhance CBDC awareness, preparedness, and acceptance across various sectors. A very small percentage of respondents agree that banks and non-bank FIs are taking effective measures to create CBDC awareness, preparedness, and acceptance among their employees, management, and the general public.

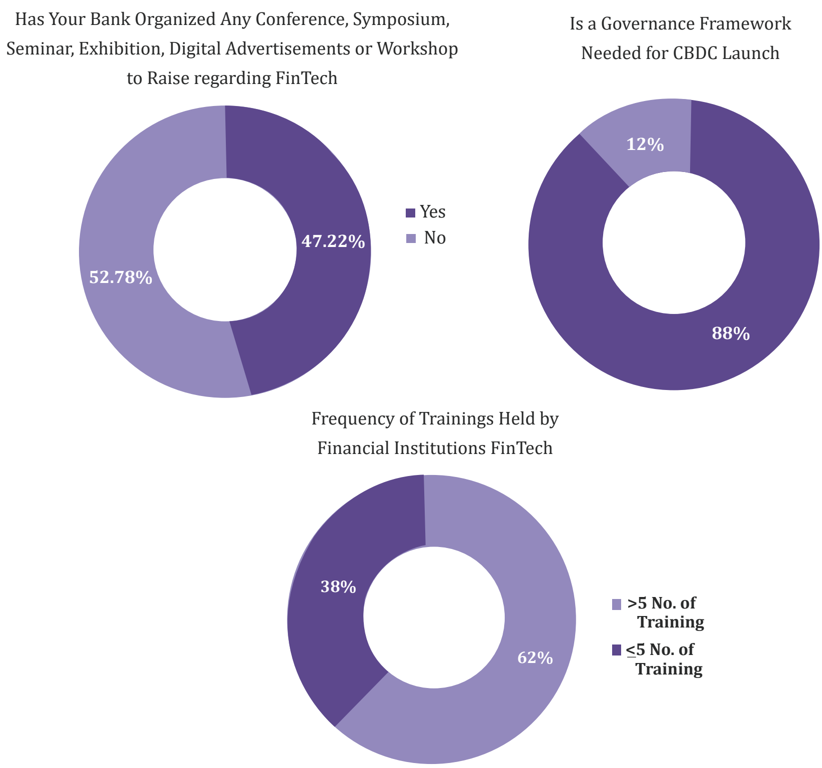
Figure 6.35: Financial Institutions Strategies to enhance CBDC Awareness, Preparedness, and Acceptance



Source: Author's construction.

Figure 6.36 shows that 47.22% of banks actively organise conferences, seminars, or campaigns to promote awareness about financial technology, but a noticeable proportion remains inactive, suggesting an opportunity for further spread of FinTech knowledge. It also shows that 88.24% of respondents feel a governance structure is required for the introduction of CBDC in Pakistan. Most FIs (62%) have held five or more FinTech training sessions, reflecting a significant focus on staff's skill development.

Figure 6.36: Bank's Strategies to Raise Awareness, Need of Governance, and Frequency of Trainings

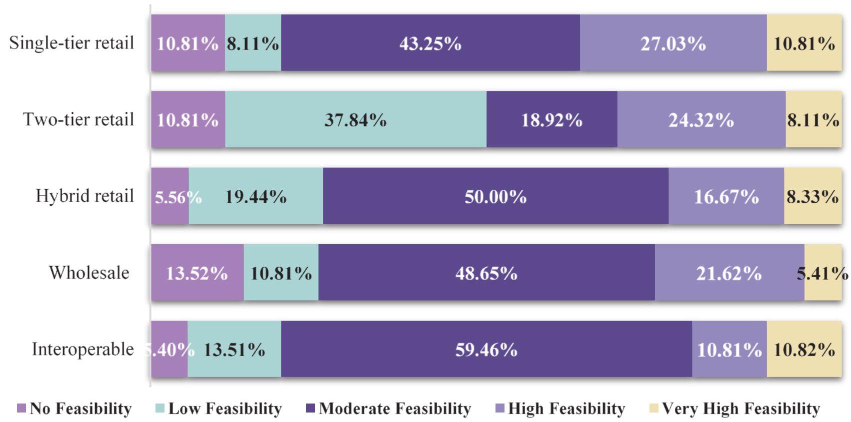


Source: Author's construction.

Designs of CBDC

Figure 6.37 shows the opinions of respondents regarding the feasible design of CBDC in Pakistan. The responses show that although the respondents were predominantly neutral about different CBDC designs in Pakistan, the single-tier retail CBDC stood out with the highest proportion of agreement, 37.84%, compared to other models.

Figure 6.37: Feasibility of Different Design of CBDC



Source: Author's construction.

7. CONCLUSIONS AND RECOMMENDATIONS

Introduction

This chapter concludes the discussion, proposes recommendations and a way forward to relevant stakeholders and policymakers, specifically the SBP. The recommendations and the way forward are based on extensive secondary sources covering the state of CBDC at the global level and the field survey conducted to gauge the understanding, perception, challenges and opportunities that CBDC presents for Pakistan from the lens of the general public, businesses, and FIs.

Application of CBDC

The situation analysis of countries at different stages of CBDC development and the review of the vast body of literature offer multifaceted implications for Pakistan. These implications are related to the appropriate design, user cases, and types and modes of CBDC regarding implementation and issuance. Moreover, implications are also offered on the various aspects of issuance, adoption, risk management, perceptions, opportunities, and challenges associated with CBDC.

Need for CBDC in Pakistan

- The first implication relates to the necessity of CBDC in Pakistan. Countries in the research phase of CBDCs can be broadly divided into two groups. The first group includes countries that have conducted extensive research, surveys, and experiments on the necessity of CBDCs and have concluded that there is no urgent need for CBDCs for them. In the other category, several countries in the research group have begun feasibility experiments to transition to the advanced stage of CBDC development.

- A comparison of economic, monetary, and financial indicators for Pakistan with those for the research group provides supporting evidence for issuing CBDC in Pakistan.

- The majority of the general public and merchants are using a variety of digital payment modes and consider financial technology useful for their financial transactions. They are also confident in adopting any technological and financial innovation having superior features than the existing ones, which supports the need to launch CBDC in Pakistan.

- The representatives of FIs also stressed the need for CBDC for financial development in Pakistan. They said Pakistan is already lagging as far as the adoption of advanced financial technology is concerned. Therefore, to be on par with other advanced and emerging economies, CBDC may be considered as a viable option.

Recommendations

- SBP may consider conducting extensive research, surveys, and feasibility studies to understand the necessity of CBDCs unique to the country by taking into consideration different stakeholders in the economy.

- A full-fledged policy framework and implementation procedure should be designed in order to effectively launch the CBDC.

- To maintain financial and trade competitiveness and better integration of the financial and economic system of Pakistan with the neighbouring countries and the rest of the world, it is necessary to adopt the most sophisticated and advanced financial system.

- Given the need for CBDC, the gaps between the existing and required financial and technological architecture need to be identified and addressed.

Design and Architecture of CBDC suitable for Pakistan

- Approximately 60% of countries are focusing on retail CBDC projects. However, a the same time, many other countries are also exploring wholesale CBDC, which has the potential to facilitate cross-border payments.

- Almost all CBDC projects at the advanced stage of CBDC development have defined intermediated/hybrid CBDC as a CBDC architecture. This evidence suggests that by involving both the central bank and private sector intermediaries, a hybrid model can enhance the resilience and security of the payment system.

- There is no consensus on the anticipated benefits associated with interest-bearing and non-interest-bearing CBDCs.

Recommendations:

- Pakistan may consider retail CBDC to align its payment system with the rest of the world. This recommendation can also be justified as retail CBDCs are designed for use by the general public and can enhance financial inclusion, reduce transaction costs, and provide a secure and efficient payment system.

- The SBP may simultaneously explore wholesale CBDC to facilitate cross-border payments. This may facilitate Pakistan's international trade with the rest of the world.

- Implementing a hybrid CBDC can be more technologically feasible for Pakistan, as it can be built on the existing financial infrastructure and leverage the expertise of private sector intermediaries.

- An entirely new system of financial payments and transactions may face significant resistance. Therefore, based on our analysis, we suggest that an account-based CBDC is a more feasible option.

- The SBP will need to conduct target-oriented training programmes and workshops for FIs to educate them about CBDC designs and the implications and benefits associated with each.

- Given the conventional and Islamic window operations of the FIs in Pakistan, the SBP should consider the compatibility of the CBDC with the Shariah.

Regulatory Framework

- Many countries pursuing CBDC have had to amend their central banking laws to account for the unique characteristics of digital currencies.

- It is also documented that CBDCs could influence monetary policy and financial stability, and also alter monetary transmission mechanisms, necessitating revisions to central banks' tools for managing interest rates and money supply.

- Aligning with international best practices is essential. Countries like China and Sweden, which have progressed in their CBDC journeys, have either amended their legal structures or are in the process of doing so to remove legal ambiguities.

- The findings from the survey of FIs highlighted the pressing need to establish a sound governance framework, setting the rules for the launch, implementation, and management of CBDC.

Recommendations:

- Pakistan may need to amend its definition of "currency" to explicitly include digital forms, as current laws primarily focus on physical currency.

- Pakistan's existing laws only recognise cash and bank deposits as legal tender. Therefore, amendments would be required to ensure CBDC is treated equally.

- While the SBP regulates electronic payment systems under laws such as the Payment Systems and Electronic Fund Transfers Act, 2007, it does not fully cover the specific dynamics of CBDC. Therefore, the SBP’s mandate under its current legal structure might need to be expanded to accommodate these changes.

- The SBP may amend the SBP Act of 1956 to ensure comprehensive legal backing and avoid potential challenges. However, it is pertinent to mention that the SBP should first implement a pilot programme to evaluate operational and regulatory aspects of CBDC before proposing the final amendments to the act.

- The SBP and the Government of Pakistan should ensure that the legal structure for CBDC is aligned with global and regional standards to integrate financial and economic institutions with the rest of the world.

- To oversee the matters related to CBDC, the SBP should establish a division designated for CBDC.

Challenges of CBDC

- The level of digitalisation encompassing digital literacy is an important factor in CBDC adoption all over the world.

- Digital literacy is necessary for the successful launch, acceptance, and adoption of CBDC in Pakistan.

- Females lack more in digital and financial literacy compared to males. This reflects the risk of the females' financial exclusion even after the launch of CBDC.

- The survey also highlighted a lack of communication, data privacy, a lack of political will, and insufficiency/inadequacy of physical and technological infrastructures, at both the SBP's and FIs' levels, which are important challenges.

- These findings highlight the need to improve the SBP's communication with stakeholders (FIs) about its programmes/initiatives with regard to CBDC and its implications.

- Investments in infrastructural development (physical, technological, hardware, and software) are required before the launch of CBDC.

- Trust in the existing financial system and security concerns are also important factors in inducing or hindering the adoption of CBDC.

Recommendations:

- The SBP should prioritise creating a simple and intuitive user interface for CBDC transactions. This includes ensuring digital wallets and payment platforms are easy to navigate.

- There should be specific initiatives to improve digital literacy across the country. This could involve educational campaigns and training programmes to help people understand and use digital financial services effectively, specifically for females.

- The SBP should conduct a comprehensive cost-benefit analysis on the design of CBDC.

- To address the financial and technical constraints for launching and implementing CBDC, the SBP may partner with the private sector, such as fintech companies.

- The SBP needs to build and maintain trust with different stakeholders by ensuring transparency in the development and implementation of the CBDC.

- SBP may invest in robust cybersecurity measures to protect the CBDC infrastructure. This includes regular security audits, implementing advanced encryption technologies, and establishing a rapid response system for any security breaches.

- A careful and holistic assessment of CBDC for monetary policy transmission is required from the SBP.

- The SBP can leverage CBDCs to gain more precise control over monetary policy, improving its ability to manage inflation, interest rates, and overall economic stability. SBP may update its underlying models to include CBDC and other forms of digital money for a more realistic monetary policy framework.

- The SBP is also required to initiate a designated platform for institutional and academic research to evaluate the implications of CBDC for monetary policy functioning and effectiveness.

Prospects and Opportunities

- Improvement in digitalisation and financial inclusion, increase in payment efficiency, and the effectiveness of monetary policy are the most frequently reported benefits of CBDC. Research, including in Pakistan, has also reported enhanced security as one of the most prominent benefits of CBDC.

- Pakistan's performance in the monetary sector is better than the average score of other countries in the proof-of-concept and pilot-testing groups. This implies that the satisfactory performance of Pakistan in the monetary sector provides an opportunity to launch CBDC.

- Pakistan has already initiated a digital transaction system since 2018 and provided basic infrastructure for digital transactions and online payments, which may serve as a platform for the launch of CBDC. These facilities include 1LINK switch, RAAST payment system, Roshan Pakistan, and Person to Person (P2P), RAAST-P2M. Thus, the availability of a digital payment system can be capitalised on to launch CBDC if and when the need arises.

- The majority of FIs reported a reduction in illicit financial flows and tax avoidance, an increase in bank competition, and monitoring and accountability of financial transactions, and compatibility of Pakistan's financial system with the global economy as significant benefits of CBDC.

- According to merchants, accuracy and efficiency of financial transactions, and better management of financial resources are pertinent opportunities that CBDC may offer in Pakistan. Similarly, efficiency in financial transactions and green banking are viewed as important benefits of CBDC in Pakistan.

- Regarding compatibility, most respondents from the general public believed that CBDC would integrate well with existing financial systems, implying minimal disruption to current banking structures.

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DISSECTING THE EFFECT OF INTERNAL R&D, IMPORTED INPUT VARIETY, AND EXTERNAL TECHNOLOGY ACQUISITION ON EXPORT COMPETITIVENESS OF PHARMACEUTICALS IN PAKISTAN

Abdul Rauf[1] , Abdul Jalil[2], and Ahsan Abbas[3]

ABSTRACT

Exports are critical for employment generation, poverty alleviation, and sustainable economic growth. This study examined the regulatory issues, R&D rigidities, and export challenges faced by pharmaceutical firms in Pakistan, and empirically investigated the impact of indigenous innovation, foreign technology spillovers, and sector- and firm-specific factors on export performance. Primary data were collected through a stratified random survey of pharmaceutical firms located in Punjab, Sindh, Khyber Pakhtunkhwa, and the Islamabad Capital Territory in 2024. Firth's logistic regression method was employed to estimate the empirical model, while thematic analysis of interviews with key stakeholders complemented the quantitative findings. The analysis confirmed that pharmaceutical firms face regulatory barriers, innovation challenges, and other sector-specific constraints that hinder their ability to enter export markets. First, the results suggested that internal R&D and external technology acquisition from domestic and foreign sources are critical determinants of firm-level export performance. The findings emphasised the importance of a prudent R&D strategy to support basic research and foreign technology transfer for high-value generics and new therapeutic avenues, including the production of biologicals. Second, the results showed a positive effect of process innovation and innovation variety

[1] Assistant Professor, National Defence University, Islamabad.

[2] Professor, National Defence University, Islamabad.

[3] Assistant Professor, National Defence University, Islamabad.

on export performance. The study highlighted improvements in production processes and distribution methods as key determinants of firm-level exports, and revealed that firms' engagement in technological and non-technological innovation reduces production costs and enhances innovative capability, both essential for sustained export growth. Third, the estimates indicated a positive effect of product diversification and technical infrastructure development on export performance. The findings confirmed the need to promote the domestic production of vaccines, sera, blood products, and nutraceuticals, and to narrow the gap in the production of herbal products. They also underscored the importance of bioequivalence/bioavailability (BE/BA) study centres and drug-testing laboratories, since BE data are mandatory for exports. Fourth, the results demonstrated a positive effect of firm size and membership of international regulatory bodies on export performance. This underscores the need for a prudent firm and drug registration mechanism to avoid reducing the pharmaceutical industry to cottage-level operations without undermining competition. The findings also revealed the importance of firms securing accreditation and compliance recognition from stringent regulatory authorities (SRAs) such as the United States Food and Drug Administration (US FDA), the UK Medicines and Healthcare Products Regulatory Agency (MHRA), the European Medicines Agency (EMA), and the Japanese Pharmaceutical and Medical Devices Agency (PMDA). Likewise, DRAP's membership in the Pharmaceutical Inspection Co-operation Scheme (PICS) was identified as critical for capacity-building and the provision of clear implementation guidelines for the sector. Fifth, the results pointed to the critical role of government support in overcoming regulatory barriers, innovation rigidities, and export challenges through incentives and facilitation. Finally, the study found a favourable impact of knowledge spillovers from foreign direct investment, contract research and manufacturing services (CRAMS), and research collaborations through university–industry linkages and strategic partnerships among firms, all of which enhance innovation and thereby export performance. The findings highlight the need to strengthen basic research, university–industry collaboration, and the development of a robust clinical trials platform. The study concludes with important policy recommendations for industry, DRAP, the federal government, the Ministry of Commerce, the State Bank of Pakistan, and academia.

1. INTRODUCTION

Exports are critical for employment generation, poverty alleviation, and sustainable economic growth (Santacreu, 2015). Exporting also enables firms to absorb knowledge spillovers from destination markets, enhance plant productivity, and improve both innovative and absorptive capacity (Baldwin & Gu, 2004; Liang et al., 2024). Moreover, the manufacturing sector exports, a relatively low trading cost sector, have a favourable impact on a country's current account balance (Boz et al., 2019). Thus, export volume is of critical importance. Nonetheless, while many developing countries succeed in exporting, they often fail to achieve sustained growth. One reason is that their export baskets are dominated by low-value-added products, which may provide only a temporary advantage, as rival countries can easily acquire the capability to produce such products (Zhu & Fu, 2013). It is therefore vital to explore the export challenges faced by manufacturing firms in developing countries.

Firms encounter multiple challenges to achieving strong export performance. Differences in export propensity, export intensity, and export quality in developing countries are attributed mainly to firm size, age, skill levels, industry structure, and the possession of tangible and intangible resources, among other factors (Chudnovsky et al., 2006; Rodríguez & Rodríguez, 2005). Government support in export promotion, market competition, credit availability, and a facilitative business environment is also crucial (Xuan & Tan, 2024). In addition, some industries, including pharmaceuticals, face stringent standardisation requirements from international regulatory bodies such as the United States Food and Drug Administration (US FDA) and the European Medicines Agency (EMA), as well as national drug authorities such as the Drug Regulatory Authority of Pakistan (DRAP).

The extant literature has highlighted technological innovation (TI) as a crucial determinant of export competitiveness. TI affects exporting both directly and indirectly: internal and external R&D activities directly increase export propensity and intensity (Harris & Li, 2009; Becker & Egger, 2013), while TI indirectly influences the decision to export and export intensity through its effect on total factor productivity (TFP) (Yu et al., 2022; Hou & Mohnen, 2013). In other words, innovation enhances productivity, which in turn improves export performance. Product and process innovation also contribute to export quality upgrading (Zhu & Fu, 2013), leading to sustained global competitiveness. TI is therefore critical to enhancing the value and quality of exports (Hausmann, Hwang, & Rodrik, 2007). This study aims to examine the effect of indigenous and foreign innovation efforts on export performance in developing countries, focusing on the pharmaceutical sector in Pakistan.

Despite the significance of TI, firms in developing countries face numerous obstacles to innovation. Limited R&D activity, low skill levels, high innovation costs, weak firm-specific resources, and lack of motivation hinder innovation (D'Este et al., 2012; Rodríguez & Rodríguez, 2005). Financial constraints, an innovation-unfriendly macroeconomic environment, and regulatory hurdles further restrict innovation (Lachenmaier & Wößmann, 2006). Beyond these broad constraints, firm-, industry-, region-, and country-specific factors warrant closer examination. This raises several research questions: What is the extent of innovation and export capability among firms in developing countries? What are the obstacles that hinder innovation and export upgrading? How can innovation capability be enhanced? What is the relative importance of different channels of TI for export competitiveness? This study addresses these questions by investigating the issues and challenges hindering the export potential of pharmaceutical firms in Pakistan, and by examining their export performance in relation to different channels of TI. Despite the sector's economic importance, systematic empirical studies linking firm-level exports and TI in Pakistan's pharmaceutical sector remain scarce.

Among the various channels of TI, this study emphasises internal R&D and external technology acquisition as key determinants of firm-level export competitiveness. Internal R&D influences export performance directly (Rodríguez & Rodríguez, 2005) and indirectly through its association with TFP (Yu et al., 2022). However, unlike developed countries, developing economies allocate fewer resources to internal R&D and instead rely on imported intermediate inputs that embed technologies developed in advanced countries (Santacreu, 2015). Evidence shows that knowledge created in developed countries transcends national boundaries through external technology acquisition, providing critical spillovers to developing economies (Wang et al., 2013). Imports of advanced machinery and equipment, technology licensing, and the recruitment of specialised technological personnel are major channels of knowledge diffusion that help firms adapt and innovate (Baldwin & Gu, 2004). These also enable firms to build new capabilities and move up the value chain. However, existing literature also demonstrates that a minimum level of internal R&D capability—absorptive capacity—is required to benefit fully from technology acquired from external sources (Cassiman & Veugelers, 2006). It is therefore essential to identify the appropriate channels of technology that enhance export competitiveness in developing countries.

Significance of the Study

Pharmaceutical exports are particularly important because they boost domestic investment, create employment, and positively influence the strained current account balance. Examining the export challenges of Pakistan's pharmaceutical firms is crucial, as an efficient sector could capture significant opportunities in the global market. This study provides a systematic empirical assessment of the impact of internal innovation and external technology acquisition on firms' export performance. Although firm-level analyses are essential for designing effective public policy, such studies remain rare in developing countries due to data limitations. In Pakistan, research has tended to focus on textiles and apparel (Wadho & Chaudhry, 2018, 2024) and ICT (Shah et al., 2024), while empirical studies of the innovation–export nexus in the pharmaceutical sector are scant (e.g., Khan et al., 2021), often limited to descriptive sector-level analysis. A firm-level investigation is therefore overdue, despite the sector's economic significance and its classification by the UN Industrial Development Organization (UNIDO) as a medium- to high-technology industry.

The pharmaceutical sector is also highly concentrated: the top 10 firms account for 43% of market share, while the top 50 hold 93%. Larger firms are more likely to innovate, and innovation is associated with higher productivity (Chudnovsky et al., 2006), which in turn facilitates export market entry (Haddoud et al., 2023). Examining the drivers and barriers of innovation and its links to exporting in this sector is thus highly relevant. Furthermore, the Pharmaceuticals Export Strategy Framework (2023–27), aligned with the Strategic Trade Policy Framework (STPF), identifies pharmaceuticals as a priority sector for export diversification. Finally, firm-level evidence is increasingly recognised in the literature as vital for understanding innovation–export dynamics, making this study a timely contribution.

Purpose and Scope of the Study

- To examine the regulatory issues, R&D rigidities, and export challenges faced by pharmaceutical firms in Pakistan.

- To analyse the extent of domestic and foreign innovation efforts in these firms.

- To empirically assess the impact of internal innovation and external technology acquisition on export performance.

Developing countries are often resource-constrained and have limited capacity to adapt to diverse forms of technological knowledge. Innovation is inherently risky, costly, and path dependent, and is shaped by firm-, industry-, state-, and region-specific characteristics, as well as firms' willingness to adopt and internalise new technologies. Firms may incur high switching costs when shifting between different technology sources or may face diseconomies of scope (Rothaermel & Hess, 2007; Hess & Rothaermel, 2011). Conversely, they may leverage imported technologies in processes where they already possess skills and capabilities, thereby lowering costs. Moreover, the nature of technology—labour-saving or labour-using—shapes its adoption, with labour-saving technologies common in developed countries and labour-using technologies often favoured in developing economies. These choices can be cost-prohibitive. Furthermore, different innovation activities may yield similar outcomes, creating a conflict of scope. For these reasons, it is important to assess the relative importance of different innovation channels for export competitiveness in developing countries.

Research Questions

1. What are the challenges hindering the export competitiveness of pharmaceutical firms?

2. What is the role of technological innovation in enhancing export competitiveness?

3. What are the appropriate strategies for developing a prudent pharmaceutical export framework?

Relevance to Public Policy

This study is directly relevant to the pressing issue of Pakistan's low pharmaceutical export performance, despite the sector's economic and strategic significance. Assessing the effects of internal R&D and external technology acquisition on export performance provides insights into the relative importance of different innovation channels. The study identifies innovation challenges and impediments to firm-level export performance in a sector that has demonstrated strong growth within large-scale manufacturing.

The findings will be valuable for policymakers involved in innovation and export strategy, including the Strategic Trade Policy Framework (2020–25) and the Pharmaceuticals Export Strategy Framework (2023–27). They can also inform DRAP in defining priority areas for export growth, and assist tax authorities in setting effective tariff rates on imported machinery and equipment. Furthermore, the results may guide the State Bank of Pakistan in revising compliance policies and policy rates relevant to the pharmaceutical sector.

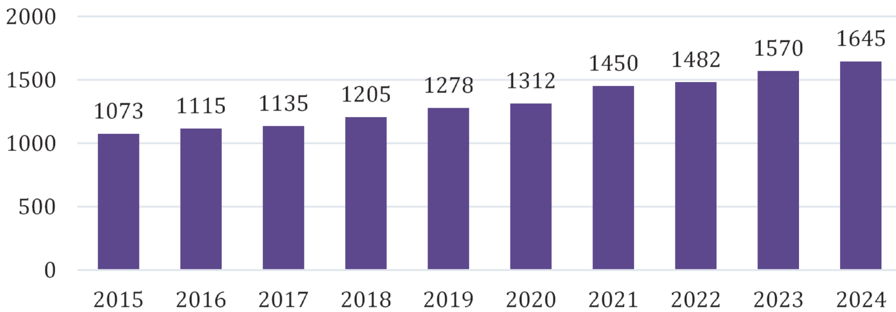
2. OVERVIEW OF THE PHARMACEUTICAL SECTOR IN PAKISTAN

Global Pharma Market

The pharmaceutical industry is a highly knowledge-intensive sector. The product cycle of a drug involves discovery, development, manufacturing, and marketing. Drug discovery requires significant R&D, which is primarily undertaken by large firms that subsequently obtain patents. Smaller firms typically develop off-patent drugs or provide toll/contract manufacturing services on behalf of larger firms. In addition, Contract Research Organisations (CROs) are engaged in the management of clinical trials and the analysis of the resulting data. Effective toll/contract manufacturing and contract research require strong linkages between large and small firms, while a minimum level of innovative capability—or absorptive capacity—is a prerequisite for smaller firms.

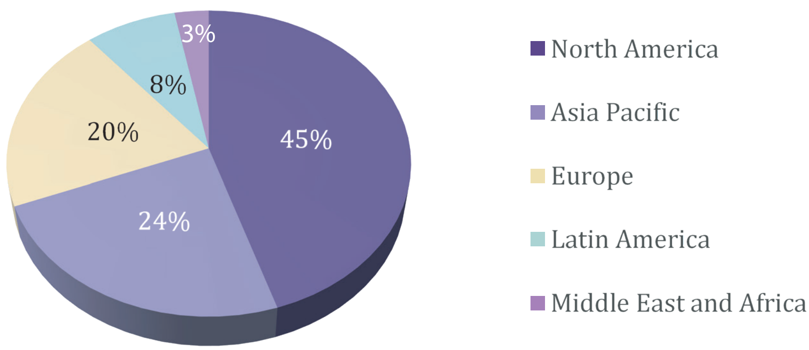
The global pharmaceutical market has experienced rapid growth in recent years. The increasing demand for medication is attributed to rising life expectancy and an ageing population, growth in per capita income, greater awareness, innovative therapeutic avenues, and market expansion. The size of the global pharmaceutical market was USD 1.31 trillion in 2020, increased to USD 1.65 trillion in 2024, and is anticipated to reach USD 1.8 trillion in 2026.

Figure 1: Global Pharma Market Size – 2015-2021 (USD Billion)



Source: VIS Credit Rating Company Limited (2023).

Figure 2: Region-wise Share of Global Pharma Sales – 2023



Source: VIS Credit Rating Company Limited (2023).

The regional pharmaceutical market is concentrated in North America, which held a dominant 45% share in 2023. This was followed by Asia and the Pacific with 24%, an emerging market that has just surpassed Europe's share of 20%. Latin America, the Middle East, and Africa accounted for relatively smaller shares of 8% and 3%, respectively. At the country level, the United States leads the global pharmaceutical market with a 43% sales share, followed by China, Japan, Switzerland, and European markets. Among established players, Pfizer (USA), Johnson & Johnson (USA), and Sinopharm (China) are the three largest pharmaceutical companies in the world. Collectively, the top ten companies account for approximately 35% of the global pharmaceutical market, five of which are based in the United States. Developed countries, as leaders in knowledge creation and technology adoption, provide a conducive environment for knowledge-intensive industries such as pharmaceuticals to research, develop, and manufacture drugs.

Table 1: Top Disease Burden/Therapeutic Class of Global Pharma Market – 2023

Oncology	Diabetes
Ophthalmology	Endocrinology
Cardiovascular Diseases	Central Nervous System/Neuro Disorders
Gastrointestinal Disorders	Nephrology

Source: ICAP (2024).

As for the therapeutic class of the global pharma market or disease burden, Oncology comes in first place, followed by diabetes, ophthalmology and so on, as depicted above.

Pakistan's Pharmaceutical Sector

The Pakistani pharmaceutical sector has undergone a disruptive evolutionary process and has now become a USD 3.3 billion industry. It has experienced remarkable growth in recent years, recording a 24% year-on-year (YoY) increase in FY2024 with a compound annual growth rate (CAGR) of 17% during FY2019–FY2024 (IQVIA, 2024). The sector is among the few leading industries within large-scale manufacturing (LSM) to achieve double-digit growth in FY2024. Between July and March 2023–24, the pharmaceutical industry grew by 23.19%, compared with 12.09% in wood products, 16.40% in fertilisers, 61.54% in machinery and equipment, and 23.13% in furniture (GOP, 2024).

The pharmaceutical sector plays a vital role in the national healthcare system, meeting 80–85% of domestic demand for medicines, with the remaining 15–20% supplied through imports.

Table 2: Main Characteristics of the Pakistan Pharmaceutical Sector

	Number of Firms	639
1	Market Size	USD 3.3 billion (2024)
2	Export value (pharmaceutical products)	USD 341 million (2024)
3	Average Annual Growth Rate	17%
4	R&D intensity	1-2%
5	Employment	90000 individuals directly 150,000 individuals indirectly
6	Contribution to GDP	1%
7	Contribution to Exports	1%
8	Contribution to domestic drug demand	80%
9	Resource base	Narrow: 90% of APIs are imported mainly from China and India

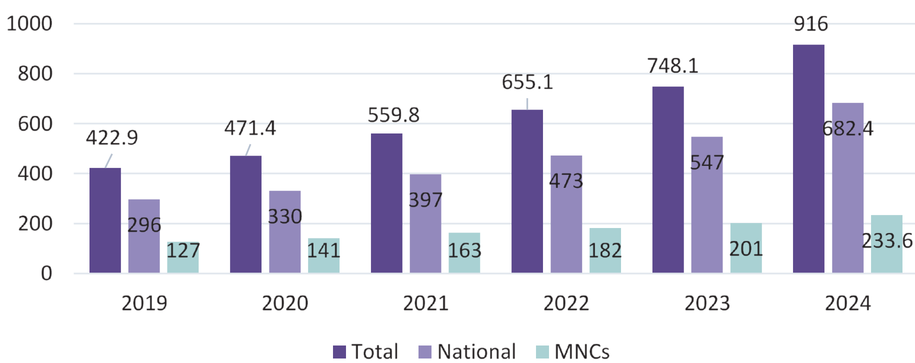
Source: Authors' own compilation based on data from IQVIA (2024) and DRAP (2024).

The sector is dynamic, offering significant graduate employment opportunities as a technology-intensive and skill-demanding industry. It provides direct employment to approximately 90,000 individuals and indirect employment to around 150,000 (IQVIA, 2024). Its contribution to GDP and total exports is about 1% each. The sector also contributes to the current account through import substitution, valued at approximately USD 2 billion (Ahmed, 2024).

However, the industry has a weak resource base, with nearly 90% of raw materials—including Active Pharmaceutical Ingredients (APIs), excipients, and concentrates—imported primarily from China, Germany, and India. The main production activity consists of formulation processes such as mixing, dilution, and packaging of final products, which are low-value-added activities with limited potential for export upgrading.

Currently, approximately 11,000 actively marketed drugs are sold through licensed pharmacies, with a significant proportion comprising Over-the-Counter (OTC) medicines, including multivitamins and pain/cold/flu relief drugs, sold directly to patients (ICAP, 2024)

Figure 3: Pakistan Pharmaceutical Market Size - 2019-2024 (PKR Billion)



Source: VIS Credit Rating Company Limited (2023).

In terms of market share, domestic firms dominate the pharmaceutical sector, recording sales of Rs 682.4 billion (74.5%) in 2024, compared to Rs 233.6 billion (25.5%) for multinational corporations (MNCs). The data indicate that domestic firms have outperformed MNCs, with the sales gap widening as the presence of MNCs in the market diminishes. The number of MNCs has declined from 40 in 2000 to 17 in 2016, and to only 5 by 2024. Among the top 10 firms, 7 are domestic.

Despite their shrinking market share, MNCs remain important for facilitating skill and knowledge spillovers to domestic firms. The Pakistani pharmaceutical market is also highly concentrated, with a small number of large firms accounting for a significant share; the top 10 firms collectively controlled approximately 49% of market sales in Q1 2024.

Table 3: Top 10 Pharmaceutical Firms in Pakistan – 2024)

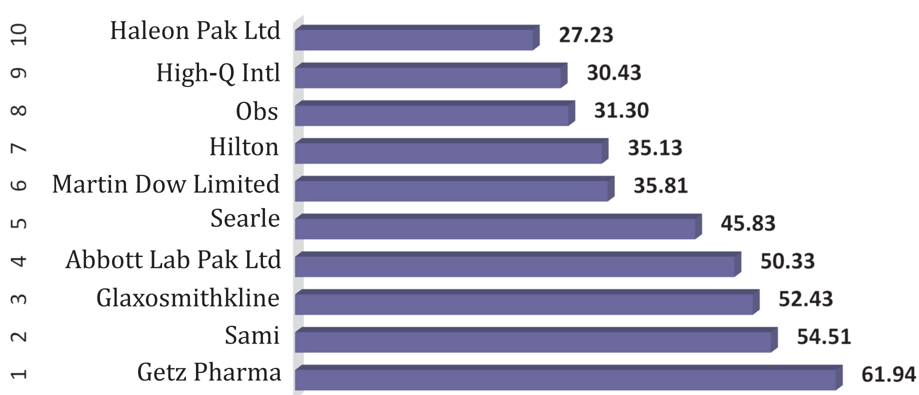
Rank	Pharmaceutical Firm	Market share (%)	National /MNC	Listed /Not listed
1	Getz Pharma	7.13	National	Not listed
2	Sami	6.27	National	Not listed
3	Glaxosmithkline	6.03	MNC	Listed
4	Abbott Lab Pak Ltd	5.79	MNC	Listed
5	Searle	5.27	National	Listed
6	Martin Dow Ltd	4.12	National	Not listed
7	Hilton	4.04	National	Not listed
8	Obs	3.60	National	Not listed
9	High-Q Intl	3.50	National	Not listed
10	Haleon Pak Ltd	3.13	MNC	Listed

Source: IQVIA (2024).

Table 3 shows that Getz Pharma leads the market with a 7.13% share, followed by SAMI (6.27%) and GlaxoSmithKline (6.03%). Collectively, these three firms account for approximately 20% of total market sales, reflecting the dominance of large firms in Pakistan's pharmaceutical sector. Other major contributors include Abbott Laboratories Pakistan (5.79%), Searle (5.27%), and Martin Dow Limited (4.12%). This distribution illustrates both the leadership and the competitive presence of large firms in the industry.

In technologically advanced countries, large firms typically drive knowledge creation and innovation, while smaller firms engage in outsourcing and contract services. However, such linkages remain limited in Pakistan.

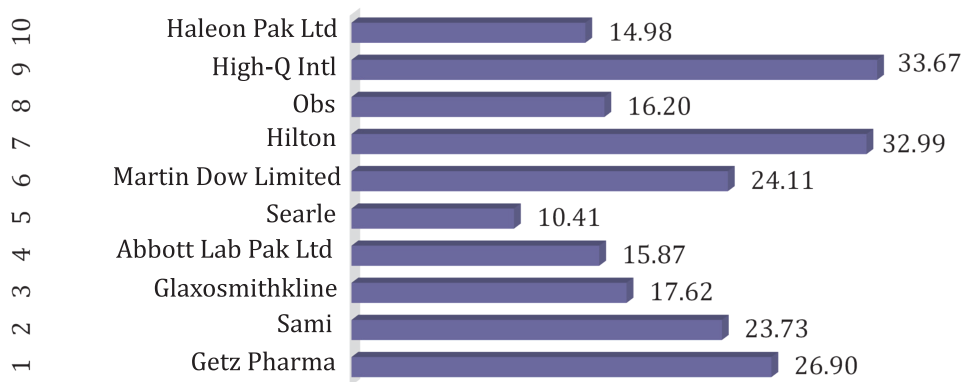
Figure 4: Sales Revenue of Top 10 Pharmaceutical Firms in 2024 (PKR Billion)



Source: IQVIA (2024).

In terms of sales revenue, Getz Pharma leads the market with PKR 61.94 billion, followed by SAMI (PKR 54.51 billion) and GlaxoSmithKline (PKR 52.43 billion). Other major contributors include Abbott Laboratories Pakistan (PKR 50.33 billion), Searle (PKR 45.83 billion), and Martin Dow Limited (PKR 35.81 billion). Additional firms, such as Hilton (PKR 35.13 billion) and High-Q International (PKR 30.43 billion), also demonstrate strong competitive performance. The data indicate that the top five companies have established a substantial sales gap over their subsequent competitors.

Figure 5: Growth Rates of Top 10 Pharmaceutical Firms – 2024



Source: IQVIA (2024).

The growth rates of leading pharmaceutical companies indicate that High-Q International (33.67%) and Hilton Pharma (32.99%) recorded the highest growth in 2024, surpassing Getz Pharma (26.90%), Martin Dow Limited (24.11%), and SAMI (23.73%). This reflects intense competition among top players and highlights the potential of High-Q and Hilton Pharma to challenge established leaders.

The pharmaceutical market also exhibits concentration at the product level. Among the 11,000 marketed drugs, the top 10 brands collectively account for approximately 9% of total sales. Table 4 presents the market share of the leading pharmaceutical products in Pakistan for Q1 2024.

Table 4: Top 10 Pharmaceutical Products in Pakistan – 2024

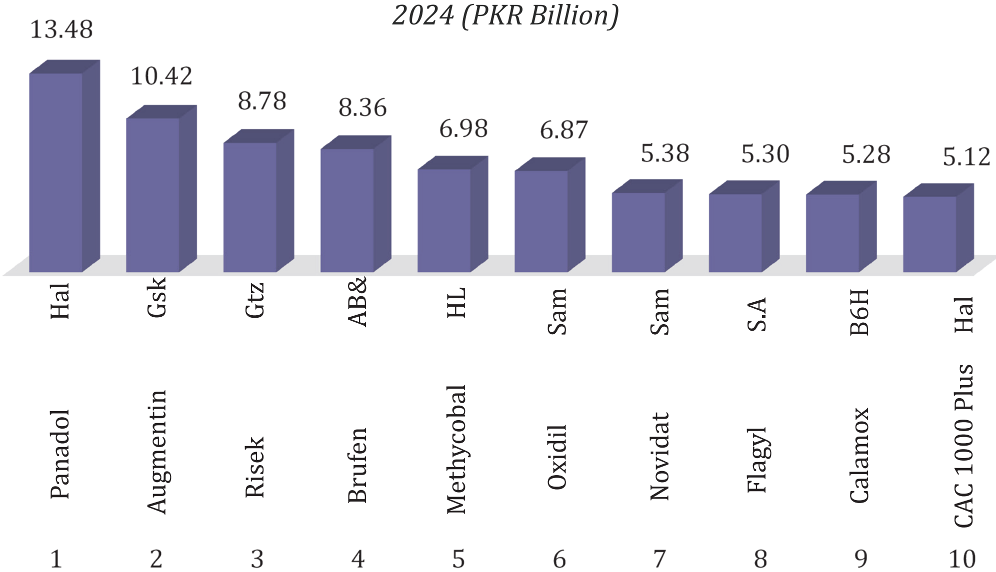
Rank	Pharmaceutical Product	Market Share (%)
1	Panadol (Hal)	1.55
2	Augmentin (Gsk)	1.20
3	Risek (Gtz)	1.01
4	Brufen (Ab&)	0.96
5	Methycobal (Hl)	0.81
6	Oxidil (Sam)	0.79

Rank	Pharmaceutical Product	Market Share (%)
7	Novidat (Sam)	0.62
8	Flagyl (Sa)	0.61
9	Calamox (B6h)	0.61
10	Cac 1000 Plus (Hal)	0.59

Source: IQVIA (2024).

The data highlights that Panadol leads the market with a share of 1.55%, followed by Augmentin (1.20%), Risek (1.01%), and Brufen (0.96%). Other notable products include Methycobal (0.80%), Oxidil (0.79%), and Novidat (0.62%). These figures reflect the strong influence of leading brands on pharmaceutical sales. In terms of market value, Panadol dominates with PKR 13.48 billion, followed by Augmentin (PKR 10.42 billion) and Risek (PKR 8.78 billion) (see Figure 6).

Figure 6: Sales Revenue of Top 10 Pharmaceutical Products in 2024 (PKR Billion)

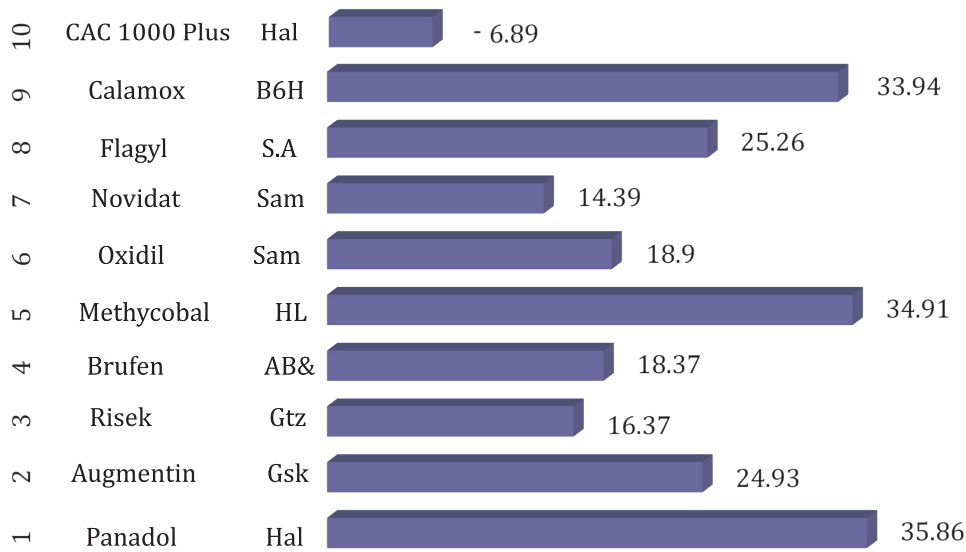


Source: IQVIA (2024).

Other notable products include Brufen (PKR 8.36 billion) and Methycobal (PKR 6.98 billion). These figures underscore the dominance of blockbuster drugs in driving market sales and highlight prevailing medication demand patterns. Panadol, being an over-the-counter (OTC) drug that can be purchased without a prescription, also reflects the self-medication trend in Pakistan.

In terms of growth, Panadol recorded a remarkable 35.86%, followed by Methycobal (34.91%) and Calamox (33.94%). Other significant products include Augmentin (24.93%), Flagyl (25.26%), and Oxidil (18.90%). By contrast, CAC 1000 Plus experienced a decline of –6.89%. This indicates a mixed performance among key products. Panadol is expected to maintain its leading position, while the strong growth of Methycobal and Calamox signals their potential to catch up with top brands.

Figure 7: Growth Rates of Top 10 Pharmaceutical Products – 2024



Source: IQVIA (2024).

Geographical Distribution

There are a total of 639 pharmaceutical firms in Pakistan (DRAP, 2024). In terms of geographical distribution, Punjab hosts the largest number of firms (344), followed by Sindh (142) and Khyber Pakhtunkhwa (KPK) (92), while Islamabad accounts for 45 firms. Balochistan has the fewest, with only 11 firms. At the city level, Lahore and Karachi are the preferred locations, hosting 175 and 130 firms, respectively. Rawalpindi and Islamabad jointly accommodate 128 firms, while Peshawar hosts 41, and the Faisalabad/Sheikhupura region has 33 firms. The Hattar Industrial Estate, the manufacturing hub of KPK, attracts 23 firms. These statistics indicate that pharmaceutical firms tend to cluster in industrial hubs within cities that are major centres of economic activity, suggesting that the industry is largely dispersed but unevenly distributed across regions. Possible reasons for these clusters include relatively favourable business environments, the availability of raw materials and essential utilities, proximity to domestic and export markets, duty and tax incentives, and the segmentation of regulatory functions among provinces.

The uneven geographical distribution of pharmaceutical firms has both positive and negative implications. Geographical dispersion allows firms to access diverse markets and efficiently cater to a broader customer base, creating growth opportunities (for example, firms in Peshawar may easily export to Afghanistan). It also encourages technology adoption to remain competitive in varied markets; firms located near industrial hubs may be required to innovate more intensively. Additionally, dispersed firms can benefit from local resources and expertise. On the other hand, uniform technology adoption across dispersed units can be costly and difficult to manage. Infrastructure constraints and fragmented regulatory oversight at different locations may further complicate technology adoption, potentially affecting firms' export performance.

Table 5: Geographical Distribution of Pharmaceutical Industry in Pakistan – 2024

Province Wise Distribution (No. of firms)			
Punjab	344	Islamabad	45
Sindh	142	Balochistan	09
KPK	92	Others	07
City-wise Distribution (No. of firms)			
Lahore	175	Haripur (Hattar)	23
Karachi	130	Multan	14
Rawalpindi/Islamabad (Rawat)	128	Sargodha	13
Peshawar	41	Gujranwala/Gujrat/Sialkot	12
Faisalabad/ Sheikhupura	33		

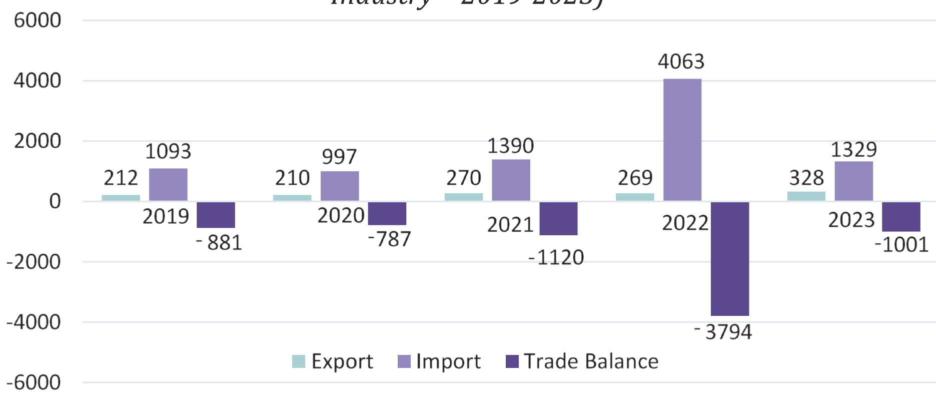
Source: Authors' own compilation based on data from DRAP (2024).

Export Performance of Pakistan's Pharmaceutical Sector

The preceding discussion indicates that the pharmaceutical sector has emerged as a dynamic industry. However, this dynamism has not translated into global competitiveness, as reflected in the sector's export performance. Pharmaceutical exports grew at a compound annual growth rate (CAGR) of 12% between 2019 and 2023, reaching USD 328 million in FY2023, and are projected to reach USD 350 million in 2024. Despite this growth, the sector ranks 17th in industry-level exports and contributes only 1.1% to total manufactured exports, compared with 17% for textiles, 14% for apparel, and 11% for cereals. At the global level, it ranks 56th in pharmaceutical exports, a relatively low position for an industry that has experienced an average annual growth rate exceeding 17% in recent years.

Figure 9 illustrates the export, import, and trade balance of pharmaceuticals over the 2019–2023 period. Although exports have increased over time, the trade deficit has widened, reaching approximately USD 3.8 billion in 2022 due to increased imports during the COVID-19 period. By 2023, the deficit had decreased to around USD 1 billion, still approximately three times the value of exports.

Figure 8: Export, Import and Trade Balance of Pharmaceutical Industry – 2019-2023)



Source: VIS Credit Rating Company Limited (2023).

One of the primary reasons for the substantial trade deficit in the pharmaceutical sector is its heavy reliance on imported active pharmaceutical ingredients (APIs). The domestic API market is currently valued at approximately USD 175 million, representing only around 10% of total API demand (Ahmed, 2024). The remaining 90% is imported, primarily from China, Germany, and India, contributing significantly to the trade deficit.

A large share of pharmaceutical exports is concentrated among a few major companies. Table 6 presents the top exporters by value (PKR billion) for 2023 and 2024, along with their ownership structure and growth rates.

Table 6: Top 15 Exporting Pharmaceutical Firms –2023-2024

Rank	Company Name	National/ MNC	Export Value (Rs Billion)		Growth(%)
			2023	2024	
1	Getz Pharma (Pvt) Ltd	National	21.94	27.58	25.7
2	Hilton Pharma (Pvt) Ltd	National	2.793	4.208	50.6
3	Sami Pharma (Pvt) Ltd	National	2.421	3.614	49.2
4	The Searle Company Ltd	National	3.333	3.485	4.5
5	Herbion Pak (Pvt) Ltd	National	2.977	3.276	10.1
6	Genix Pharma (Pvt) Ltd	National	3.689	3.074	-16.6
7	Ccl Pharma (Pvt) Ltd	National	1.950	2.975	52.6
8	Abbott Lab (Pak) Ltd	MNC	2.132	2.596	21.7
9	Pharmevo (Pvt) Ltd	National	1.457	2.512	72.4
10	Nabi Qasim Ind (Pvt) Ltd	National	1.997	2.055	2.9
11	Atco Laboratories Ltd	National	1.591	1.958	23.1
12	Martin Dow Ltd	National	1.621	1.843	13.7
13	Agp Ltd	National	1.252	1.751	39.8
14	Scilife Pharma (Pvt) Ltd	National	0.793	1.371	72.9
15	Highnoon Lab Ltd	National	0.992	1.248	25.8

Source: Government of Pakistan (2024) Customs Trade Statistics.

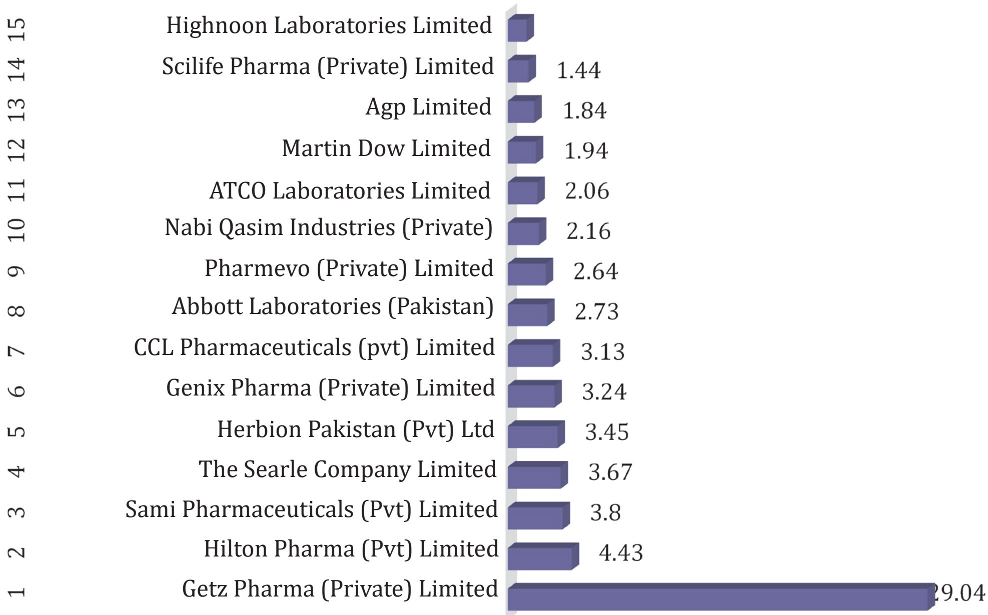
Getz Pharma leads the sector with exports of PKR 27.58 billion, followed by Hilton Pharma with PKR 4.20 billion. The substantial gap of PKR 23.38 billion between Getz Pharma and its closest competitor highlights its dominance in international markets. Other notable exporters include Sami Pharmaceuticals, The Searle Company, Herbion Pakistan, Genix Pharma, and CCL Pharma, each recording exports of approximately PKR 3 billion in 2024. Additional contributions come from Abbott Laboratories (PKR 2.60 billion), Pharmevo (PKR 2.51 billion), and Nabi Qasim Industries (PKR 2.06 billion).

In terms of growth, Scilife Pharma, Pharmevo, and CCL Pharma recorded the highest increases, with growth rates of 72.9%, 72.4%, and 50.6%, respectively, indicating strong catch-up potential relative to the top three firms. Most leading exporters experienced substantial growth in 2024, except Genix Pharma, which recorded a decline of 16.6%.

Figure 10 illustrates the export shares of pharmaceutical firms in 2024, showing a market highly skewed towards large firms. The top 15 firms account for 67% of total exports, with Getz Pharma alone contributing

29.04%. Hilton Pharma (4.43%) and Sami Pharmaceuticals (3.80%) follow as strong performers, albeit far behind Getz. Other key exporters include The Searle Company (3.67%), Herbion Pakistan (3.45%), Genix Pharma (3.24%), and CCL Pharma (3.13%), reflecting a highly competitive environment. Pharmevo and Nabi Qasim Industries also contribute above 2% each, while smaller firms, such as Scilife Pharma and Highnoon Laboratories, maintain notable, albeit lower, export shares.

Figure 9: Exports Share of Top 15 Pharmaceutical Firms - 2024

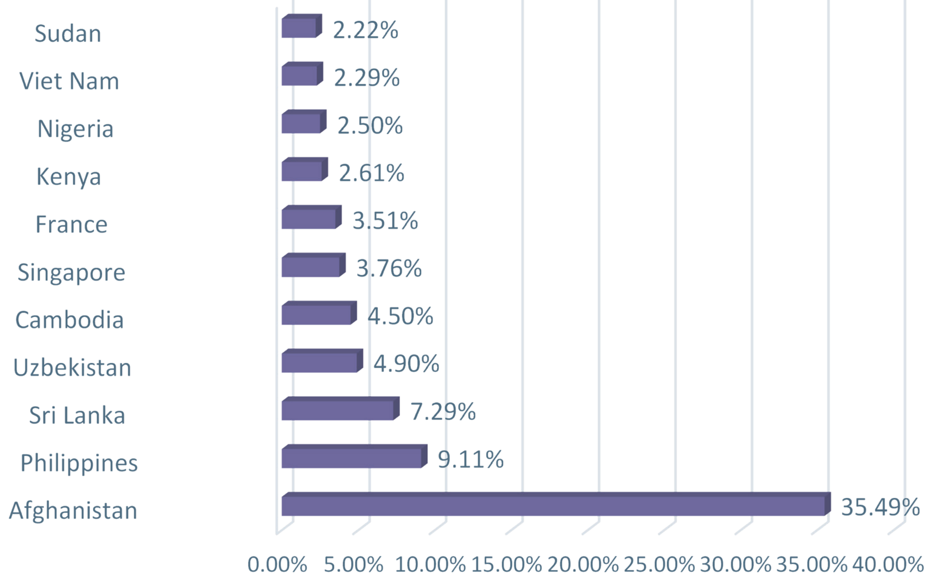


Source: Government of Pakistan (2024) Customs Trade Statistics.

The statistics presented in Table 6 and Figure 9 indicate that export market shares are more concentrated in favour of a few large firms, such as Getz Pharma, compared with domestic sales. In other words, the export market is dominated by relatively few players, whereas the domestic market has a larger number of major firms. This suggests that other large and highly productive firms have substantial potential to enter the export market by enhancing both domestic and foreign innovation activities.

Furthermore, learning-by-exporting represents an important channel for acquiring international knowledge spillovers.

Figure 10: Top 10 Export Destinations by Share – 2023



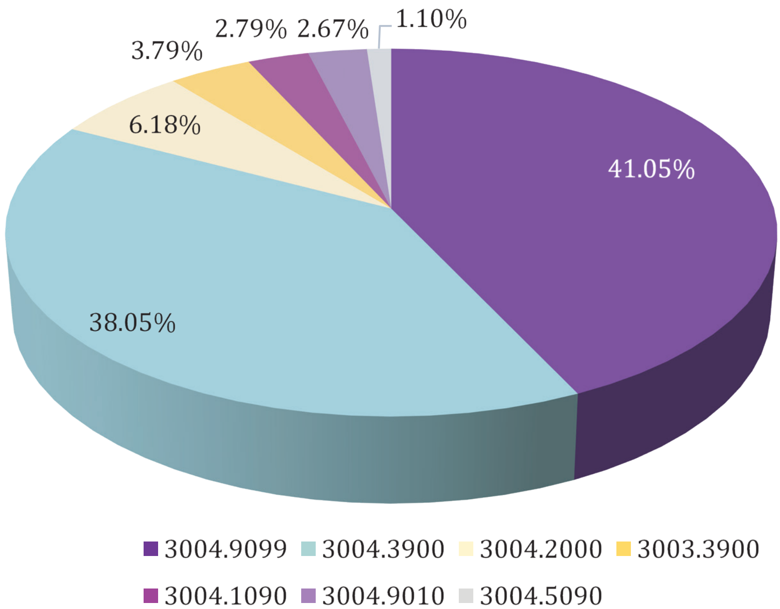
Source: Government of Pakistan (2024) Customs Trade Statistics.

Export destinations of pharmaceutical firms illustrate the opportunities for learning-by-exporting, suggesting that firms exporting to advanced economies are more likely to enhance their innovation capabilities by adopting and internalising advanced technologies. Figure 11 presents the major destinations for Pakistan's pharmaceutical exports. The data indicate that Afghanistan is the dominant market, accounting for 35.49% of the total export value, substantially higher than other countries. The Philippines (9.11%) and Sri Lanka (7.29%) are also significant destinations, followed by Uzbekistan (4.90%) and Cambodia (4.50%). Several countries, including Kenya, Nigeria, and Sudan, represent smaller shares. This pattern underscores a heavy reliance on Afghanistan, with some diversification into secondary markets.

Moreover, the concentration of exports in semi-regulated Asian markets has important implications for learning-by-exporting. Limited exposure to highly regulated or technologically advanced markets restricts access to international knowledge spillovers, a critical source of technological upgrading for firms in developing countries.

In addition, the composition of exports provides insights into the quality and technological content of exported products. Evidence suggests that technology-intensive products constitute the fastest-growing segment of global trade (Lall, 2000). Figure 11 further illustrates the export distribution by HS Code for the period January to August 2024.

Figure 11: Exports Shares by HS Code - 2024

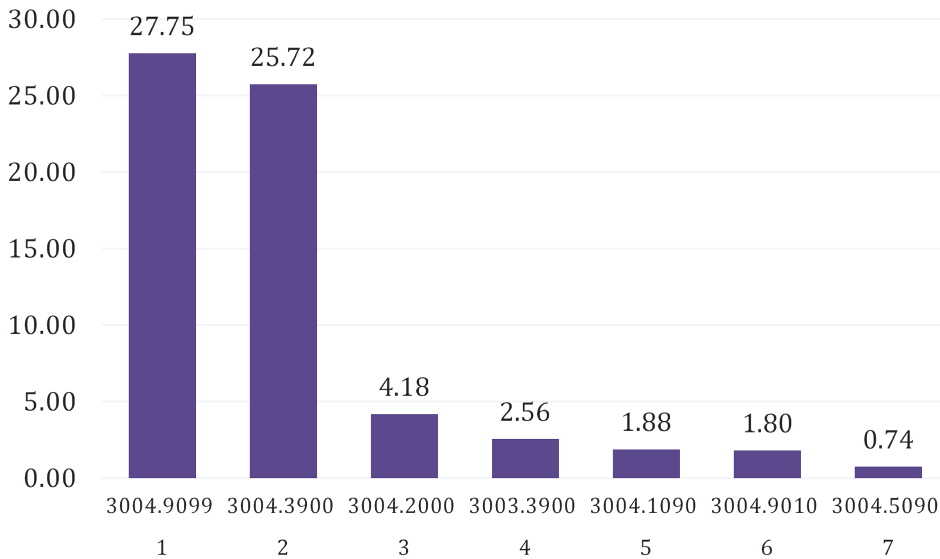


Source: Government of Pakistan (2024) Customs Trade Statistics.

The data indicate that HS Code 3004.9099 (medicaments in specific forms, e.g., tablets, capsules, syrups) dominates Pakistan's pharmaceutical exports, accounting for 41.05% of total exports, closely followed by 3004.3900 (medicaments containing hormones but not antibiotics) at 38.05%. These codes correspond to formulated drugs in which APIs are combined with appropriate excipients and packaged for retail. Other notable contributors include 3004.2000 (6.18%) and 3003.3900 (3.79%).

This pattern reflects a concentration of exports in a limited range of products and highlights the lack of diversification in export offerings. The composition of exports also demonstrates that formulation is the primary activity of pharmaceutical firms in Pakistan, with comparatively less focus on drug discovery or development. Low value addition through formulation may limit the country's ability to achieve export upgrading. Technological innovation (TI) can play a crucial role in promoting product diversification and enhancing export quality.

Figure 12: Top Export Products by Value – 2024 (PKR Billion)



Source: Government of Pakistan (2024) Customs Trade Statistics.

The data presented in Figure 13 indicate that HS Code 3004.9099 leads Pakistan's pharmaceutical exports with PKR 27.75 billion, followed by 3004.3900 at PKR 25.72 billion and 3004.2000 at PKR 4.18 billion. Other notable contributors include 3003.3900 (PKR 2.56 billion) and 3004.1090 (PKR 1.88 billion). These figures illustrate the dominance of a small number of pharmaceutical products in exports and the substantial gap between the top two products and the subsequent ones.

Opportunities

Evolving Drug Demand Patterns

The global pharmaceutical market is undergoing extensive structural changes on both the demand and supply sides. Increases in life expectancy, an ageing population, rising per capita income, higher health expenditure, and growing awareness of healthcare systems have substantially increased global drug demand. This has also diversified the composition of demand towards a wider range of products, including pharmaceuticals, nutraceuticals, herbal medicines, and biologicals. The global nutraceuticals market reached USD 419.9 billion in 2023 and is projected to grow to USD 976.7 billion by 2032 (Fortune Business Insights, 2024). Similarly, the global herbal medicine market was valued at USD 216.4 billion in 2023 and is expected to reach USD 437.2 billion by 2032 (Fortune Business Insights, 2024).

Furthermore, demand for small-molecule drugs is increasing in developing countries, as developed markets are shifting towards biologicals and personalised therapeutic approaches. This evolving global demand pattern presents an opportunity for Pakistan to enhance its export share by producing small-molecule therapeutics, particularly high-quality branded generics, dietary supplements (vitamins), indigenously developed herbal medicines, biosimilars, and simpler biological products, including vaccines.

Global Off-Patent Market

The global off-patent market is projected to reach USD 700 billion in branded generics and USD 381 billion in generics by 2025 (Khan et al., 2021). This presents developing countries with a unique opportunity to produce generics of original drugs at relatively low R&D cost. Consequently, it not only provides cheaper alternatives for the domestic market but also enhances the export potential of countries capable of meeting international regulatory standards. Targeting generics of off-patent drugs further stimulates innovation activities, which, in turn, contributes to export quality upgrading.

Outsourcing Opportunities

Outsourcing serves as an efficient channel for technology transfer in developing countries, which often rely heavily on foreign technology spillovers due to low domestic R&D spending and limited indigenous innovative capability. In the pharmaceutical sector, large firms outsource various stages of drug development through Contract Research and Manufacturing Services (CRAMS) to reduce costs. The global CRAMS market is expanding rapidly, reaching USD 145.37 billion in 2024, with a CAGR of 9.6% (Research and Markets, 2024). Developing countries with an experienced pharmaceutical sector, such as Pakistan, can leverage this opportunity to strengthen indigenous innovative capability via paramedic training, standardisation of laboratories, hospitals and clinical sites for international certification, and the establishment of BE study centres and testing laboratories. Such initiatives facilitate compliance with stringent export requirements imposed by international regulatory authorities.

Indigenous Vaccine Development

The global vaccine market comprised 12.7 billion doses, valued at USD 122 billion in 2022 (WHO Global Vaccine Market Report, 2023), with leading manufacturers including Pfizer (36%), Moderna (15%), and Merck/MSD (9%). As developed countries increasingly shift towards biologicals and personalised treatments, countries with experienced pharmaceutical sectors and robust regulatory frameworks are well-positioned to excel in the production of biosimilars and simpler biologicals, including vaccines and antisera. In Pakistan, vaccine demand has increased due to the government's focus on national immunisation programmes. In 2023, imports of human vaccines amounted to USD 37.05 million, of which approximately 46% came from India and 27% from Germany (WITS, 2024). Imports of antisera and other blood fractions totalled USD 245.27 million, with 48% from Belgium and 14% from India (WITS, 2024). Domestic production of vaccines remains very limited. Technology adoption for indigenous vaccine development is vital and feasible, given the existing industry expertise. Public-private partnerships, such as collaborations between pharmaceutical firms and the National Institute of Health, can act as key drivers for import substitution and capacity building. Furthermore, Asian countries represent relatively less stringent export markets for vaccines.

Thematic Analysis: Issues and Challenges

Regulatory Barriers

Stringent Requirements: Many countries, particularly those with high or medium regulatory standards, impose rigorous drug approval processes—including preclinical and clinical trials, manufacturing, marketing, and post-marketing surveillance—to ensure safety, efficacy, and quality. Pakistani pharmaceutical companies frequently struggle to meet the high-quality standards demanded by international regulatory authorities such as the US FDA, UK MHRA, EMA, and Japan's PMDA. Firms that are members of these regulatory bodies are better positioned to fulfil such requirements. Membership, however, entails a rigorous and costly process, including inspections, plant accreditation, product testing, and other compliance procedures. Table 7 indicates that, among regional countries, India has the highest number of US FDA-approved plants, which correlates with its strong export performance.

DRAP Capacity and Membership: The Drug Regulatory Authority of Pakistan (DRAP) issues guidelines to ensure the safety, quality, and efficacy of formulated drugs. Although guideline clarity has improved, implementation remains weak. DRAP is not a member of any international regulatory body, which poses significant challenges, particularly in medium-regulated markets such as the PICS countries. Membership in PICS evaluates the comprehensiveness of a country's regulatory standards, as well as the technical and human capacity of pharmaceutical firms and regulatory bodies. DRAP is actively working to meet these standards in collaboration with industry stakeholders; however, capacity enhancement—particularly human resources—and legislative amendments are required to ensure compliance with international norms. Furthermore, DRAP's technical expertise in emerging therapeutic areas, including biologicals and AI-based medicines, remains limited.

Bioequivalence (BE) Studies: All countries now require BE studies to evaluate the therapeutic equivalence of a drug to reference products and ensure regulatory compliance. Pakistan currently lacks BE centres approved or partnered with major regulatory authorities, with only five BE/BA study centres operating at a limited scale (DRAP, 2024). Consequently, Pakistan's drug exports are primarily directed towards semi-regulated, low-income countries. Economic theory suggests that exporting is a significant source of foreign technology spillovers via learning-by-exporting; however, this benefit accrues only when exporting to advanced markets while maintaining a threshold absorptive capacity. Table 7 shows that India's main export destinations include highly regulated markets such as the USA, Netherlands, and the UK, supported by one of the largest groups of US FDA-approved manufacturing plants. China also competes in the production and export of biologicals to Europe and the USA, with a substantial number of US FDA-approved facilities and PICS membership. Pakistan and Bangladesh lag in this regard, primarily exporting to semi-regulated Asian markets, although Bangladesh has three US FDA-approved plants and its pharmaceutical exports are emerging, whereas Pakistan has no US FDA-approved plants.

Table 7: Export Value, Destinations and Regulatory Status of Regional Countries – 2023

Country	Export Value ($)	Major Export Destination	US-FDA App	PICS Member	Nature of Product
China	11.3 b	Germany, Switzerland, USA, Belgium, Ireland	28	Yes	Biologicals (Antibiotics , etc.)
India	27.9 b	USA, Netherlands, UK, South Africa, Brazil	650	No	Branded Generics
Pakistan	328 m	Afghanistan, Philippines, Sri Lanka, Uzbekistan, Cambodia,	0	No	Branded Generics
Bangladesh	175.4m	Myanmar, Sri Lanka, USA, Philippines, Afghanistan	3	No	Branded Generics

Source: United Nations (2024); US FDA (2024).

Burdensome Molecule Registration Criteria: The current molecule registration process in Pakistan often leads to significant delays and high post-production costs, leaving firms with a limited R&D budget. For example, once a molecule becomes available for formulation, approximately 350 to 400 firms may apply for generic registration. While this increases competition, it also creates substantial delays. The high number of firms competing for a single molecule drives up advertising costs and places firms at the discretion of prescribing doctors.

In a market dominated by many small firms, low turnover reduces their capacity to comply with quality standards, while operating costs for firms with low standards remain minimal. This dynamic disrupts the capture of off-patent market opportunities. For instance, if 200 molecules go off-patent and many firms seek registration, the resulting backlog at DRAP creates significant delays. Establishing specific criteria for molecule launch permission is therefore critical; however, this is complicated by DRAP's legal obligation to grant registration to any firm that meets all requirements.

Price Rigidity: DRAP regulates the maximum retail price (MRP) of drugs in coordination with the Cabinet Division. Before DRAP's establishment, the pharmaceutical industry experienced a price freeze from 2001 to 2012. Under the Drug Pricing Policy (2018), companies may increase the MRP of essential drugs by 70% of the Consumer Price Index (CPI) with a 7% cap, and non-essential drugs by 100% of CPI with a 10% cap. DRAP may also review hardship cases in consultation with the federal government.

Economic theory identifies several negative consequences of price controls. First, they distort competition. Second, narrow price margins reduce incentives for innovation. Third, they encourage rent-seeking behaviours, such as reporting inflated input costs, creating artificial shortages, and lobbying for monopolistic advantages. Fourth, price control may lead to lower-quality or counterfeit medicines, prompting firms to introduce costly next-generation versions of low-price products. Finally, in an industry reliant on 90% imported APIs, annual currency depreciation of roughly 10%, and high utility costs, price controls significantly constrain business opportunities. Regarding innovation, price caps reduce R&D revenues and limit investment in subsequent drug discovery. Recognising these challenges, in February 2024, the government deregulated prices for drugs not listed on the National Essential Medicines List (NEML).

Legal and Operational Barriers to Toll/Contract Manufacturing Activities: Contract Research and Manufacturing Services (CRAMS) is a proven business model that enables firms to reduce drug manufacturing costs. In this model, a firm outsources clinical trials or the manufacturing of an innovative drug—either fully or partially—to another firm. This allows more innovative, resource-intensive firms to leverage external expertise, while less innovative firms gain access to advanced capabilities through outsourcing collaborations.

Table 8: Clinical Research Landscape in Pakistan

1	**Contract Research Organisations (CROs)**	**26**
2	Bioequivalence/Bioavailability (BE/BA) Centres	05
3	Bioequivalence Studies	05
4	Clinical Trial Sites	103
5	Bioanalytical Laboratories	05

Source: DRAP (2024).

Table 9: Clinical Trials Map

	Region Name	No of Studies
1	World	468,457
2	South Asia	8690
3	India	5287
4	Pakistan	2675
5	Bangladesh	572
6	Nepal	267
7	Sri Lanka	101

Source: ClinicalTrials.gov.

This opportunity is particularly attractive for firms in developing countries, where internal R&D capabilities are minimal. Specifically, the pharmaceutical sector can benefit from attracting foreign clients through clinical trials, outsourcing, or contract manufacturing—especially given that a significant number of SMEs operate below 50% capacity. Low-cost drug manufacturing via contract manufacturing also draws interest from multinational corporations (MNCs).

Currently, Pakistan has a very limited infrastructure to support such activities, with only 26 Contract Research Organisations (CROs), five Bioequivalence/Bioavailability (BE/BA) centres, five bioanalytical labs, and 105 clinical trial sites. University–industry linkages are weak, resulting in firms' reluctance to engage medical universities for clinical trials. Providing incentives to academia could promote the development of facilities conducive to conducting clinical trials. Compared to India and the South Asian average, Pakistan lags in the number of clinical trial studies. Additional legal and operational barriers—including delayed clinical trial approvals, short license durations, and a limited number of products eligible for outsourcing—further constrain the sector.

Innovation Challenges

Low Overall Innovative Capability: Pakistan's overall innovative capability remains low due to insufficient R&D investment and relatively low per capita health and education expenditures compared to regional averages. Table 10 shows that in 2021, Pakistan's R&D spending was only one-fourth of the South Asian average. Similarly, per capita health expenditure in Pakistan stood at USD 43.09, significantly below the South Asian average of USD 70.18. Government expenditure on education was 1.69% of GDP, slightly below the South Asian average of 1.83% in 2021. These indicators collectively point to structural limitations in building strong innovation capacity within the pharmaceutical sector.

Table 10: Innovative Capability: Pakistan Vs South Asia – 2021

1	**Gross Expenditure on R&D (% GDP)**	**South Asia 0.63**
		Pakistan 0.16
2	Health Expenditure per capita (current USD)	South Asia 70.18
		Pakistan 43.09
3	Govt Expenditure on education (% GDP)	South Asia 1.83
		Pakistan 1.69

Source: World Bank (2024).

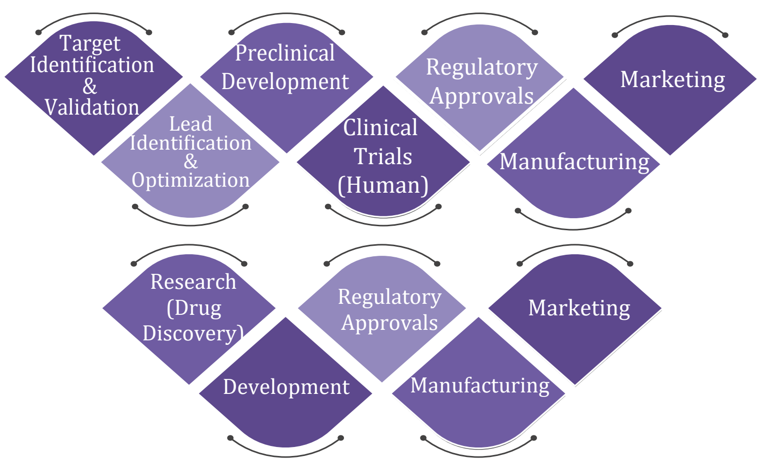
This situation has led to low absorptive capacity and a weak innovation culture in the economy, adversely affecting firm-level innovation. The limited innovative capability is reflected in the low share of medium- and high-tech value addition in manufacturing and the low technological content of exports. In 2021, the share of medium- and high-tech products in total manufactured exports was only 12%, compared to 36% in India and 62% in China, highlighting a substantial gap in the technical sophistication of Pakistan's export basket (World Bank, 2024). Similarly, the share of medium- and high-tech value added in total manufacturing stood at 23%, approximately half of India's 46% and China's 42%, indicating the low technological intensity of domestic manufacturing.

Weak Innovation Value Chain in Pharmaceuticals: The pharmaceutical industry is highly technology-intensive, and its growth largely depends on the production of scientific knowledge. Leading exporters demonstrate that success hinges on a robust innovation value chain, which spans from basic research for drug discovery to raw material procurement, production, and post-production activities, including marketing.

The drug discovery stage is costly and risky, relying heavily on high-quality basic research and effective knowledge collaboration between firms, universities, and public research institutions. The drug development stage depends on well-equipped clinical research organisations and supporting infrastructure. Pakistan's overall weak innovation capability disrupts the pharmaceutical innovation value chain at multiple points. Initial-stage disruptions arise from limited internal and external R&D, the absence of high-quality drug testing laboratories (e.g., US FDA-approved labs), insufficient knowledge-sharing platforms, weak public-private collaboration, a lack of clinical research sites, and delays in regulatory approvals.

At the raw material stage, dependence on imported APIs introduces vulnerabilities related to cost, trade barriers, and macroeconomic fluctuations. Manufacturing-stage rigidities result from inadequate medium- and advanced-scale production facilities and limited bioequivalence testing labs. Although more attention is paid to post-production stages in Pakistan, the distribution system remains fragile, with inefficiencies in drug retail, the absence of model pharmacies, and weak drug courts. Furthermore, strong firm–doctor linkages, while strategically important, impose additional costs on patients. Expenditure concentrated at this stage reduces the funds available for critical drug discovery and development, further weakening the innovation pipeline.

Figure 13: Innovation Value Chain in Pharmaceuticals



Source: Authors' illustration.

Narrow Product Base and Less Technical Product Specialisation: Figures 12 and 13 highlight that Pakistan's pharmaceutical export basket is both less technical and poorly diversified. The data show that 79.1% of exports are concentrated in just two products—HS 3004.9099 and HS 3004.3900—which are relatively simple formulations involving APIs and excipients. This low-value-added formulation activity limits opportunities for technological upgrading.

Regarding product diversification within the sector, nutraceuticals, dietary supplements (e.g., vitamins), and indigenous herbal products account for a negligible share of total turnover. The production and export of these products could increase substantially within 3–5 years if appropriate regulatory and financial measures are implemented, including duty and tax remission incentives for top performers.

In terms of industrial specialisation, Pakistan's pharmaceutical sector remains heavily focused on basic formulation. Approximately 95% of firms are engaged in the formulation of APIs and excipients, while only 5% are involved in semi-basic or basic manufacturing (Table 11). This production specialisation has direct implications for export performance: relying primarily on imported APIs and simple formulation into tablets, syrups, injections, and ointments without innovation constrains entry into markets regulated by stringent regulatory authorities (SRAs). Access to SRA markets is critical for sustained export growth and for benefiting from international technology spillovers, such as learning-by-exporting.

Table 11: Production Specialisation

Production Activity	*No of firms*	*Share in total (%)*
Formulation	623	95%
Semi Basic Manufacture	23	4%
Basic Manufacture	7	1%

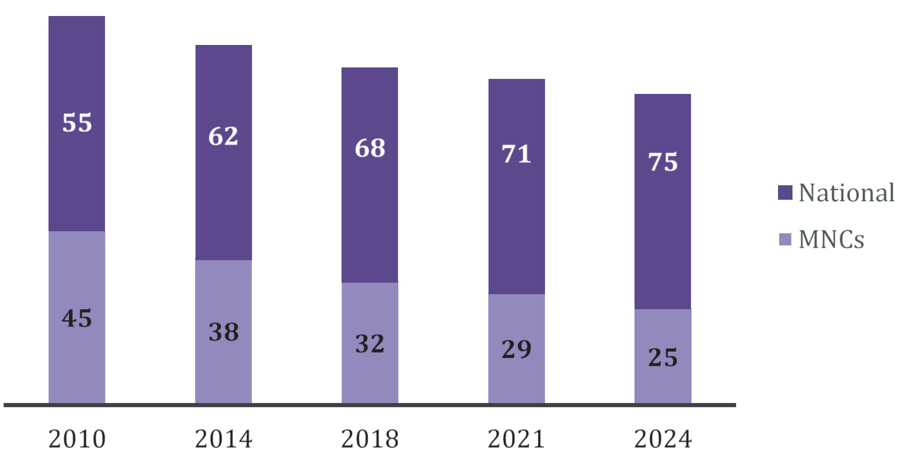
Source: Authors' own compilation based on data from DRAP (2024).

Poor Problem Identification at the Basic Research Institutions: The applicability and industrial use of knowledge generated through basic research are critical for innovation output. Currently, there is a lack of longitudinal or horizontal studies that link academic research to practical industry applications. For instance, some studies suggest that honey can treat typhoid, but they often fail to specify crucial details such as the appropriate dosage form or duration of treatment. Furthermore, the curriculum in national universities offers limited coverage of established standards and pharmacovigilance systems, leading to skill mismatches in the pharmaceutical workforce. This gap largely stems from weak linkages between universities, research centres, and industry, although a few emerging collaborations are visible. Strong linkages would enable the industry to communicate its specific needs to universities, which could then update curricula with modern, relevant content. Currently, processes for identifying industry problems and incorporating them into academic curricula are largely absent. Additionally, offices of commercialisation (ORICs) in most universities show limited capability or interest in supporting startups or fostering student entrepreneurship.

Dwindling sizes of MNCs in the Pharmaceutical Industry: The declining presence of multinational corporations (MNCs) in Pakistan's pharmaceutical sector compounds these challenges. MNC market share has dropped from 45% in 2010 to 30% in 2020 and further to 25% in 2024. The total number of MNCs with a significant market presence has fallen from 40 in 2000 to only 5 in 2024. MNCs play a crucial role in skill and knowledge transfer to domestic firms and are strategically important for ensuring drug availability during crises or pandemics; for example, they were critical in providing timely vaccine access during the COVID-19 pandemic. The current diminished presence of MNCs has limited technology transfer opportunities for local firms.

Several factors contribute to this decline. Price caps, coupled with rising production costs due to currency devaluation and utility price hikes, an unconducive macroeconomic environment, and security uncertainties, discourage MNC investment. Intellectual property rights are weakly protected, allowing generics of newly developed synthetic drugs to enter the market quickly. This erodes monopoly rents for innovator firms and discourages the development of new medicines. Low synergy between MNCs and local firms, often driven by secrecy concerns, further limits skill and knowledge transfer. Consequently, domestic small firms with minimal internal R&D capacity face constrained opportunities for innovation.

Figure 14: MNCs Market Share by Sales Revenue (%)



Source: VIS Credit Rating Company Limited (2023).

The Low Retention Rate of the Export Proceeds

Exporters are allowed to retain a portion of their export proceeds in a special foreign currency account to meet foreign liabilities. The permissible retention rates vary across sectors: up to 33.3% for publishers, 50% for software, IT-enabled services, and freelance services, 15% for pharmaceutical products, 5% for cement, 2% for cotton, and 10% for other goods as specified in Chapter 12 of the Foreign Exchange Manual.

The retention rate of 15% for pharmaceutical firms is relatively low, especially for companies engaging in branding activities for export promotion. These firms incur various expenses, including advertising, staff salaries, and monitoring costs, while purchasing and transferring foreign exchange, particularly USD, from alternative sources is costly. Consequently, this limit constrains market search and export promotion activities. The State Bank of Pakistan (SBP) has relaxed the limit for leading exporters—those achieving a 10% increase in net export proceeds—allowing a retention rate of up to 50% on the additional proceeds. However, industry experts suggest that a flat increase in the retention rate would be more effective, even for potential exporters.

The Skewed Structure of the Pharmaceutical Sector

Pakistan currently hosts approximately 639 pharmaceutical firms, yet the market structure is highly skewed. The top 5 firms account for 30% of market share, the top 10 for 43%, the top 25 for 75%, and the top 50 for 93%. The remaining 590 small firms compete for a mere 7% of the market, highlighting the dominance of a small group of large firms.

Table 12: The Industry Structure of the Pharmaceutical Market

Corporates with 40 Billion Above Value		Corporates with 10 Billion Above Value	Corporates with 5 Billion Above Value	Corporates with 1 Billion Above Value
No of Firms	5	20	12	40
Value (Bn)	Rs 277	Rs 414	Rs 88	Rs 101
Rank/Total	1-5	6-25	26-37	38-77
Market Share:	30.19%	45.19%	9.54%	11.04%
Growth:	20.27%	27.72%	19.31%	20.57%

Source: IQVIA (2024).

This skewed structure has implications for product quality, technology transfer, and export competitiveness. Large firms are more likely to engage in innovative activities and maintain high productivity (Chudnovsky et al., 2006), supported by significant R&D budgets, enabling them to compete on product quality and enter export markets. Conversely, small firms operate on low margins, often competing on price rather than quality, and have limited incentive or capacity to innovate. While small firms provide outsourcing services to large firms, the synergy between the two is minimal, limiting skill and technology transfer. Only a few small firms actively leverage contracts from large firms, often through mergers or acquisitions. Moreover, small firms generally have low compliance capacity with DRAP guidelines, which aim to harmonise with international standards. In the last five years, DRAP has cancelled more than 100 small firm licenses due to compliance issues.

High Production Costs

High Dependence on Imported APIs, Excipients and Packaging Materials: Pharmaceutical production in Pakistan relies heavily on imported APIs, excipients, and packaging materials. Approximately 90% of APIs are imported, and local firms primarily perform formulation into tablets, syrups, ointments, and other dosage forms. This results in limited value addition and minimal product innovation. The reliance on imported raw materials, coupled with rapid exchange rate fluctuations, average annual currency devaluation of ~10%, double-digit inflation, and high financing costs, significantly reduces firm profitability (Business Recorder, 2024)..

High Energy and Other Utility Costs: Pharmaceutical manufacturing is energy-intensive, requiring 10–12 processing steps involving heat and pressure. Electricity costs in Pakistan are 20–22 cents per kWh—much higher than India (7–8 cents) and Malaysia—often necessitating a self-owned standby supply at 50–52 cents per kWh. Water quality is also a concern; TDS values in major cities reach 10,000–11,000 ppm, compared with 75–90 ppm in India and 55–60 ppm in Malaysia. Purification via imported RO plants further escalates production costs. Gas tariffs increased by up to 35% in February 2024, compounding utility expenses.

Lack of Government Support: The sector faces inadequate policy and financial support in several areas:

- Subsidies, tax relief, and export incentives to expand export potential and simplify export rebate and Duty and Tax Remission for Exporters (DTRE) procedures.

- Trade facilitation, including market information sharing, trade shows, and regulatory/importer visits.

- Subsidy schemes for product registration, GMP audit fees, BE study fees, and clinical trial costs; limited facilitation for upgrading manufacturing plants for international accreditation (WHO, USFDA, MHRA, TGA, EMA).

- Financial support for technology transfer projects in vaccines, anti-cancer therapies, and biotechnology, including reduced tariffs for machinery and raw materials.

Local API Production Incentives: DRAP issued an API policy in 2022 offering financial and non-financial incentives for domestic API manufacturing, including customs duty reductions for materials and machinery for five years and tariffs on imported APIs manufactured locally (DRAP, 2022).

3. LITERATURE REVIEW

Standard classical and neo-classical models assume technology to be exogenous and uniformly available across countries. Among the early frameworks recognising the role of technology in production and trade are neo-technology models and technology gap theories (Krugman, 1979). In his seminal study, Krugman (1979) argues that technology develops and matures in advanced countries before diffusing to developing countries, thereby creating trade opportunities. These models emphasise firms' heterogeneity and product differentiation as major drivers of trade (Grossman & Helpman, 1995; Melitz, 2003). However, they predominantly reflect phenomena in developed countries, assuming learning as a constant factor and attributing a limited role to technology adoption.

An early framework addressing capability enhancement in developing countries is the resource-based view (RBV), which posits that firms' capabilities are shaped by heterogeneous and immobile resources—including assets, organisation, attributes, and knowledge—which determine sustained competitive advantage (Barney, 1991). The capability approach (Lall, 2000) further argues that firms' innovation capabilities can be strengthened through learning and knowledge spillovers arising from trade and foreign direct investment (FDI). Government policies on trade and innovation are also critical in this context (Rodrik, 2006). Extending this, the dynamic capability view emphasises the creation of new capabilities by firms and the utilisation of internal and external competencies to adapt to technological change. More recently, endogenous growth models associated with new trade theories underscore technology's role in intra-industry and intra-product trade, highlighting that product variety—alongside scale and agglomeration economies—determines export potential (Schott, 2008).

Technological innovation affects export performance through multiple channels. Existing literature identifies two primary mechanisms: internal R&D and external technology acquisition (Herzer, 2022). Internal R&D fosters a culture of innovation, with universities and public institutions initiating basic research while industries facilitate applied research (Loof & Heshmati, 2002). In developing countries, external technology diffusion—via imports or direct technology acquisition—is particularly crucial due to the limited capacity to develop indigenous technologies (Rauf et al., 2023). Combined, these efforts enhance labour productivity and reduce average production costs, enabling firms to compete globally through low costs, high quality, and diversified products (Coe & Helpman, 1995; Cassiman & Veugelers, 2006).

Evidence indicates that various dimensions of technological innovation enhance a firm's export propensity and intensity (Becker & Egger, 2013). In developing countries, this is largely driven by innovation-induced productivity improvements (Herzer, 2022), differences in resource endowments (Barney, 1991; Loof & Heshmati, 2002), firm-level absorptive capacity (Harris & Li, 2009), technology transfer via trade and FDI (Lall, 2000), product variety (Schott, 2008), and external technology acquisition (Hou & Mohnen, 2013). Nevertheless, empirical evidence on the relationship between innovation and export performance in developing countries remains limited. Available studies suggest a positive impact of domestic and external technology acquisition on total factor productivity and export performance in China (Wang et al., 2013; Yu et al., 2022). Herzer (2022) reports positive effects of domestic and foreign R&D on exports across 32 developing countries. Similar findings have been documented in India (Rijesh, 2020) and Sub-Saharan Africa (Barasa et al., 2021). In Pakistan, Wadho & Chaudhry (2018) provide insights into the innovation–firm performance nexus in the textile and apparel industry, demonstrating a positive impact of innovation on firm performance; however, the study does not address export performance.

To our knowledge, the present study is the first to systematically analyse the relationship between innovation and firms' export performance in Pakistan's pharmaceutical sector—a sector that has received limited attention despite its substantial economic significance.

A summary of related studies' objectives and findings is presented in Table 13 below.

Table 13: Summary of Literature Review

Author(s)	Objective and Results of the Study
Coe & Helpman (1995)	This seminal study assesses the role of international R&D spillovers through trade in the productivity growth of firms, concluding that the R&D capital of trading partners significantly affects innovation in domestic enterprises.
Alvarez (2001)	The study concludes that there is a two-way causation between exports and technological innovation in the Chilean manufacturing industry. Further, FDI and technology licensing also affect innovation, but to a lesser extent than indigenous innovation.
Lööf & Heshmati (2002)	The study assesses the relationship between knowledge capital and performance heterogeneity of 619 Swedish manufacturing firms during 1995-1998. The results show a positive relation between knowledge capital and performance heterogeneity. The result holds after controlling for human capital, firm size, type of output and other related factors.
Baldwin & Gu (2004)	Using a dataset of 1430 Canadian manufacturing plants, the study mainly retrieves three findings. First, trade liberalisation stimulates export growth. Second, a firm's participation in the export market is attributed to the plant's productivity growth. Third, technology transfer attributed to exporting enhances the absorptive capacity of firms.
Rodríguez & Rodríguez (2005)	The study investigates the impact of technological capacity on export behaviour of 1234 Spanish firms in 1998-99, finding a positive impact of technological capacity of firms on export propensity and export intensity.
Cassiman & Veugelers (2006)	The study investigates the complementarity between internal R&D and knowledge acquisition from foreign sources in the Belgian manufacturing industry. The results show that internal R&D and foreign knowledge acquisition are complementary and that the extent of this complementarity depends upon basic R&D capability.
Chudnovsky et al. (2006)	The study argues that Internal R&D and external technology acquisition increase the likelihood of firms' involvement in new product and process innovation. Large firms are more likely to engage in innovative activities, and innovators have high productivity.

Author(s)	Objective and Results of the Study
Lachenmaier & Wößmann (2006)	The study investigates whether innovation causes exports using a sample of 981 German manufacturing firms in 2002. The results of the study show that specific impulses and obstacles cause variation in innovative activity of firms and are exogenous to firms' exporting activity. Innovation associated with this variation induces export.
Rothaermel & Hess (2007)	The study develops a multilevel (individual, firm and network or external level) model of innovation strategies, corroborating that knowledge spillovers from technology alliances and technology acquisition induce firms' innovation performance.
Şentürk and Erdem (2008)	The differentiating factors of exporting firms from non-exporting firms include the number of employees, firms operating in cities having a development index above zero and others. Further, the exporting intensity growth of firms is determined by having a marketing department, the number of employees, firms having quality standard certificates, having
Lages et al., (2009)	The paper utilises the resource-based view (RBV) to examine the impact of firms' capabilities (learning capability, quality capability, among others) on product quality and export performance. The results of the study show that firms' diverse capabilities improve product quality and induce export competitiveness.
Foster & Rosenzweig, (2010)	The authors study the barriers to international technology diffusion to low-income countries by reviewing related microstudies. The findings of the study reveal that the difference in own and social learning, skill of workers, innovation externality and scale economies are barriers to technology diffusion to firms in developing countries.
Lileeva & Trefler (2010)	The study assesses the role of input variety owing to higher access to foreign markets and technology, arguing that input variety enhances labour productivity, promotes product innovation and accelerates the rate of adopting imported manufacturing technology.
Hagedoorn & Wang (2012)	The study examines the substitutability or complementarity of internal and external R&D efforts for the innovation output of pharmaceutical firms. The results show that the internal and external R&D are complements for firms with higher levels of R&D capability, while substitutes for firms with low levels of R&D capability.
D'Este et al. (2012)	Revealed and deterring barriers hinder the innovation activity of firms. Firms that actively engage in innovative activities face revealed barriers, which can be minimised by micro-level policies leading to better innovation management. Firms that do not engage in innovation face deterring barriers such as the high cost of innovation. Revealed and deterring barriers may simultaneously present.

Author(s)	Objective and Results of the Study
Becker & Egger (2013)	The findings of the study show that product and process innovation increase a firm's propensity to export, but product innovation induces export propensity to a greater extent.
Zhu & Fu (2013)	The paper assesses the drivers of export sophistication in low-, middle- and high-income countries. The study finds that knowledge creation activities, import of intermediate products and absorptive capacity contribute to export upgrading.
Wang et al. (2013)	External technology acquisition (domestic and foreign) has a positive and significant impact on the export performance of the Chinese firms.
Santacreu (2015)	The paper develops a multi-country endogenous growth model in which countries are grouped as emerging, less innovative and more innovative. The study confirms that domestic innovation and the adoption of imported technology are crucial drivers of growth. Further, the study finds that the import of technology is a relatively more significant channel to enhance the innovation capability of enterprises in developing countries, which account for 65% of embodied growth.
Feng et al., (2016)	The paper estimates the impact of imported intermediate input use on exports in China. The results suggest that firms in the import of intermediate inputs increase volume as well as the scope of export. Further, the benefit of imported input use depends upon the firms' ownership structure, R&D capability, and innovation capability of source and destination countries. The study finds that, in terms of magnitude, a 1% increase in intermediate input raises exports by 1.6%. However, Liu and Qiu (2016) find that tariff reduction for intermediate input decelerates innovation in Chinese firms.
Atkin et al., (2017)	The study employs an experimental approach to study the barriers to technology adoption in soccer ball firms in Sialkot, Pakistan. The study performed two experiments by providing employees with a new technology to witness its adoption. The study finds the misalignment of incentives between owners and employees as a barrier to technology adoption.
Wadho & Chaudhry (2018)	The paper utilises a multi-stage structural model to determine the link between production innovation and firms' performance using a sample of textile and apparel industry firms in Pakistan. The study finds that innovation enhances labour productivity and firm performance, while the role of foreign knowledge spillovers is critical for firms' innovation performance.
Wang & Tao (2019)	The study finds that firms with both product exports and a technology import mechanism have higher growth rates. A firm's entry into export leads to an increased probability of engaging in technology import. Thus, there is a complementary effect of export entry and technology import on growth rate.

Author(s)	Objective and Results of the Study
Rijesh (2020)	Using a sample of 3209 Indian firms during 1995-2016, the study shows that the embodied technological knowledge promotes the export of intermediate and capital goods while disembodied technological knowledge fosters the export of consumer and capital goods.
Khan et al. (2021)	The study seeks to unleash the potential of pharmaceuticals in Pakistan, suggesting that different kinds of regulatory, market structure and value chain-related issues may be resolved to improve its economic significance.
Yu et al. (2022)	The study examines the effect of the different channels of technology transfer and absorptive capacity on total factor productivity (TFP) of 420 Chinese firms from 2004 to 2017. The results show that cross-national knowledge transfer (CNKT) enhances the TFP and provides absorptive capacity to absorb international knowledge spillovers.
Herzer (2022)	Domestic R&D and international R&D spillovers induce total factor productivity (TFP) in developing countries, while domestic R&D has a much greater effect on TFP in them.
Rauf et al. (2023)	The paper investigates the role of imported technology in the export performance of manufacturing industries in China, finding that although technology embedded in imported intermediate goods directly affects export upgrading, the technology acquired through licensing does not directly affect export performance but rather requires a threshold level of absorptive capacity.
Haddoud et al. (2023)	Using a Sample of 446 Moroccan SMEs, their study shows that R&D expenditure and licensing of foreign technology foster innovation, which in turn enhances export intensity.
Wadho & Chaudhry (2024)	The study constructs five metrics of process innovation using primary data collected from the textile sector of Pakistan to assess innovation-performance interplay. The findings show that process innovation enhances labour productivity and sales revenue, suggesting significant firm heterogeneity in the extent of the impact.
Xuan & Tan (2024)	Government support directly affects the export performance of Vietnamese SMEs, and it indirectly affects export through its interaction with a firm's internal export stimuli.
Audretsch & Belitski (2024)	The findings of the study show that knowledge collaboration at the regional/national/international level and firm productivity promote TI.

Source: Authors' compilation.

4. DATA AND METHODOLOGY

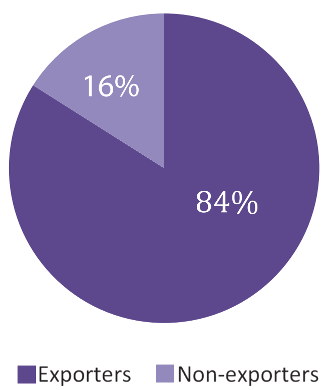
Data Description

The pharmaceutical sector is defined as all manufacturing activities classified under Section 21 (Class 2100) of the Pakistan Standard Industrial Classification (PSIC), Revision 4.0, 2010, and under the International Standard Industrial Classification (ISIC), Revision 4.0, 2008. This study employs a research design based on primary data. Between August and October 2024, we surveyed pharmaceutical firms located in Punjab, Sindh, Khyber Pakhtunkhwa (KPK), and the Islamabad Capital Territory.

The total population of pharmaceutical firms in Pakistan is 639, of which 623 (97%) are located in these provinces. The sampling frame was drawn from the directory of pharmaceutical manufacturing firms issued by the Drug Regulatory Authority of Pakistan (DRAP), which lists all registered pharmaceutical firms in the country (DRAP, 2024). A stratified random sampling method was employed, with strata defined by the geographical location of the firm as indicated in the sampling frame. The sample is representative at both the provincial and regional/district levels.

The sample size comprises 100 firms, representing 16% of the population. All regional and district-level industrial clusters with more than 15 pharmaceutical firms were surveyed. The overall response rate was 51%, reflecting the sensitive nature of the industry. Moreover, many firms consist of only two or three operational sections and have limited involvement in innovation or export activities. Consequently, the main sample was reduced to 51 firms, of which 43 firms (84%) reported positive export values in 2023–24.

Figure 15: Export Wise Firm Frequency



Source: Authors' compilation.

Table 14 presents the region- and district-wise distribution of respondents. Twelve respondents each belong to Lahore, Karachi, and Islamabad, representing 7%, 9%, and 9% of the total sample, respectively. Nine responses were collected from Peshawar, accounting for 22% of the total, while three respondents each were from Faisalabad and the Hattar Industrial Estate, Haripur, representing 9% and 13% of the population, respectively.

Table 14: Region/District Wise Distribution of the Main Sample

	Total	Responses	%
Lahore	175	12	7%
Karachi	130	12	9%
Rawalpindi/Islamabad (Rawat)	128	12	9%
Peshawar	41	9	22%
Faisalabad/ Sheikhupura	33	3	9%
Haripur (Hattar)	23	3	13%

Source: Authors' own compilation based on survey responses.

Section 2 above discusses the regulatory barriers, R&D rigidities, and export challenges faced by pharmaceutical firms in Pakistan. This study also aims to empirically examine the impact of different channels of technology and innovation (TI) and other critical factors, as discussed in Section 2, on the export performance of pharmaceutical firms. To this end, we developed a structured questionnaire to collect information on firms' characteristics (size, productivity, absorptive capacity), firms' engagement in innovation activities—including sources (internal and external, domestic and foreign) and types (product, process, and organisational) of innovation—the factors constraining innovation activities, and the factors promoting TI. In addition, information was collected on other supply- and demand-side factors influencing firms' export performance. Furthermore, we conducted twelve semi-structured interviews with key stakeholders from manufacturers, the Pakistan Pharmaceutical Manufacturers' Association (PPMA), academia, and DRAP to refine and consolidate the collected information.

Regarding firms' characteristics, firm size (Size) and firm productivity (Productivity) are measured by the number of employees and the ratio of sales revenue to employment, respectively. Firms' absorptive capacity is proxied by two variables: human capital (HCAP), measured as the share of university graduates in total employment, and training and hiring of R&D personnel (Training).

Regarding sources and types of innovation, the former is proxied by internal R&D (Int_R&D) and external technology acquisition (Ext-Tech) from domestic and foreign sources, while the latter is measured by process innovation (Process), organisational innovation (ORGINV), and innovation variety (Variety).

Concerning factors accelerating TI, the study includes technology transfer through FDI (FDI), infrastructure development (Infrastructure), research collaboration (Collaborate), and knowledge spillovers (Spillovers). Factors hindering TI include industry structure (Ind_Structure), regulatory factors (Regulatory), and financial/cost factors (Financial).

Finally, other critical factors influencing export performance include product diversification (Diversify), membership of regulatory bodies (Membership), infrastructure development (Infrastructure), and government incentives and facilitation (Gov-support). A detailed description of all variables is provided in Table 1A of the appendix.

Methodology

We develop two single-equation empirical models: an innovation equation and an export equation. The objectives are twofold: first, to empirically assess the factors that significantly enhance firms' innovation performance; and second, to systematically estimate the impact of various channels of technology and innovation (TI), along with other critical determinants, on firms' export performance. This holistic approach enables a comprehensive empirical evaluation of the factors influencing firm-level export performance. The innovation equation is specified as follows:

$$\begin{aligned} Innovation_i &= \alpha + \beta_1 Size_i + \beta_2 HCap_i + \beta_3 Prductivity_i + \beta_4 Ex\_Tech_i + \beta_5 FDI_i + \beta_6 Training \\ &+ \beta_7 ORGINV_i + \beta_8 Spillovers_i + \beta_9 Collaborate_i + \beta_{10} Regulatory_i + \beta_{11} Ind\_Structure_i \\ &+ \beta_{12} Financial_i + \varepsilon_i \qquad (1) \end{aligned}$$

The dependent variable of the innovation equation is measured by the firm's decision to innovate (Decision) and R&D intensity (R&DINT). These are regressed on several determinants, including firm size (Size), firm productivity (Productivity), human capital (HCAP), training and hiring of R&D personnel (Training), and external technology acquisition (Ext_Tech). Equation (1) also incorporates measures of factors that accelerate innovation, such as knowledge spillovers (Spillovers) and research collaboration (Collaborate), as well as factors that constrain innovation, including regulatory factors (Regulatory), industry structure (Ind_Structure), and financial/cost factors (Financial).

Similarly, our export equation takes the following form:

$$EXP_i = \alpha + \beta_1 Size_i + \beta_2 Int\_R\&D_i + \beta_3 Ex-Tech_i + \beta_4 PROCESS_i + \beta_5 Variety_i + \beta_6 Diversify + \beta_7 Infrastructure_i + \beta_8 Membership_i + \beta_9 Gov\_Support_i + \varepsilon_i \quad (2)$$

Where the dependent variable EXP is measured using two variables, including export propensity (EXPPRO) and export intensity (EXPINT), which is then estimated on Firm size, Internal R&D, External technology acquisition, Innovation variety, Product diversification, Infrastructure development, firm's membership of stringent regulatory bodies (Membership) and government incentives and facilitation (Gov-Support).

Table 1A shows that two of our dependent variables, Decision and EXPPRO, as well as several independent variables, are dichotomous, taking binary values of 0 or 1. Binary data are common in many practical problems across disciplines, particularly in social and medical sciences. Such models are typically estimated using standard logistic regression. However, our dataset presents three challenges.

First, the sample size is small, with only 50 observations. In such cases, standard logistic regression may be unstable and prone to bias, as inference in logistic models generally relies on large-sample properties.

Second, there is a severe imbalance in the data. For instance, the dependent variable Decision contains 45 cases of "1" and only 5 cases of "0." This imbalance increases the likelihood of separation, leading predicted logistic probabilities to approach 1. Consequently, the model struggles to distinguish between the two outcomes because the zeros are so sparse.

Third, there is a risk of separation, which occurs when independent variables perfectly or nearly perfectly predict the dependent variable for one category. In our case, with very few zeros, the model may assign extreme probabilities. For example, the standard logistic model predicted a probability of 0.97, which can cause maximum likelihood estimates to diverge toward infinity.

To address these issues, we employ Firth's Logistic (FL) regression to estimate equations (1) and (2). The FL regression applies a penalisation method that reduces bias in maximum likelihood estimates arising from small sample sizes and imbalanced data, while also producing stable and finite estimates even in the presence of separation. In short, FL regression enables us to obtain meaningful and reliable insights despite the skewed distribution of the dependent variable.

Consider the logistic regression model with the log-likelihood function for nnn subjects:

$$l(\beta) = \sum_{i=1}^{n} \left[y_i \beta^T x_i - log\left(1 + exp(\beta^T x_i)\right)\right] \tag{3}$$

The Firth's Method modifies the log likelihood function by introducing a penalty term:

$$l^*(\beta) = l(\beta) + \frac{1}{2} log|(I\beta)| \tag{4}$$

Where $I(\beta)$ is the information matrix evaluated at β

It is important to mention a limitation that the magnitude of the coefficients in an FL regression model is not directly interpretable as odds ratios or the marginal effects in the standard logit models. While these values do not translate directly into changes in odds ratios, they credibly indicate the significance, relative strength and direction of the influence of the independent variables on the dependent variable. Further, to enhance the reliability of our results, we applied the bootstrap method to obtain robust standard errors. This approach involves resampling the data multiple times to create various subsets and recalculating the estimates for each sample. By doing so, we account for variability in the estimates caused by the small and imbalanced dataset. The bootstrap-derived standard errors provide a more accurate measure of uncertainty around the coefficients, ensuring that the interpretations remain robust and dependable even under challenging data conditions. This combination of FL regression and bootstrap methodology strengthens the credibility of our findings. Moreover, we estimate bivariate specifications of the estimation equation to tackle the strong association in independent variables in the wake of binary outcomes.

5. RESULTS AND DISCUSSIONS

The FL regression estimates for the innovation and export equations are presented in Tables 16 and 17, respectively. Before examining these results, we conducted a correlation analysis, summarised in the correlation matrix in Table 15.

The correlation coefficients indicate significant associations between the independent and dependent variables. For instance, firm size exhibits a positive correlation with both the decision to innovate (Decision) and R&D intensity (R&DINT), suggesting that larger firms are more likely to allocate resources towards innovation. Similarly, firm productivity (Productivity) shows a positive association with Decision and R&DINT, indicating that more efficient firms tend to engage more actively in innovation. Human capital (HCAP) and training (Training) also demonstrate meaningful relationships with Decision and R&DINT, underscoring the importance of absorptive capacity in promoting innovation activities.

Table 15: Correlation Matrix

Variable	*Decision*	*R&DINT*	Variable	*EXPPRO*	*EXPINT*
Firm Size	0.1676	0.2335	***Firm Size***	0.3271	0.2734
Human Capital	0.1410	0.2436	***Internal R&D***	0.4677	0.198
Firm's Productivity	0.1831	0.2464	***External Technology Acquisition***	0.5789	0.2451
External Technology Acquisition	0.8079	0.6692	***Process Innovation***	0.4677	0.198
FDI	0.5059	0.4880	***Innovation Variety***	0.5789	0.2451
Training	1.0000	0.6876	***Product Diversification***	0.4677	0.198
Organizational Innovation	1.0000	0.6876	***Infrastructure***	0.5789	0.1386
Knowledge Spillovers	0.8079	0.6692	***Membership***	0.5789	0.2451
Research Collaboration	0.8079	0.6692	***Gov_Support***	0.5789	0.2451
Regulatory Factors	0.6999	0.4812			
Industry Structure	0.6999	0.4812			
Financial Factors	0.6999	0.4880			

Source: Authors' compilation.

External technology acquisition (Ext_Tech) and FDI are also strongly associated with both dependent variables, highlighting that external R&D and foreign technology transfer play a significant role in enhancing firms' innovation performance. Organisational innovation (ORGINV) is positively correlated with both Decision and R&D intensity, suggesting that internal capacity-building efforts are closely linked to the development of firms' innovative capabilities. Additionally, knowledge spillovers (Spillovers) and research collaboration (Collaborate)—key collaborative drivers of innovation—show positive associations with Decision and R&DINT, emphasising the benefits of knowledge-sharing and cooperative endeavours. Interestingly, Table 15 indicates that regulatory factors (Regulatory), industry structure (Ind_Structure), and financial factors (Financial) also influence these outcomes. While these factors would a priori be expected to exert a negative effect, the correlations suggest some ambiguity, underscoring the need for a systematic empirical assessment of the determinants of firms' innovation performance.

Similarly, the associations of Propensity to Export (EXPPRO) and Export Intensity with the selected variables are reported in Table 15. The correlation coefficients indicate that firm size (Size), internal R&D (Int_R&D), external technology acquisition (Ext_Tech), and innovation variety (Variety) are positively associated with both export propensity and intensity, highlighting the critical role of firm size as well as the sources and types of innovation in shaping firms' export performance. Additionally, product diversification (Diversify), infrastructure development (Infrastructure), membership of regulatory bodies (Membership), and government support (Gov_Support) are positively correlated with both export outcomes, suggesting that these factors equip firms with the capabilities required to compete effectively in international markets. The preceding discussion provides a strong rationale for an in-depth empirical assessment of the determinants of innovation and export performance in the pharmaceutical sector.

Empirical Estimates of the Determinants of a Firm's Innovation Performance

Table 16 presents the Firth's Logistic regression estimates for the determinants of firms' decision to innovate (Decision). The signs and significance levels of the estimated coefficients indicate the direction and relative influence of the independent factors. Overall, the estimates are plausible, as confirmed by the model diagnostics reported at the bottom of Table 16. The McFadden R^2 ranges from 0.649 to 0.688, while the Cragg-Uhler R^2 ranges from 0.689 to 0.735, reflecting a reasonable goodness of fit.

The estimated coefficients for external technology acquisition (Ext_Tech), FDI, and firm productivity (Productivity) in Model 1 are positive and statistically significant, with results consistent across Models 1 to 10. These findings highlight the positive effect of acquiring technology from domestic and foreign sources—through the import of machinery and equipment (embodied knowledge) and the licensing of technology (disembodied knowledge)—on a firm's decision to innovate. FDI is similarly critical, underscoring the role of multinational corporations in facilitating skill and knowledge spillovers to domestic firms. The positive and significant coefficient for firm productivity indicates that more efficient firms are more likely to engage in innovation activities. The coefficient magnitudes—2.676 for Ext_Tech, 1.39 for FDI, and 1.6148 for Productivity—suggest that external technology acquisition has a stronger effect on the decision to innovate than either FDI or firm productivity.

The coefficients for training (Training) and human capital (HCAP), reported in Models 2 to 4, are positive and significant, highlighting the crucial role of absorptive capacity in fostering innovation. These results indicate that employees' skills, technical expertise, and access to internal and external training enhance firms' ability to internalise and exploit knowledge, thereby supporting innovation. Economic theory suggests that firms must reach and maintain a threshold level of absorptive capacity to benefit from indigenous innovation and to adopt foreign technology spillovers effectively.

Similarly, the coefficient for organisational innovation (ORGINV) in Model 5 is positive and significant, implying that the adoption of modern organisational methods, business practices, and workplace arrangements strengthens firms' innovative capabilities, facilitating greater engagement in innovation activities.

The estimated coefficients for knowledge spillovers (Spillovers) and research collaborations (Collaborate) are positive and significant in Models 6 and 7, indicating their critical role in driving firms' innovation performance. In the pharmaceutical sector, contract research and manufacturing services (CRAMS) serve as important channels for knowledge spillovers. These results highlight the significance of contract research organisations (CROs) and toll/contract manufacturing services in enhancing firms' innovation capabilities. Furthermore, the findings confirm that research collaborations—through strategic partnerships and joint ventures—are key drivers of firms' innovation decisions, underscoring the importance of university–research institution–industry linkages. Notably, the coefficient magnitudes for knowledge spillovers and research collaborations exceed those of external technology acquisition and FDI, suggesting that these more inward-oriented factors may have a greater influence on innovation than outward-oriented determinants.

Regarding factors restricting innovation, the estimated coefficients for industry structure (Ind_Structure) and financial factors (Financial) in Models 8 to 10 are negative but statistically insignificant, while the coefficient for regulatory factors (Regulatory) is also insignificant, contrary to a priori expectations. A possible explanation is that these institutional and structural factors are relatively stagnant and may only exhibit notable changes following major policy shifts, which our dataset may not fully capture.

Table 16: Empirical Estimates of the Determinants of a Firm's Decision to Innovate

Regressors	Dependent Variable: Decision to Innovate									
	Model 1	**Model2**	**Model 3**	**Model 4**	**Model5**	**Model6**	**Model 7**	**Model 8**	**Model 9**	**Model 10**
Constant	-23.8655*	-9.66944	-2.0237	-2.3887	-1.6094	-23.8655	-23.8655	-19.1173	-20.5233	-20.5211
	-12.7244	-7.20998	-0.5056	-0.748	-0.4278	-12.2963	-13.0424	-10.0235	-11.2652	-11.777
External Technology Acquisition	2.6769***	1.3837**	1.0224*	0.9363*	1.0986*	1.6148**	0.9911*	2.1101**	2.4451***	2.0341**
	-1.08	-0.6391	-0.5849	-0.5481	-0.5713	-0.865	-0.5122	-1.0991	-1.0413	-1.1405
FDI	1.3933*	1.4254***	1.4786***	1.4721***	2.2687***	1.3933*	1.3933*	2.2974**	1.3192*	1.3192*
	-0.8494	-0.5693	-0.5082	-0.4933	-0.4909	-0.8542	-0.7723	-1.0413	-0.6761	-0.8013
Firm's Productivity	1.6148*	0.5775*	--	--	--	--	1.6148	1.3079	1.41	1.4221
	-0.8973	-0.3128	--	--	--	--	-0.9099	-0.9454	-0.8172	-0.7221
Training	--	1.9725***	2.6300***	2.6067***	--	--	--	--	--	--
	--	-0.8259	-0.5649	-0.5271	--	--	--	--	--	--
Human Capital	--	--	0.1530*	--	--	--	--	--	--	--
	--	--	(0..0901)	--	--	--	--	--	--	--
Organizational Innovation	--	--	--	--	2.7081***	--	--	--	--	--
	--	--	--	--	-0.5486	--	--	--	--	--
Research Collaboration	--	--	--	--	--	2.6769***	--	--	--	--
	--	--	--	--	--	-1.1228	--	--	--	--
Knowledge Spillover	--	--	--	--	--	--	2.6769***	--	--	--
	--	--	--	--	--	--	1.0659	--	--	--
Regulatory Factor	--	--	--	--	--	--	--	1.3339	--	--
	--	--	--	--	--	--	--	1.3962	--	--
Industry Structure	--	--	--	--	--	--	--	--	-0.1917	--
	--	--	--	--	--	--	--	--	0.2043	--
Financial Factors	--	--	--	--	--	--	--	--	--	-0.1916
	--	--	--	--	--	--	--	--	--	-0.2811
Observation	50	50	50	50	50	50	50	50	50	50
Diagnostic Test										
Mcfadden R2	0.678	0.649	0.689	0.668	0.673	0.678	0.671	0.655	0.632	0.688
Cragg-Uhler R2	0.721	0.701	0.735	0.718	0.725	0.721	0.711	0.688	0.686	0.7322
Log-likelihood (intercept)	-10.077	-11.927	-11.234	-11.529	-11.996	-10.077	-11.558	-6.987	-11.919	-11.2265
Log-likelihood (Full Model)	-3.244	-4.192	-3.496	-3.824	-3.917	-3.244	-3.8145	-4.5858	-4.381	-3.4489

*Notes: Standard errors are in parentheses. * Significance level of 10%, ** Significance level of 5%, *** Significance level of 1%.*

Source: Authors' compilation.

Empirical Estimates of the Determinants of a Firm's Export Performance

The Firth's Logistic regression estimates for the determinants of firms' propensity to export (EXPPRO) are reported in Table 17. The rationale for estimating bivariate models is discussed in the methodology section. Overall, the results are plausible, with McFadden R^2 ranging from 0.364 to 0.51 and Cragg-Uhler R^2 ranging from 0.46 to 0.62, indicating a reasonable goodness of fit.

The estimated coefficient for firm size (Size) is positive and significant, confirming that larger firms are more likely to enter export markets. This result is consistent across Models 1 to 8. Larger firms tend to allocate more resources to innovation and maintain R&D-friendly organisational structures. Given that firm size is also a critical determinant of innovation performance, these findings suggest that more innovative and productive firms are better positioned to engage in global trade.

The coefficients for internal R&D (Int_R&D) and external technology acquisition (Ext_Tech) are positive and significant (Models 1 and 2), indicating that both internal innovation activities and technology acquired from domestic and foreign sources are essential for market entry. These findings align with neo-technology models, which emphasise the role of R&D in production and trade structures (Krugman, 1979). R&D enhances product design, variety, quality, and reliability (Rodil et al., 2016) while increasing labour productivity, which is particularly critical in developing countries with high labour cost shares (Rauf et al., 2021). External technology acquisition—through the import of advanced machinery (embodied knowledge) and licensing of technology (disembodied knowledge)—complements internal R&D, enhancing export performance (Hagedoorn & Wang, 2012). In developing countries, these findings indicate that firms can boost exports by accelerating indigenous innovation and internalising international technology spillovers. Coefficient magnitudes suggest that internal R&D and external technology acquisition have a greater effect on export propensity than firm size.

Process innovation (Process) and innovation variety (Variety) are also positive and significant (Models 3 and 4), indicating that engagement in diverse technological and non-technological innovations reduces production costs and facilitates compliance with Good Manufacturing Practices (GMP), which is crucial for export performance in the pharmaceutical sector.

The estimated coefficients for product diversification (Diversify) and infrastructure (Infrastructure) in Models 5 and 8 are positive and significant, confirming their role in promoting entry into global markets. Export success is particularly associated with products in emerging therapeutic areas, including high-quality generics and simpler biologics such as vaccines. Infrastructure development—such as drug testing laboratories and bioequivalence/bioavailability study centres—is critical for enhancing export propensity.

Finally, the coefficients for membership in regulatory bodies (Membership) and government support (Gov_Support) (Models 6 and 7) are positive and significant. Membership in international regulatory bodies (e.g., US FDA) and relevant authorities in PICs countries facilitates access to export markets. Additionally, government incentives—such as support for local API production, import of machinery, export rebates, funding for bioequivalence studies and GMP inspections, and facilitation of drug registration and capacity-building—play a critical role in strengthening export performance for firms in developing countries.

Sensitivity Analysis

To ensure the robustness of our estimates, we conducted a sensitivity analysis. In this exercise, R&D intensity, measured as the share of R&D expenditure in sales revenue, and export intensity, measured as the share of exports in sales revenue, were used as dependent variables. We estimated bivariate models using the ordinary least squares (OLS) method to preserve the dataset's degrees of freedom.

The results are broadly consistent with the Firth's Logistic regression estimates presented in Tables 16 and 17, indicating that our findings are robust to changes in variable proxies and estimation methods. The consistency across methods reduces concerns regarding potential bias. Notably, the results from the bivariate models align with theoretical expectations, further strengthening our confidence in their reliability and relevance.

Table 17: Empirical Estimates of the Determinants of Export Propensity

Regressors	Dependent Variable *Export Propensity*							
	Model 1	**Model 2**	**Model 3**	**Model4**	**Model5**	**Model6**	**Model7**	**Model 8**
Constant	-5.9989***	-6.1852***	-5.9989***	-6.1852***	-5.9989***	-6.1852***	-6.1852***	-6.1855***
	-1.8077	-1.7631	-1.823	-1.7555	-1.7695	-2.0456	-2.1103	-2.1997
Firm Size	1.1164***	1.0256***	1.1164***	1.0256***	1.1164***	1.0256**	1.0256***	1.0352*
	-0.4384	-0.4139	-0.4575	-0.4036	-0.4397	-0.4852	-0.4913	-0.4661
Internal R&D	1.7040**	------	------	------	------	------	------	------
	-0.8418	------	------	------	------	------	------	------
External Technology Acquisition	------	2.4908***	------	------	------	------	------	------
	------	-0.8422	------	------	------	------	------	------
Process Innovation	------	------	1.7040**	------	------	------	------	------
	------	------	-0.8721	------	------	------	------	------
Innovation Variety	------	------	------	2.4908***	------	------	------	------
	------	------	------	-0.8283	------	------	------	------
Diversification	------	------	------	------	1.7040**	------	------	------
	------	------	------	------	-0.8256	------	------	------
Membership	------	------	------	------	------	2.4908***	------	------
	------	------	------	------	------	-0.8541	------	------
Gov_Support	------	------	------	------	------	------	2.4908**	------
	------	------	------	------	------	------	-0.9039	------
Infrastructure	------	------	------	------	------	------	------	2.4908***
	------	------	------	------	------	------	------	-0.9087
Observation	50	50	50	50	50	50	50	50
Diagnostic Test								
Mcfadden R2	0.364	0.415	0.425	0.4004	0.4565	0.4675	0.4404	0.5022
Cragg-Uhler R2	0.461	0.515	0.6145	0.5071	0.5665	0.676	0.5578	0.6232
Log-likelihood (intercept)	-20.552	-20.377	-19.2514	-22.6072	-22.4147	-21.1765	-24.8679	-24.6562
Log-likelihood (Full Model)	-13.073	-11.918	-10.2344	-14.3803	-13.1098	-11.2578	-15.8183	-14.4208

*Notes: Standard errors are in parentheses. * Significance level of 10%, ** Significance level of 5%, *** Significance level of 1%*

Source: Authors' compilation.

Discussion

The study's findings highlight the critical importance of domestic and foreign R&D for firms' export performance. In the pharmaceutical sector, R&D focuses on formulation stability and, in some contexts, new molecule discovery. Currently, most firms operate at the basic dosage formulation stage, with new drug discovery largely absent. Increasing R&D in formulation can add value, enabling the production of high-quality generics and conferring a competitive advantage in global markets.

Basic research for new molecule discovery is traditionally conducted in universities or public research institutions. Our results underscore the importance of university–industry linkages in enhancing firms' innovation performance. Mechanisms for effective problem identification at universities and curriculum updates aligned with industry needs are critical. Additionally, the applicability and industrial relevance of academic research should be strengthened through longitudinal or cross-disciplinary studies. A modern approach in pharmaceutical research involves small research groups or specialised labs in academia conducting early-stage studies (up to Phase 1), with clinical trials handled by contract research organisations (CROs) and manufacturing by toll or contract manufacturing services—a model successfully implemented in China eight years ago.

FDI emerges as another crucial source of knowledge spillovers. However, drug discovery is costly and risky, and the weak intellectual property rights (IPR) environment in Pakistan further discourages investment in this area. Establishing testing laboratories is a necessary precursor for discovery, highlighting the need for a structured roadmap for R&D.

Globally, the pharmaceutical industry is shifting from conventional dosage forms to biologicals, with 30% of medicines projected to be biologicals by 2033. Pakistan faces limitations in technology, skills, and affordability for such a transition. Technological evolution—from mechanical to electrical, electronic, digital, and AI-based systems—requires significant investment and continuous updating. In the short to medium term, Pakistan may prioritise the production of biosimilars and simple biologicals such as vaccines, sera, and blood products, with joint ventures and strategic partnerships playing a crucial role in facilitating this shift.

Knowledge spillovers through CRAMS are instrumental for both innovation and export performance. CRAMS expose firms to advanced science and technology, supporting GMP and Good Clinical Practice (GCP) implementation, and facilitating the development of drug testing infrastructure, including bioequivalence and bioavailability study centres—critical prerequisites for drug export. Pakistan offers an ideal environment for CROs due to the prevalence of diverse diseases, making it suitable for Phase 3 clinical trials. The positive impact of infrastructure on export performance in our results corroborates this argument.

Membership in international regulatory bodies, including the US FDA and PICS countries, enhances compliance and facilitates market entry. However, achieving and maintaining membership involves a rigorous, costly, and holistic process requiring government and stakeholder facilitation. While the initial costs may strain domestic market operations, strategic membership decisions can yield sustained growth.

Regarding the 15% retention rate against export proceeds, industry stakeholders consider it insufficient for meeting foreign liabilities. In response, the State Bank of Pakistan (SBP) has implemented measures: exporters achieving at least a 10% increase in net export proceeds can retain 50% of additional earnings in foreign currency accounts, and restrictions on the use of funds in special foreign currency accounts have been liberalised. These steps, if properly disseminated, could support leading exporters.

The study confirms the positive effect of firm size, productivity, and absorptive capacity on export propensity. However, the structure of Pakistan's pharmaceutical sector adds complexity: approximately 640 companies compete for USD 3.5 billion in 2024, making the average firm size extremely small. Except for the top 100 firms, the remaining 540 firms engage minimally in innovation due to survival constraints, with limited turnover restricting GMP compliance and innovation capacity. The top 100 firms, which constitute 98% of the market, possess the capability to innovate and produce high-quality generics, including WHO, MHRA, and PICS prequalifications. Their export performance depends on domestic versus international market focus and willingness to invest in innovation.

Price control by the government also influences sector dynamics. Price approvals routed through the cabinet cause delays, restrict adjustments to production cost changes, and constrain gross margins. The deregulation of non-essential drug prices in February 2024 helped absorb rupee devaluation, leading to a 25% sales growth in Q4 FY-2024, of which 20% was due to price increases and 5% to volumetric growth. Consistent price adjustment criteria and a dedicated price board are essential to mitigate the adverse effects of price rigidity on R&D reinvestment.

Finally, product diversification emerges as a key driver of export performance. Current avenues, including nutraceuticals and herbal products, are underutilised. Enhancing production capacity in these areas could facilitate import substitution and, subsequently, exports. A relevant example is China's strategic focus on traditional medicines, which provides a competitive advantage.

6. POLICY RECOMMENDATIONS

For Industry

- R&D-Based Development Framework: A three-pronged R&D strategy is recommended:

  1. Formulation-focused R&D to enhance capabilities for producing high-quality generics and capturing off-patent markets.

  2. Basic research for new molecule discovery through university–research group–industry linkages.

  3. R&D to build capacity for the production of synthetics or biologicals. In the short to medium term, firms should increase R&D intensity, leveraging the Central Research Fund (CRF).

- R&D Consortium for Large Firms: Over the next 3–5 years, large pharmaceutical firms (annual turnover > PKR 10 billion) should establish an R&D consortium, supported by government allocations from CRF and S&T funds. This consortium could involve academic scientists for high-value formulation, drug discovery, and capability-building for biologicals.

- Plant Accreditation and Technology Upgrading: Firms should pursue accreditation from international regulatory bodies (US FDA, MHRA, EMA, WHO) to access SRA countries. Collaboration with DRAP for technology upgrading guidelines is essential.

- CROs and Clinical Trial Facilities: Pakistan should develop pre-clinical and clinical trial facilities, establishing CROs and analytical labs affiliated with medical universities (e.g., Aga Khan University, Dow University). Government facilitation is needed for inspector visits from the WHO, US

FDA, and other stringent bodies to attain Good Clinical Practices (GCP) certification and establish Bioequivalence/Bioavailability (BE/BA) study centres.

- Toll/Contract Manufacturing: Firms unable to conduct basic research should engage in toll/contract manufacturing at lower R&D cost, enabling capability-building for domestic manufacturing and regional supply.
- Utilisation of USD Retention Incentives: Leading exporters should maximise the benefits of the expanded USD retention limit (up to 50% of additional export proceeds for exporters achieving ≥10% growth).
- Product Diversification: Firms should explore herbal medicines, nutraceuticals, and specialised high-value medicines. Investments should prioritise R&D over post-production expenses, with balanced mechanisms to maintain market competition.

For Academia

- Curriculum Updates: Integrate global standards, pharmacovigilance, and industry-relevant skills.
- University–Industry Linkages: Strengthen mechanisms for problem identification, knowledge transfer, and curriculum integration.
- Applied Research and Commercialisation: Promote longitudinal and horizontal studies, track entrepreneurial outputs, and monitor startup creation and industry contribution.
- Biotechnology Expansion: Establish additional biotechnology schools and research labs to develop capacity for emerging therapeutic avenues.
- Digital and AI Integration: Gradually shift from mechanical to digital and AI-based pharmaceutical equipment in teaching and research.

For DRAP

- CRF Implementation: Facilitate R&D projects in academia and industry, and upgrade public laboratories. Amend the Drug Act 1976 if necessary.
- Phase 2–3 Trial Approvals: Minimise approval time for bid-based trials to prevent bid expiry.
- Capacity Building: Enhance human resources, update the Drugs Act, and expedite PICS membership. Facilitate GMP inspections by international inspectors.

- Toll Manufacturing Policy: Provide flexibility and expand product limits for capable firms.
- CRO Accreditation: Facilitate site inspections for accreditation from US FDA, EU, MHRA, etc., enabling global recognition of clinical trials and BE studies.
- Molecule Registration Guidelines: Limit redundant molecule registrations; prioritise life-saving drugs based on performance.
- AI and Biological Drugs: Build capacity for guidelines, monitoring, and implementation.
- Automated Management Systems: Upgrade for fast-track registration and streamlined commercial activity compliance.

For the Federal Government

- Reduce tariffs on imported machinery and equipment to facilitate plant accreditation.
- Establish a dedicated price board for drug pricing, considering production costs and market factors.
- Revise the APIs policy and establish a task force to monitor implementation.
- Reduce electricity tariffs for the pharmaceutical industry and improve water supply, ensuring quality.
- Implement an indigenisation policy for MNCs, with clear criteria for technology transfer via joint ventures.
- Facilitate visits of regulators, inspectors, and importers for plant accreditation.
- Offer financial incentives for technology transfer in vaccines, antisera, blood products, and other biologicals. Prioritise BE/BA study centres and testing laboratories.
- For the State Bank of Pakistan (SBP)
- Increase the USD retention limit for export proceeds of pharmaceutical firms, using mechanisms similar to those applied in the IT sector and freelancers.
- Ensure effective dissemination of incentives regarding flexible retention limits for high-performing exporters.

For the State Bank of Pakistan

- Increase the USD retention limit for export proceeds of pharmaceutical firms, using mechanisms similar to those applied in the IT sector and freelancers.
- Ensure effective dissemination of incentives regarding flexible retention limits for high-performing exporters.

For the Ministry of Commerce

- Liaise with DRAP to accelerate export-related commercial activities.
- Utilise export development funds for BE studies, a prerequisite for drug exports.
- Facilitate market intelligence and importer information sharing via embassies and consulates.
- Encourage TDAP to organise healthcare product exhibitions in targeted export markets.

Future Research

Pharmaceuticals is a medium-high to high-technology sector. Future studies should explore the complex interplay between innovation and firm performance, with particular focus on:

- Factors accelerating or hindering capacity development for biological production.
- Determinants of firm-level innovation in modern therapeutic avenues, including emerging technologies and AI-based drug development.

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APPENDIX

Table 1A: Description of Variables

Variable Name	Acronym	Description
Decision to innovate	Decision	1 if a firm in 2024 has invested in internal R&D and/or external technology acquisition; 0 otherwise
R&D intensity	R&DINT	The share of R&D in sales revenue
Export Intensity	EXPINT	The share of exports in sales revenue
Export Propensity	EXPPRO	1 for positive export sales in 2024; 0 otherwise
Internal R&D	Int_R&D	1 if a firm in 2024 has invested in any of the following: (i) internal R&D, (ii) internal and external training of workers
External Technology Acquisition	Ext_Tech	1 if a firm in 2024 has invested in any of the following (i) import of machinery and equipment, (ii) licensing of technology, (iii) hiring of R&D personnel from external sources; 0 otherwise
Firm Size	Size	Total number of employees
Human Capital	HCAP	Share of employees with a university degree
Firm Productivity	Productivity	The ratio of sales revenue to employment
Foreign Investment	FDI	1 if a firm considers MNCs as a highly important external source for skill and knowledge spillovers during 2021-24; 0 otherwise
Training of workers	Training	1 if a firm in 2024 has engaged in the training of internal workers and hiring of R&D personnel from external (domestic and foreign) sources; 0 otherwise
Process innovation	PROCESS	1 if a firm during 2021-24 has actively engaged in process innovation; 0 otherwise
Organisational Innovation	ORGINV	1 if a firm during 2021-24 has actively engaged in organisational innovation; 0 otherwise
Innovation Variety	Variety	1 if a firm in 2024 has engaged in both TI and non-technological innovation (marketing and organisational innovation); 0 otherwise
Product Diversification	Diversify	1 if a firm considers the following modes of sector diversification as very important for export growth during 2021-24: products focusing on emerging therapeutic avenues; nutraceutical & Herbal products; indigenous vaccine development; 0 otherwise

Variable Name	Acronym	Description
Infrastructure Development	Infrastructure	1 if a firm considers the following factors as highly important for innovation and export: Drug testing laboratories; Clinical Trials Facility; Bioequivalence/bioavailability study centres during 2021-2024; 0 otherwise
Membership	Membership	1 if a firm considers any of the following factors very important to fulfil stringent regulatory requirements for export during 2021-24: Membership of firms of international regulatory bodies, e.g., US FDA, MHRA, etc; WHO prequalification of Pharmaceuticals (WHO PQP); Membership of DRAP of Pharmaceutical Inspection Cooperation Scheme (PICS) countries; 0 otherwise
Government Incentives and Facilitation	Gov_Support	1 if firm considers the following factors very important for export competitiveness during 2021-24: Incentives for local production of APIs; Incentive for import of machinery and equipment; Export rebates for the leading exporters; Financial support for BE studies and GMP inspection expenses; Facilitation for drug registration and export NOCs; Facilitation through capacity enhancement; commercial activities related facilitation; Facilitation in GMP inspections; Trade facilitation; 0 otherwise
Research Collaboration	Collaborate	1 if a firm considers the following factors as highly important collaborative sources accelerating innovation during 2021-24: university-Research group/centre-industry linkages; Strategic partnership; joint ventures; network resources; 0 otherwise
Knowledge Spillovers	Spillovers	1 if a firm considers knowledge spillovers from Contract Research and Manufacturing Services (CRAMS) as highly important for innovation activities during 2021-24; 0 otherwise
Regulatory Factors	Regulatory	1 if a firm considers any of the following factors as highly important restricting innovation activities during 2021-24: Price regulations; weak intellectual property rights; underutilisation of central research fund; relatively higher tariff rate on machinery and equipment; Regulatory control on CRAMS; 0 otherwise

Variable Name	Acronym	Description
Industry Structure	Ind_Structure	1 if a firm considers any of the following factor as highly important restricting innovation activities during 2021-24: A significant share of few large firms in market share; limited linkages for technology transfer between domestic large firms and SMEs, domestic and foreign firms; high production cost of drugs; more spending on postproduction (e.g., Packaging, Marketing etc.) activities but less spending on innovation; 0 otherwise
Financial Factors	Financial	1 if a firm considers any of the following factors as highly important hampering

Source: Authors' computations.

PART II

TECH FOR COMPETITION AND GROWTH

Policy Briefs

EFFECT OF FIRM'S BIG DATA ANALYTICS CAPABILITY ON COMPETITIVE ADVANTAGE: MEDIATING EFFECT OF BUSINESS MODEL INNOVATION AND MODERATING EFFECT OF ENVIRONMENTAL UNCERTAINTY

Chaudry Bilal Ahmad Khan, Fizza Khan, Mehwish Iftikhar, and Muhammad Imran Qureshi

INTRODUCTION

Big data analytics has been the focus of research interests in recent times because of its ability to analyse a large amount of data and transform it into valuable information. It enables a business to make better and informed decisions, improve goods and services, and reduce costs.

The success of any business also depends upon the business model it adopts. It provides the framework for a firm to implement its innovative ideas by using technology to achieve a competitive advantage. However, considering the rapidly changing external environment, even a successful business model adopted by any firm cannot be used permanently. Therefore, to cope with the changing dynamics, business firms should innovate their business models.

The focus of the business model is limited to the firm level, while business model innovation is focused on the customers' value proposition and structural redesigning of the firm. Thus, through business model innovation, firms can tackle the changing dynamics and environmental uncertainty while maintaining their market share and achieving a competitive advantage. Research shows that firms with big data capabilities perform better when it comes to innovation and differentiating in the market.

COMPETITIVENESS AND THE ROLE OF DATA

Across the globe, firms compete on innovation, efficiency, profitability, and market reach. In Pakistan, the telecommunications sector once stood out for its rapid growth and dynamism, but the recent exit of a major operator has exposed the sector's vulnerabilities. This development underscores not only the intensity of competition but also the critical need for telecom firms to continually adapt their business models and build capabilities that secure lasting advantage.

In a technology-driven economy, competitiveness now hinges on knowledge-based decisions. For telecom operators, big data analytics is no longer optional—it is central to innovation, customer insight, and resilience under uncertainty. Firms that can harness data effectively are better placed to respond to shifting market conditions, sustain competitiveness, and chart a path for long-term growth in Pakistan's evolving telecommunications landscape.

METHODOLOGY

The study, on which the current viewpoint is based, used a multistage sampling technique to randomly select telecommunication firms. In the sampling stage, nine firms were selected out of a total of 18 firms in the telecommunications sector. Eventually, seven companies participated in the study. In total, 304 responses were collected from the seven selected companies. The survey data was validated through the triangulation technique by conducting semi-structured interviews with the top and middle management. A total of eight individuals from the high-level and middle-level management were interviewed.

MAIN FINDINGS

The telecommunication firms in Pakistan have developed big data analytics capabilities, which contribute to the competitive advantage of these firms. The big data analytics run by the firms are used for the improvement of their existing products as well as to identify target markets for their new products/ services. It shows that the telecommunication firms have innovated their business model and are offering more than just a medium to communicate with their customers. The business model innovations have enabled telecommunication firms to gain a competitive advantage and differentiate themselves in the market. However, insights from the respondents from the telecommunication firms point towards multiple challenges in acquiring big data analytics. These challenges include infrastructure and human resources challenges because of a dynamically changing market and technology.

To address the dynamically changing requirements of customers and the evolution of technology, telecommunications firms need to improve their infrastructure continuously. However, due to the uncertain macroeconomic environment in Pakistan, the cost of acquiring new hardware and technology has increased. One of the reasons is the unstable PKR/USD exchange rate. Since the firms acquire hardware, technology, and spectrum licenses in US dollars but earn in Pakistani rupees, their average return per unit (ARPU) has declined over the year and is one of the lowest in the world. This environmental uncertainty, along with heavy taxes and embargoes on hardware imports, has threatened the survival of the firms in the telecommunications sector in Pakistan.

The human resources capabilities issues have exacerbated the situation. Telecommunication firms are finding it increasingly difficult to retain capable human resources professionals. One of the reasons is the heavy taxation on individuals and inadequate facilities. Resultantly, any good and experienced human resources professional leaves the country whenever they find an attractive opportunity in the international market.

Despite possessing big data analytics capabilities, along with innovating their business models, which is enabling them to gain a competitive advantage, the telecommunications sector's overall competitive advantage is being eroded due to the environmental uncertainties caused by market turbulence, technological changes, and competition intensity. The rapid technology change also changes the customer preferences/ requirements, which increases competition. Along with an unstable exchange rate, heavy taxation, and a lack of facilities, uncertain government policies make the situation even more challenging. Although the government is encouraging the local cloud environment, it needs to facilitate the firms to develop the clouds so that they can compete in the international market.

POLICY RECOMMENDATIONS

- To take the cloud services to maturity, it is important that telecommunications firms are provided with the appropriate infrastructure to improve big data analytics capabilities. To do so, the government needs to develop a framework to facilitate the telecommunication firms with easy access to the required hardware equipment. In case the import of hardware for the development of clouds with big data analytics capabilities is not possible, the government should try to get the international cloud providers to invest and bring their data centres to Pakistan.

As the Data Secrecy Act does not allow firms in Pakistan to store data on international clouds, the government must look into the revision of the policy.

- As the Data Secrecy Act does not allow storing big data on international clouds and the government encourages the development of clouds at the national level, the government should facilitate such organisations. The government may, in such cases, plan a supportive financing/subsidy so that the firms can acquire the hardware easily. Pakistan also has embargoes on the hardware, which provides high processing capacity. Efforts should be made to lift the embargoes on such equipment.

- A framework needs to be developed by the government to retain the intellect in the country and reduce the brain drain from Pakistan. The individuals with expertise in the area of computing/big data analytics/computer-related knowledge should be facilitated with better quality of living, financial stability, and stable infrastructure. The government should try to create a more secure environment in the country with equality and a guarantee of better living standards.

- The licensing of spectrum for the telecommunication firms should be rationalised and aligned with the Pakistani market's realities. The steps taken to reduce the spectrum cost for telecommunications firms may allow them to leverage the cost to develop cloud infrastructure. This will further improve their big data analytics capabilities and allow them to adapt to the rapidly changing technology and market dynamics. The telecommunications industry must remain financially sustainable so that it can invest in infrastructure, which serves as the foundation for the digital ecosystem and enablement.

- The government, while receiving the services from the telecommunications firms, should treat telecommunications firms as partners rather than as vendors. The tariffs offered by the government to the telecommunications firms should keep the commercial interests in view. An agreement should be made between the government and the telecommunications firms that safeguards the commercial interests of telecommunications firms and also benefits the government.

TECH INDEX PAKISTAN: A STATISTICAL APPROACH TO UNDERSTANDING THE RELATIONSHIP BETWEEN TECHNOLOGY, COMPETITION, AND GROWTH

Muhammad Haris Hanif and Mubeen Ahmed

INTRODUCTION

Technology, Competition, and Economic Growth: A Global Perspective

Technology has become a critical driver of economic growth and development in today's world, transforming industries and creating new economic sectors through innovations like artificial intelligence, automation, and renewable energy. Countries that invest in technology and foster competitive markets have seen substantial benefits. The relationship between technological innovation and economic growth highlights the importance of fostering competition to encourage innovation and efficiency, as neoclassical growth theory highlights. Similarly, it is essential to address structural barriers, enhance infrastructure, and prioritise research and development (R&D) to bridge gaps in technology adoption, especially in developing countries.

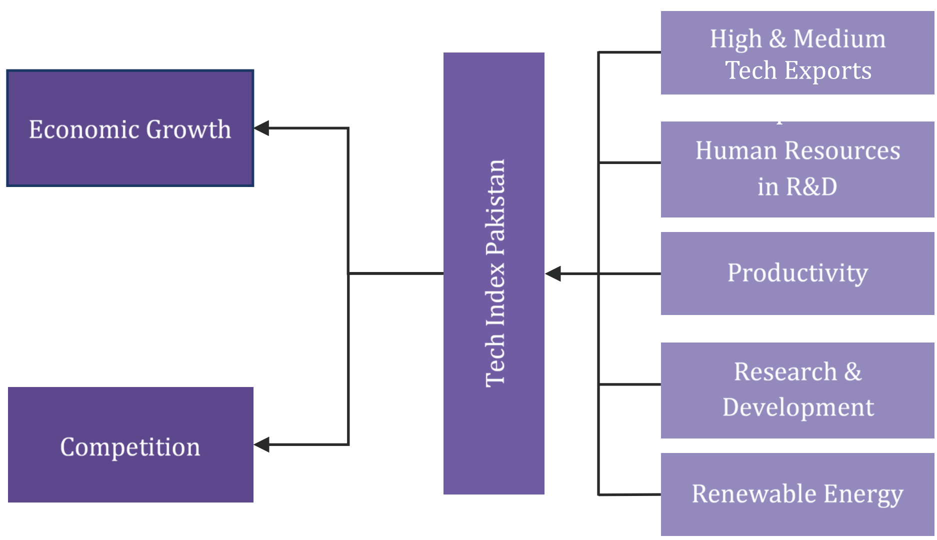
Pakistan's Technology Landscape: Challenges and Opportunities

Pakistan has made some strides in technological advancement over the past few decades, supported by a young population, a growing digital infrastructure, and an urgency to harness technology for growth. However, despite these opportunities, challenges such as limited R&D expenditure, inadequate STEAM education, regulatory constraints, and a lack of venture capital hinder the country's ability to capitalise on its potential entirely. These barriers, coupled with an insufficient understanding of technology's economic impact, restrict technological development and, in turn, economic growth. This research addresses these challenges by proposing targeted solutions to enhance competition, innovation, and sustainable growth.

Building a Tech Index: Rationale and Approach

The rationale behind this study is rooted in the pressing need to understand the role of technology in driving economic competitiveness and growth. Thus, the primary objective of this research project was to develop the technology index for Pakistan. This technology index depicts the country's overall situation concerning technology adoption, advancement, and proliferation. By thoroughly examining the dynamics of technological sophistication and competition, we tried to uncover how technological advancements shape the competitive market landscape and economic growth. The idea was to synthesise the findings into data-driven recommendations. These recommendations have been tailored for policymakers and stakeholders.

Figure 1: Schematic Depiction of the Research Project



Source: Authors' computations.

Scope and Policy Relevance of the Study

The scope of this study lies in the fact that a wide-based understanding of how technology, competition, and economic growth interact in Pakistan does not exist. As such, this research bridges these critical knowledge gaps by digging deep into the intricate relationships between the three pillars: technology, competition, and economic growth. The study aimed to catalyse a systematic exploration beyond surface-level observations through such an approach.

RESEARCH METHODOLOGY

The Tech Index was developed as a comprehensive measure to evaluate technological adoption and advancement across Pakistan, Egypt, India, Sri Lanka, and Uzbekistan. Five sub-indicators were chosen for the composition of the index: patents, high-tech and medium-tech exports (EXP), labour productivity (PROD), human resources in R&D (HR), and renewable energy percentage of total energy consumption (RENEW). Each sub-indicator was assigned an equal weight of 20%. Two indices were created to account for missing data: one using R&D expenditures and the other using patent counts as proxies for innovation activity. Data for the sub-indicators were sourced from reputable international organisations, including UNIDO, UNESCO, ILOSTAT, and the World Bank. Uncertainty and sensitivity analyses were conducted to ensure the Tech Index's robustness. The results showed that the index with patent data was more stable over time and robust to methodological variations.

Following the construction of the Tech Index, econometric analyses were conducted to explore the relationships between technological advancement, market competition, and economic growth. Two models were specified. The first analysed the impact of technological advancement (measured by the Tech Index) on market competition, using industrial design applications as a proxy for competition. The second examined the relationship between economic growth (measured by GDP), competition, and technological advancement. The econometric methodology included ordinary least squares (OLS) and two-stage least squares (2SLS) regression techniques to address endogeneity concerns. Moreover, the Toda-Yamamoto causality approach and generalised impulse response functions (GIRFs) were also applied to understand the directional and dynamic relationships among the variables.

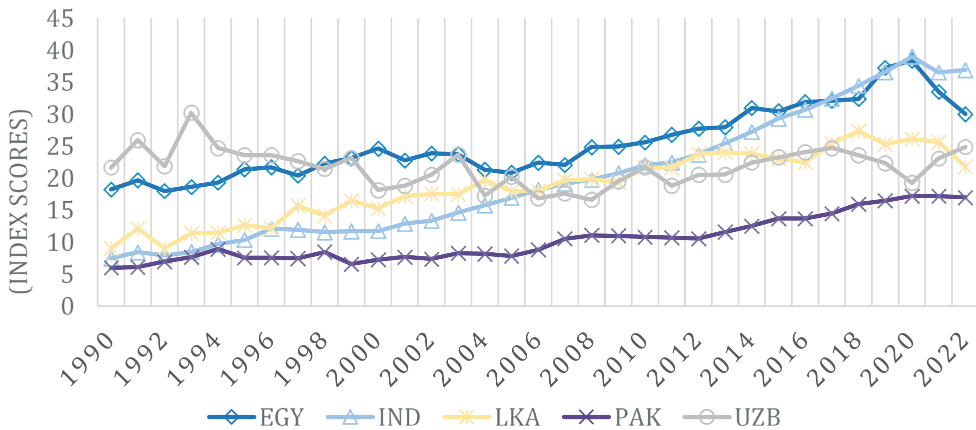
RESULTS AND DISCUSSION

Tech Index Results

The Tech Index results reveal distinct disparities in technological advancement across the five countries studied: Pakistan, India, Egypt, Sri Lanka, and Uzbekistan. Figure 2 shows the index scores for all countries from 1990 to 2022. Pakistan witnessed consistent but modest growth, peaking in 2020 at 17.22. Significant growth phases were observed from 1990 to 1994, 2005 to 2007, and 2012 to 2020. Sri Lanka and India started relatively just above Pakistan, such that the scores of India and Sri Lanka were 7.50 and 9.02, whereas that of Pakistan was 5.99. After 33 years, in

2022, India and Sri Lanka scored relatively much better than Pakistan at 36.89 and 21.81, where Pakistan scored 17. India has experienced an upward trend and shows signs of sustained growth from 1990 onwards. Sri Lanka also showed a positive growth trend, but it was modest compared to India. Its trajectory slowed and flattened, especially after 2012, and after an abrupt upsurge from 2016 to 2018, it started a declining trend until the end of 2022. Egypt also showed modest growth in its tech index scores. It showed a significant growth trend in its scores after 2007, but it slowed and started declining after 2020. India and Egypt consistently outperform Pakistan in most sub-indicators, including patents, high-tech exports, labour productivity, and renewable energy adoption. While trailing behind India and Egypt, Sri Lanka and Uzbekistan also rank higher than Pakistan in key areas such as high-tech exports and renewable energy consumption, highlighting persistent structural and policy challenges.

Figure 2: Tech Index Scores (Comparison between Five Countries across Time)



Source: Authors' computations.

Post Index Estimations of Econometric Models, Toda-Yamamoto Causality and Impulse Response Functions (IRFs)

The regression results showed that technological innovation leads to increased market concentration, as dominant players capitalise on technological leadership and monopolise the powers, decreasing market competition. The second model assessed the impact of technological advancement and competition on economic growth, measured by GDP. The findings confirmed a positive and significant relationship between the Tech Index and GDP, highlighting the critical role of technological progress in driving economic expansion.

The Toda-Yamamoto causality analysis revealed significant bidirectional causality between technological advancement and economic growth, emphasising their mutual reinforcement. Technological progress drives GDP growth and is enhanced by economic expansion, as higher GDP enables increased investment in R&D and innovation. Unidirectional causality from technological advancement to competition was observed. The impulse response function analysis further validated the dynamic relationships among the key variables.

Shocks to technological advancement produced a delayed but sustained positive impact on GDP, reflecting the long gestation period of innovation-driven growth. In contrast, the impact of technology on competition was negative, consistent with the concentration effects observed in Model 1. Meanwhile, market competition has a negligible to slightly negative impact on GDP, suggesting structural and institutional weaknesses in harvesting competition's benefits.

CONCLUSION AND POLICY RECOMMENDATIONS

This study highlights the critical role of technological advancement in driving economic growth and fostering market competition. The Tech Index results reveal Pakistan's lagging performance compared to peers such as India and Egypt, underscoring structural weaknesses in patents, high-tech exports, R&D capacity, and renewable energy adoption. Econometric analyses confirm the interconnectedness of technology, competition, and growth, with human capital emerging as a pivotal factor. While Pakistan shows potential for improvement, bridging the technology gap requires focused, actionable policy interventions to address systemic challenges and unlock sustainable growth.

Policy Recommendations

1. Increase R&D Investment and Strengthen Innovation Ecosystems: The R&D investment must increase by at least 1% of GDP, as argued under international norms, to strengthen technological innovation. A concrete recommendation is to create a Competitive Technology Fund

(CTF) and dedicated R&D funding bodies to incentivise innovation in high-tech sectors such as IT, renewable energy, and biotechnology. Moreover, the focus and incentive should be given to developing commercially viable technologies, which could contribute to better growth.

2. Policy Coherence and Continuity: The implementation and funding of key policies, particularly those related to technology and innovation, must be improved, and they must align with competition policy and national economic objectives. Besides, long-term planning and insulation from political and institutional changes are crucial for Pakistan, and a way to do this is to have a dedicated, autonomous, efficient, and centralised body overseeing the implementation of technology policies.

3. Vertical Transfer of Technology: The country should focus on vertical technology transfer to bridge the gap between research and commercialisation. Although STEDEC and PCSIR are already working to commercialise indigenous products, they have been unable to improve vertical technology transfer significantly due to their lack of effectiveness. Thus, accountability should be reinforced in these institutions, and performance-based metrics should be implemented; similarly, funding and incentive structure should be tied to clear outcomes such as patents, commercialisation success, and industry collaboration.

4. Human Capital Investment: Human capital is another foundational pillar for technological progress, and without a skilled workforce, investments in R&D and market reforms are bound to have a constrained impact. Thus, Pakistan should scale up its skills development programmes, modernise STEAM education curricula, align university programmes and research with industry needs, and expand technical training institutes focused on high-tech manufacturing and digital skills. In addition, an intense monitoring and evaluation system should be in place to ensure the continuity and effectiveness of such programmes.

EXPLORING THE AVENUES FOR THE ADOPTION OF AGRICULTURAL UNMANNED AERIAL VEHICLES BY SMALL TO LARGE LANDHOLDING FARMERS

Shoaib Rashid Saleem, Muhammad Faisal Ali, Muhammad Naveed Tahir, and Abdul Saboor

INTRODUCTION

Pakistan's agriculture plays a vital role in ensuring both the nation's food security and its national security. The Government of Pakistan has recently launched a significant initiative, establishing the Special Investment Facilitation Council (SIFC), with a particular focus on revitalising key industries, including agriculture. Agriculture not only contributes around 22.9% to Pakistan's GDP but also engages approximately 37.4% of the total workforce in the country. However, the agriculture sector is facing several challenges, which include issues such as poor seed quality and management, limited adoption of technology, a shortage of skilled labour, and the prevalence of small landholdings. Consequently, progressing the agricultural sector is essential to bolster Pakistan's fragile economy. To address these challenges effectively, the agricultural sector requires the implementation of efficient, sustainable, innovative, modern, and environmentally friendly approaches. These measures are crucial for bridging the yield gaps per acre between Pakistan and developed countries.

The introduction of Unmanned Aerial Vehicles (UAVs) is one of the latest additions to the precision agriculture gadgets to manage crop growth and quality efficiently. Spraying using UAVs has proven to be faster, efficient, effective, less laborious, and cost-effective as compared to traditional technologies being used for agrochemical spraying (Moskvitch, 2015). Proper planning and management of targeting hotspots of weeds and pests through UAVs can minimise and save large amounts of unnecessary chemical applications. However, UAV operators can easily position themselves outside the field and can avoid direct contact with pesticides. UAVs are also ultra-low volume (ULV) systems when compared to conventional spraying techniques. Therefore, they reduce the impact of chemical residues on nature and people compared to traditional spraying methods. Overall, adoption of UAVs could be farmer and end-user-friendly, which could also result in improved soil fertility and minimal harmful impacts on human health.

Despite challenges, the long-term benefits of UAV adoption in precision agriculture outweigh the initial hurdles. With appropriate policy interventions, increased awareness, and investment in research and development, UAVs can play a transformative role in optimising resource use, improving farm productivity, and ensuring environmental sustainability. As Pakistan strives to modernise its agricultural sector under initiatives like the Special Investment Facilitation Council (SIFC), prioritising UAV technology can serve as a key enabler in achieving precision agriculture goals. By addressing existing barriers and fostering an ecosystem conducive to UAV adoption, Pakistan can enhance food security, strengthen its agricultural economy, and move towards a more sustainable and technology-driven farming landscape.

This study aims to examine the factors influencing farmers' readiness to embrace agricultural UAVs, focusing particularly on three crops: Cotton, Sugarcane, and Maize. The choice of these crops is deliberate, as they require intensive spraying, which will further facilitate the development of UAV services/products. Additionally, the study seeks to offer valuable insights to policymakers for crafting a comprehensive strategy to establish and promote a national UAV policy for agriculture. To achieve this, a qualitative approach will be employed to pinpoint the key regulatory barriers impeding the advancement of the UAV market in Punjab. Thus, the study has three primary objectives:

1. Identify various constraints, including regulatory constraints linked with the adoption of UAV technologies and their import.

2. Assess the willingness to pay of farmers to adopt UAV technologies for spraying purposes.

3. Present recommendations based on the study's findings.

METHODOLOGY

The study was designed to collect survey-based information from the major agricultural cities of Pakistan, especially focusing on the cotton belt of Pakistan (Multan, Rahim Yar Khan, and Khanewal). This selection was primarily motivated by the significant number of agrochemical applications required in these districts, ranging from approximately 8 to 10 during the cotton crop's growing season, to mitigate pest and weed damage. Interviews were conducted with key stakeholders to gather comprehensive insights into the integration of UAVs in the agricultural sector. The stakeholders interviewed were private service providers, agrochemical companies, government institutions, national agricultural research centres, and agricultural universities in Punjab.

The interviews explored various aspects such as the constraints faced in purchasing and importing UAVs, service delivery and pricing mechanisms, operational challenges and skill requirements, market limitations, and necessary improvements. Additionally, the interviews focused on input on governmental support needed, current policies and regulations, and the potential role of UAVs in enhancing agricultural productivity. Farmer surveys were also conducted in the selected districts of Multan, RYK, and Khanewal, and surveys from cotton, sugarcane, and maize farmers.

The sampling was semi-biased as both progressive and unprogressive farmers, small and large landholding farmers, were targeted in these three districts. Additionally, farmers from each administrative unit were selected based on their proportional representation. A total of 228 farmers were interviewed during the study, and the focus of the questions was the availability of drones in the locality, willingness to adopt, willingness to pay, constraints and challenges faced by farmers, and how demographics such as age groups and literacy rates are affecting the adoption of UAVs.

RESULTS AND DISCUSSION

Interviews with stakeholders

A total of 15 stakeholders were interviewed during the study. This stakeholder feedback was crucial in identifying regulatory and policy hurdles, informing a robust policy framework for UAV integration, and evaluating the commercial viability and market development potential of UAVs in agriculture. Key Constraints and Challenges Identified:

Policy Challenges: Major findings during the KIIs were the absence of a national drone policy for agriculture. All stakeholders discussed that the difficulties in UAV adoption at the national level were mainly due to the challenges faced by these organisations in importing UAVs in Pakistan. All stakeholders were on board in terms of the earliest availability of the national drone policy. One of the interesting arguments made by a PSP was that an easy documentation and approval process is mandatory during policy development, as a tedious policy could further discourage the UAV adoption. Another suggestion put forward by the Agriculture Department representative was the development of safe zones for UAV operation that would reduce the unnecessary approval processes in the safe zones.

Technical Awareness and Lack of Research: The very limited availability of UAVs for the research institutes is a major limitation in creating awareness among agriculture extension workers and PSPs. The representatives from research institutions, GoP representatives, and PSPs highlighted that more technical awareness is needed to increase the adoption rate among farmers. A study conducted by PMAS-Arid Agriculture University (PMAS-AAUR) revealed that the ROI is 2 to 5 years for more than 500 acres of coverage per year. Preliminary findings of the research work conducted in a few of the major crops show benefits in terms of labour savings and time savings between 10 to 40% depending on the sprayed acreage. One of the interviewees argued that research will strengthen the rapid technology transfer to the farmers.

Famers Interests: The KIIs revealed that farmers showed high interest in the adoption of the UAVs, highlighting their cost and time-saving benefits. However, due to a lack of infrastructure, current adoption rates are very low. Two PSPs highlighted that government subsidies and loans will improve the overall adoption rates of the UAVs. However, PSPs informed that the willingness to pay varies from region to region and crop to crop. The price ranges from 400 to 2400 per acre per spray.

Famers Interviews

The use of Unmanned Aerial Vehicles (UAVs), or drones, is gaining recognition in agriculture for their potential to improve efficiency in crop monitoring, pesticide spraying, and overall farm management. However, the adoption of UAV technology in the agricultural sectors of Khanewal, Multan, and Rahim Yar Khan districts is still in the early stages. The survey conducted in these areas aimed to assess the awareness, adoption, and challenges surrounding UAV technology among local farmers. Results of farmer surveys revealed that awareness of UAV technology is growing, especially among young and more educated farmers. However, actual adoption remains low due to high initial costs, high spraying costs, limited access to service providers, and a lack of

- The respondents from financial institutions are of the view that the lack of political will and insufficiency/inadequacy of physical and technological infrastructures at both the SBP and the financial institutions' level are important challenges.

- The findings highlight the need to improve SBP communication with stakeholders (Financial institutions) about its programmes /initiatives concerning CBDC and its implications. Similarly, the respondents are also not clear (stay neutral) about their respective bank initiatives for creating awareness regarding CBDC.

- Investments in infrastructural development (physical, technological, hardware, software) are required before the launch of CBDC. However, the financial resources required to initiate such investment are another prominent challenge for SBP and financial institutions.

- Trust in the existing financial system and security concerns are also important factors in inducing or hindering the adoption of CBDC.

- The data theft, information privacy, and security protocols are found to be some of the biggest challenges posed by CBDC.

- According to the financial institutions' survey, CBDC does not have the potential to improve the effectiveness of monetary policy, nor can it improve financial stability and funds allocation in Pakistan.

- Moreover, financial stability and bank disintermediation are also important concerns (Figure 10) that cannot be overlooked. In a country with a dismal financial profile, digital innovation of this scale may yield risks that may surpass the perceived benefits. Thus, the issuance and design of CBDC require intense scrutiny measures.

- The analysis highlighted that developing and implementing a CBDC infrastructure would require significant investment, which could be a challenge in the given financial resources of Pakistan.

Prospects /Opportunities

- Improvement in digitalisation and financial inclusion, increase in payment efficiency, and effectiveness of monetary policy are the most frequently reported benefits of CBDC. Research, including Pakistan, has also reported enhanced security as one of the most prominent benefits of CBDC.

training programmes. Smallholder farmers are more inclined towards government subsidies or pay-per-use models.

The study also highlighted that farmers in areas with better exposure to technology showed a higher inclination toward adoption, while others showed their reliance on traditional methods. The major solutions to the highlighted challenges are the development of a national UAV policy for agricultural use, introducing service provider models, and integrating UAV training into educational programs. Addressing these barriers will ensure the successful wide-scale adoption of UAV technologies in Pakistan's agricultural industry, which will ultimately improve farm productivity and food security.

POLICY RECOMMENDATIONS

The following policy recommendations are put forward for the adoption of UAVs in the agriculture sector among small to large landholding farmers, based on KIIs and farmer surveys.

1. A clear and well-structured national UAVs for agriculture use policy framework is needed. The national UAV policy should streamline the approval process, covering all operational safety standards and legal concerns.
2. Approval process under one ministry and one application is required to reduce bureaucratic hurdles. An online application system for drone import, purchase, and operation could boost the UAV usage in Pakistan.
3. Financial assistance programs need to be introduced, including subsidised loans and tax exemptions, which will help farmers and service providers to afford UAV technology.
4. Universities and research institutions need to play a pivotal role in UAV training centres to provide technical knowledge on the use of UAVs for different crops. TEVTA/NAVTC can also introduce short courses to train farmers in various age groups and service providers.
5. Collaborations between government institutions, private service providers, and agrochemical companies need to be developed, which will help in introducing an affordable UAV service structure for smallholder farmers.
6. One of the major constraints in UAV adoption is access to UAVs in the local regions. Development of private or governmental UAV service hubs in key agricultural regions can

increase the use of UAVs for spraying among small-scale farmers.

7. The agriculture extension department can play a pivotal role in conducting targeted awareness campaigns through demonstration events to educate farmers on the economic and environmental benefits of agricultural UAVs.

8. Establishment of local workshops for the repair and assembly of UAVs is necessary to provide timely maintenance services and reduce reliance on expensive imports.

Implementation of these policy recommendations will boost the adoption rates of UAVs in Pakistan and overall precision agriculture technologies. Pakistan need to incorporate these technologies to ensure sustainable crop production and food security.

CENTRAL BANK DIGITAL CURRENCY, FINANCIAL COMPETITION, AND GROWTH: IDENTIFYING CHALLENGES, OPPORTUNITIES, AND APPLICATIONS

Abdul Rashid, Zainab Jehan, and Saira Tufail

INTRODUCTION

The rapid advancement of digital technologies has reshaped the global financial system, and Central Bank Digital Currencies (CBDCs) are emerging as a transformative innovation. CBDCs, as digital equivalents of fiat currencies issued by central banks, promise significant benefits, including enhanced financial inclusion, efficient payment systems, increased transparency, and effective monetary policy implementation. They stand at the intersection of technological progress and monetary innovation, representing a new era of financial transactions.

Approximately 134 countries and currency unions, representing 98% of the global GDP, are currently exploring CBDCs. Currently, about 68 countries are in the advanced stages of exploration, including development, pilot testing, or launch. Countries like China, India, Nigeria, and the Bahamas are at the forefront of CBDC development, using these digital currencies to drive economic integration and enhance fiscal transparency. In contrast, other countries, such as Argentina, do not see an urgent need to issue a CBDC and are focusing on improving their current payment systems. European countries such as Hungary and the Czech Republic have also stated that they are not considering the launch of a CBDC shortly. Currently, 17 countries have disabled their CBDC projects.

For Pakistan, where more than 80% of transactions are cash-based, CBDCs present an opportunity to modernise the economy, improve financial inclusion, and address the challenges posed by unregulated digital currencies. Initiatives such as Raast already foster a digital payment ecosystem, and the adoption of CBDCs could complement these efforts. However, challenges like digital illiteracy, lack of access to financial systems, security of digital transactions, and inadequate infrastructure remain significant obstacles.

This brief explores the potential of CBDCs in Pakistan by conducting an extensive literature review, analysing global trends, evaluating the country's status regarding selected macro-financial-technological factors, and assessing the perceptions of key stakeholders regarding the level of readiness, benefits, challenges, opportunities, and implications of CBDC in Pakistan. The study offers strategic recommendations for the State Bank of Pakistan (SBP) regarding CBDC.

METHODOLOGY

The paper on which this policy brief is based employed a mixed-methods research methodology to analyse the suitability of a CBDC for Pakistan. The study used both qualitative and quantitative data for the study. The qualitative part of the analysis included an extensive literature review as well as insights from the relevant stakeholders. The quantitative part included a primary data survey and its analysis.

Findings

These findings and implications are related to the appropriate design, user cases, and types and modes of CBDC regarding implementation and issuance. Moreover, implications are also offered on the various aspects of issuance, adoption, risk management, perceptions, opportunities, and challenges associated with CBDC.

Need for CBDC in Pakistan

- Comparing Pakistan's economic, monetary, and financial indicators with those of the research group, it is found that Pakistan's performance in these indicators provides support for the launch of CBDC.

- Another important finding related to the necessity of CBDC is that Pakistan's neighbouring countries, such as India and China, are moving fast toward the adoption of CBDC with the perspective of first-mover advantage. This can facilitate their financial integration and improve trade competitiveness.

- The majority of the general public and merchants are using a variety of digital payment modes and considering financial technology useful for their financial transactions. They are confident in adopting any technological and financial innovation comprising superior features to the existing ones, hence highlighting the need to launch CBDC in Pakistan.

- It was also highlighted by the representatives of financial institutions that CBDC is essential for financial development, and Pakistan is already lagging as far as the adoption of advanced financial technology is concerned.

Design and Architecture of CBDC Suitable for Pakistan

- Approximately 60% of countries around the globe are focusing on retail CBDC projects. Nonetheless, it is observed that many other countries are also exploring wholesale CBDC, which has the potential to facilitate cross-border payments.

- This evidence suggests that by involving both the central bank and private sector intermediaries, a hybrid model can enhance the resilience and security of the payment system. This dual-layer approach can help mitigate risks associated with cyber threats and operational failures.

- According to findings drawn from Financial Institutions, the neutral response of financial institutions regarding the design of CBDC may reflect a lack of awareness and knowledge of financial institutions about the implications of each design.

Regulatory Framework

- Launching and regulating CBDCs would require new frameworks that address unique concerns such as distribution, control, and integration with monetary policy.

- Additionally, it is also documented that CBDCs could influence monetary policy and financial stability and also alter monetary transmission mechanisms, necessitating revisions to central banks' tools for managing interest rates and money supply.

Challenges of CBDC

- Our findings from thematic analysis of institutional and academic research highlighted the usefulness as the most important factor in the adoption of CBDC, followed by ease of use and digitalisation.

- The survey of the general public and merchants confirmed that digital literacy is necessary for the successful launch, acceptance and adoption of CBDC in Pakistan. Lack of digital literacy, along with lack of communication and data privacy, can pose a serious challenge to gaining potential benefits from the CBDC. Especially for females lack of digital skills may pose serious challenges.

- Pakistan's performance in the monetary sector is better than the average score of other countries in the proof of concept and pilot testing group.

- Pakistan has already initiated a digital transaction system since 2018 and provided basic infrastructure for digital transactions and online payments, which may serve as a platform for the launch of CBDC. These facilities include 1LINK switch, RAAST payment system, Roshan Pakistan, and Person to Person (P2P), RAAST-P2M. Hence, the availability of a digital payment system can be capitalised to launch CBDC if and when the need arises.

POLICY RECOMMENDATIONS

- SBP may consider conducting extensive research, surveys, and feasibility studies to understand the necessity of CBDCs unique to the country by taking into consideration different stakeholders in the economy.

- A full-fledged policy framework and implementation procedure should be designed in order to effectively launch the CBDC.

- akistan may consider retail CBDC to align its payment system with the rest of the world. SBP may simultaneously explore a wholesale CBDC to facilitate cross-border payment.

- Implementing a hybrid CBDC can be more technologically feasible for Pakistan, as it can be built on existing financial infrastructure and leverage the expertise of private sector intermediaries.

- Given the current levels of digital literacy, overall education, and demographic profile, transitioning to an entirely new system of financial payments and transactions may face significant resistance. Therefore, based on our analysis, we suggest that an account-based CBDC is a more feasible option.

- SBP shall conduct target-oriented training and workshops for financial institutions to educate them about CBDC designs and the implications and benefits associated with each. Moreover, SBP may also motivate and engage financial Institutions to provide awareness and the necessary skills required in the management of CBDC.

- Given the conventional and Islamic window operations of financial institutions in Pakistan, it is recommended that the SBP should consider the compatibility of the CBDC with the Shariah legitimacy.

- Pakistan's existing laws only recognise cash and bank deposits as legal tender; the SBP's mandate under its current legal structure might need to be expanded to accommodate CBDC. However, SBP should first implement a pilot programme to evaluate operational and regulatory aspects of CBDC before proposing the final amendments to its Acts.

- SBP may establish a specialised unit for exploration, launch, implementation , management, and monitoring of CBDC. Moreover, SBP may formulate a multi-stakeholder steering committee comprising government representatives, central bank officials, academic researchers, financial institutions, neobanks, and the corporate sector to coordinate the launch and operations of CBDC.

- The SBP should prioritise creating a simple and intuitive user interface for CBDC transactions. This includes ensuring digital wallets and payment platforms are easy to navigate, even for those with limited technological knowledge and experience.

- Investing in robust technological infrastructure and cybersecurity is essential, with blockchain technologies offering scalable and secure solutions.

- The SBP can leverage CBDCs to gain more precise control over monetary policy. SBP is required to update its underlying models to include CBDC and other forms of digital money.

- Pakistan may follow India's strategy of improving access in rural areas and China's focus on unbanked populations to ensure financial inclusion.

- Pakistan should ensure that its CBDC integrates with the existing payment systems like JazzCash, Easypaisa, RAAST, P2P, RAASTP2M, and internet banking.

DISSECTING THE EFFECT OF INTERNAL R&D, IMPORTED INPUT VARIETY AND EXTERNAL TECHNOLOGY ACQUISITION ON EXPORT COMPETITIVENESS OF PHARMACEUTICALS IN PAKISTAN

Abdul Rauf, Abdul Jalil, and Ahsan Abbas

INTRODUCTION

Exports are critical for employment generation, poverty alleviation and sustainable economic growth. They are also a significant source of international technology spillovers through learning-by-exporting. Thus, it is crucial to explore the determinants of firm-level export performance in developing countries. One crucial determinant is technological innovation (TI), which enhances firm capability and export competitiveness. TI directly induces exports, along with indirectly affecting exports via its positive impact on productivity. However, firms in developing countries face several micro-level constraints, including limited R&D activities, low skill level, lack of firm-specific tangible and intangible resources, and lack of motivation for R&D.

Several macro-level rigidities, including financial constraints, an innovation- unfriendly macroeconomic landscape, and regulatory hurdles, also stifle innovation activities. Furthermore, some sectors, e.g., pharmaceuticals, face extremely stringent product (drug) registration and quality and safety compliance requirements from international regulatory bodies, which restrict the firm's entry into the export market.

Against this backdrop, this study examined the regulatory issues, R&D rigidities, and export constraints of pharmaceutical firms in Pakistan. The study also empirically investigated the impact of indigenous innovation, external technology acquisition, and sector/firm-specific factors on firms' export performance.

The pharmaceutical industry is a USD 3.45 billion industry in Pakistan. It had an annual average growth rate of 17% during FY19-FY24. The sector is among a few leading sectors in large-scale manufacturing (LSM), which registered double-digit (23.19%) growth during FY2024. The sector fulfils 80% of domestic medication demand and employs approximately half a million people. However, the sector's dynamic growth does not reflect in its global competitiveness. Pharmaceutical exports grew at an annual average rate of 12% during 2019-23, with exports reaching USD 328 million in FY-2023. The pharmaceutical sector's exports were projected to reach USD 350 million in 2024, contributing only 1% to the overall exports of Pakistan.

The export competitiveness of Pakistan's pharmaceutical firms is constrained by several regulatory barriers and R&D rigidities at home and abroad. First, the firms face stringent drug registration and mandatory pharmacovigilance requirements in medium to high regulatory standard countries, which are hard to fulfil with their existing level of technology. It restricts firms' entry into stringent regulatory authority (SRA) markets, forcing them to export to semi-regulated markets of the developing countries in Asia and Africa, weakening the learning-by-exporting potential.

Second, the domestic drug pricing mechanism and molecule registration criteria are convoluted, which encourages more spending on post-production (marketing and distribution) activities rather than on R&D activities for drug discovery and high-quality formulations.

Third, the Drug Regulatory Authority of Pakistan's (DRAP) human resource capacity and technical capacity to explore new avenues of biologicals and AI-based medicine are low, which leads to an inability to comply with the required standards and discourages the production of new medicines. Furthermore, there are several legal and operational barriers to contract research and manufacturing services (CRAMS), which hinder R&D and knowledge spillovers from innovator firms/countries.

Fourth, R&D rigidities, weak innovation value chain (from drug discovery research to manufacturing and marketing), low technology transfer opportunities, and a non-collaborative industry structure hamper TI, which, in turn, restricts export quality upgrading. Lastly, a narrow product base, high production costs and lack of government support are also detrimental to export.

The study utilises useful insights from neo-technology models, which consider firms' heterogeneity and product differentiation as major drivers of trade and the resource-based view (RBV), which postulates that firms' resources drive differences in firms' capabilities, leading to determining their sustained competitive advantage. The study is also linked with the capability approach and the dynamic capability view, which posit that knowledge spillovers from trade, FDI, and the government's trade and innovation policies encourage the innovation capability of firms. Recently, endogenous growth models associated with new trade theories highlight the role of technology in intra-industry and intra-product trade.

DATA AND METHODOLOGY

The research design of the study was based on primary data. The pharmaceutical firms in Punjab, Sindh, Khyber-Pakhtunkhwa, and Islamabad Capital Territory were surveyed to gather data. These regions comprise 97% (623 of the total 639) of pharmaceutical firms. The data were collected using a structured questionnaire. The information was collected on firms' characteristics (size, productivity, absorptive capacity), firms' engagement in innovation activities, including sources (internal and external, domestic and foreign) and types (product, process and organisational) of innovation, the factors hampering innovation activities, the factors promoting TI, and the supply and demand side determinants of exports. The sample size was 100, which is 16% of the total population of pharmaceutical firms in Pakistan. We also executed 12 semi-structured interviews of key stakeholders from manufacturers, the pharma association (PPMA), academia, and DRAP to refine and consolidate the collected information.

For concreteness, we developed two single-equation empirical models, including the innovation and exports equations. The objective was twofold: to empirically assess the factors that significantly induce firms' innovation performance and to systemically estimate the impact of diverse channels of TI and other crucial factors on firms' export performance. To tackle the issue of small sample size, imbalance in data points and the risk of separation, which may arise due to strong linear association among variables, we utilised the Firth's Logistic (FL) regression because the abovementioned issues render standard logistic regression models inconsistent.

FINDINGS

The empirical results of the innovation equation show that external (embodied and disembodied) technology acquisition and knowledge spillovers from FDI induce pharmaceutical firms' decision to innovate, suggesting the important role of the import of machinery and equipment, technology licensing and

FDI in firm-level innovation. The results reveal that firms' characteristics, including productivity, absorptive capacity, and organisational innovation, are significant determinants of firms' propensity to innovate. It not only reveals the importance of skill, human capital, and internal and external training of workers for innovation but also highlights the significance of implementing modern organisational methods and business practices for a firm's innovation decision. Furthermore, research collaboration and knowledge spillovers from CRAMS activities are critical for a firm's involvement in innovation activities. The results advocate the significance of contract research organisations (CROs) and toll/contract manufacturing services for a firm's probability to innovate. The findings of the study also suggest that research collaborations among firms through strategic partnerships and joint ventures are critical drivers of a firm's innovation decisions. It also highlights the critical importance of the university-research institution-industry linkages for a firm's engagement in innovation activities.

The empirical results of the export equation show that internal R&D and external technology acquisition are two crucial channels for firms' export propensity. It reveals the importance of R&D induced decrease in average cost and improvement in quality and reliability of products for a firm's global competitiveness. It also highlights the significance of international technology spillovers through the import of machinery and equipment and licensing of technology for export. The results confirm the neo-technology models, which explain the role of R&D in production and trade structure. The empirical results also show that firm size, process innovation and innovation variety are critical for firm-level export, suggesting that large firms with improved production processes or distribution methods and those involved in a variety of technological and non-technological innovation activities are more likely to enter the export market.

Furthermore, the empirical results show that product diversification and the development of infrastructure are critical for a firm's probability of exporting. It reveals that the products focusing on emerging therapeutic avenues are critical for global competitiveness. In the context of Pakistan, it broadly involves the production of high-quality generics and simpler biologicals, such as vaccines and others. Findings advocate the establishment of drug testing laboratories and bioequivalence /bioavailability (BE/BA) study centres, which are crucial for pharmaceutical exports.

The estimates also show that the firms' membership of international regulatory bodies (e.g., US FDA) and the membership of the drug regulatory body (e.g., DRAP) of PICS countries is critical for entry into the export market. Lastly, findings confirm that incentives provided by the government for local production of APIs, import of machinery and equipment, export rebates, financial support for BE/BA studies, and GMP inspections and facilitation for drug registration are critical for a firm's entry into the export market.

RECOMMENDATIONS

- The study recommends a three-pronged R&D strategy.
    - First, R&D for the production of high-quality generics and capturing the off-patent market;
    - Second, basic research for drug development through university-research group -industry linkages; and
    - Third, R&D to enhance the production of biologicals. To this end, firms are required to enhance R&D intensity, large firms to establish R&D consortia and the government to utilise the Central Research Fund (CRF).
- Firms should focus on accelerating indigenous innovation activities and relying on external technology acquisition for technology upgrading, leading to plant accreditation. Furthermore, there is a need to upgrade to electronic/digital and AI-based machinery and equipment. The government should facilitate technology upgrading activities at the firm level.
- The study recommends that firms should be involved in toll/contract manufacturing to save on drug discovery costs. Furthermore, we recommend the establishment of CROs, analytical labs, and BE/BA study centres for pre-clinical and clinical trials and BE/BA studies.
- The study recommends a change in curriculum pertinent to understanding the global standards and pharmacovigilance system. Also, there is a need to develop a viable university-industry linkage where the problem identification and implementation into the curriculum will be smooth. The study proposes an increase in the biotechnology schools and research labs in order to gain the capability to move to new therapeutic avenues.

- As for DRAP, the human resource capacity enhancement and capacity development for guidelines and their implementation of AI-based/biological drugs are critical at this stage. Furthermore, DRAP should materialise the use of CRF, seek amendments in the Drug Act 1976 where necessary and expedite the process of PICS membership. Furthermore, DRAP should revise the toll manufacturing policy to enhance low-cost manufacturing. Also, there is a need to devise a criterion to limit the registration of a single molecule by so many firms to avoid more spending at the post-production stages.
- The study recommends that drug price decisions should not go to the cabinet. The Federal Government should establish a dedicated price board that monitors the cost of production and other related factors. The Federal Government should revise the existing APIs policy based on the available experience and set up a task force to examine its implementation.

Finally, we suggest an increase in the USD retention limit of the export proceeds of pharmaceutical firms.

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