

TRANSFORMING EXPORT COMPETITIVENESS: TECHNOLOGICAL
UPGRADATION AND DIGITALIZATION IN THE INDIAN HVAC INDUSTRY

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Dedication

This doctoral work is humbly dedicated to my parents, whose lifelong sacrifices, unwavering faith, and strong value system laid the foundation for my academic and professional journey. Their blessings and constant encouragement have been my greatest source of strength throughout the demanding course of this research.

I also dedicate this work to my wife and my son, whose patience, understanding, and unconditional love sustained me through the many challenges of this doctoral journey. Their presence gave meaning to my efforts and renewed my determination to persevere.

I gratefully dedicate this work to my organization and to the Managing Director, whose trust, encouragement, and support in allowing me to pursue this doctoral research alongside my professional responsibilities made this achievement possible.

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ABSTRACT

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Export competitiveness in the manufacturing industry is being increasingly influenced by technological sophistication and digital preparedness, especially in emerging economies such as India. The Indian Heating, Ventilation, and Air Conditioning (HVAC) industry has witnessed growing at a fast rate and now holds a large space in the global supply chain. However, little empirical research has looked at the effect of technological upgradation and digitalization on competitiveness in exports or their interaction. This study fills this gap by examining the role of technological development and digital transformation in the export competitiveness of the Indian HVAC industry and also identifies the key barriers and enablers of technological transformation. A mixed methods research design was used. The quantitative component consisted of the panel data regression analysis of 51 low and middle-income countries, including India, with the 2000-2022 time period. Diagnostic tests supported that the best specification was the Random Effects Model. While the qualitative component was conducted through semi-structured interviews with key stakeholders of the Indian HVAC market which included manufacturers, exporters, policymakers, and

technology experts. The qualitative data were analyzed in terms of firm-level experiences through thematic analysis. The quantitative results indicate a strong and positive statistically significant correlation between technological upgradation and export competitiveness, which implies increasing levels of higher technological advancement in favour of export performance. In contrast, the existence of digital infrastructure alone is not found to have statistically significant direct impact, raising the assumption that digitalization only contributes to competitiveness when combined with technological capabilities and support organizational systems. The qualitative findings provide support for these findings that automation, advanced manufacturing and energy efficient technologies enhance product quality, compliance with international standards and export readiness. Digital tools further boost coordination, transparency and engagement with the global markets. Human capital preparedness, leadership commitment, financial capacity, and organizational readiness were found to be key determinants for successful technology adoption. The research finds that the emergence of export competitiveness in the Indian HVAC industry with the result of synergy between technology upgradation, digitalization and organizational capability with technology being the driver and digitalization serving as strategic enabler.

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CHAPTER I: INTRODUCTION

1.1 Introduction

In the context of the fast moving global economy, export competitiveness has been proven to be an important driving force for economic growth and development, especially for emerging countries such as India. Operating under the principles of comparative advantage, global trade has allowed nations to experience high economic expansion (Kumar, 2019). Recognizing this, India has shifted from an import substitution strategy toward an outward oriented, export driven approach. The Economic Survey (2022) reports that India achieved over 75% of its US\$400 billion export target for 2021-22, reinforcing exports as a key pillar of its ambition to become a US\$5 trillion economy by 2024-25.

The Heating, Ventilation and Air Conditioning Industry (HVAC) plays an important role in this extensive economic transformation. As India's population expands and accelerates urbanization, the construction sector is ready for significant expansion, which is expected to increase the area built from 2100 million square meters in 2005 to 10400 million square meters by 2030 (HVAC Market Assessment and Conversion Report, 201). Because of this quick development, there is now more demand for energy saving HVAC systems and a better understanding that new strategies designed for India are required. Also the HVAC industry in India is responding to what customers, governments, and society expect, which means more room for expansion, yet proves more competitive. India's HVAC sector has to overcome several issues such as expensive investments, complicated technical and operational problems, difficulties in data security, and disinterest in using new technology (cited in Chandrashekhar, 2022; EEPC India, 2022).

The Indian industry is expected to grow by 16% each year over the next 10 years, mainly exporting to important destinations such as the USA, UAE and China (EEPC India, 2022). To keep up with this growth, a strategic use of new technologies and digital change can help get past existing difficulties and raise the nation's competitiveness in the global market. Upgrading technology is important for better quality products, more energy savings, and improved operational results in the HVAC sector. Thanks to intelligent controls, sustainable coolants, and state-of-the-art heating systems, Indian organizations are able to supply the domestic as well as the foreign markets with less harm to the environment. At the same time, digitalization has facilitated how businesses operate and work by enhancing the supply chain management, the management of inventories, the possibility to check operations remotely and the ability to better deal with customers. The use of digital tools in marketing, sales, and customer support helps Indian companies in the HVAC sector to expand their market and work more efficiently and provide tailored service to consumers. The idea of this research is to investigate how technology and digital solutions affect India's HVAC industry with respect to export competitiveness. It wants to focus on some important problems and study the strategic situations and provide insights which fit in with India's strategy for sustainable growth and leadership in the world. This research attempts to find out how innovation can help to the Indian HVAC industry to perform well in the international market.

1.2 Research Problem

Strong growth in India has not been beneficial for the heating, ventilation and air conditioning (HVAC) industry to gain a strong foothold in the international market. The biggest reason for this challenge is using old technology, the insufficient usage of digital solutions, the higher average costs, and challenges due to regulations. As a result, it is more

difficult for the sector to grow rapidly, bring new ideas and meet the competition from large-scale enterprises from overseas. Managing these problems matters for the HVAC sector as well as India's goal of contributing more to the international market and reaching its USD 5 trillion economy target. Although the market for HVAC in India is vast and expanding, it consists mostly of small and medium sized companies that make growing difficult (Dixit and Bhasin, 2022). Large companies find it hard to compete with Chinese companies in manufacturing, technology and efficiency. In addition, barriers such as not having enough money, not investing properly in research and development, and less effective digital infrastructure make it hard for technology to be used effectively.

The whole world is experiencing rapid changes in the HVAC industry due to technology and digital advancements.

Modern control systems, safe refrigerant, and mostly energybased designs play a key role in improving device quality, improving performance and protecting the environment.

Digital transformation, with IoT, automation, data analytics and smart supply chains, changes business methods, increases the ability to serve customers and gives better access to the market. Both factors are playing a key role in determining how well companies compete internationally.

Even so, most Indian manufacturers have not picked up these new technologies quickly. Although older technologies are still used, firms invest little in R&D and linger behind in Industry 4.0 by not using automation and advanced analytics.

Companies have difficulty reducing costs, improving products and adapting to new expectations around the world due to old technology. At the same time, foreign competitors often use digitalization and new ideas to simplify how they work, upgrade their products and position them better in the market. Because the world is moving to digital and intelligent

manufacturing systems, Indian HVAC companies that do not keep up could be lost in the competition. If technological and digital changes are not adopted urgently, it is likely that India's HVAC industry will find it hard to keep or increase its position in the global market. These challenges raise an important question: To what extent can technological upgradation and digital transformation enhance the export competitiveness of India's HVAC industry?

The study further considers the impact of technological innovation on the competitiveness of regions around the world. The study is aimed at resolving two principal research questions, namely, (1) How will digitalization and upgraded technology impact the export performance of the Indian HVAC sector and (2) Which actions can be adopted to overcome difficulties in adopting technology in this sector.

The investigation of these issues is meant to encourage strategies which help India's economy to secure its involvement in trade with other countries and also encourage growth in the industry by the use of technology and new ideas.

1.3 Purpose of Research

The goal of this study is to determine the consequences of the development of technology and digitalization on the export potential of the HVAC industry. The main objective of the study is to discover the major barriers, see if the industry is ready for new technologies, and suggest useful strategies for better business results. Having this vision, study intends to give helpful advice to people in industry, policy, and business leadership.

The research aim includes various objectives which are detailed in the literature review. First, researchers want to look into how having better technology and digital tools increase a country's ability to compete in exports worldwide. The purpose is also to find out what strategies will help the Indian HVAC sector accept technology by learning about the main

obstacles to growth. In particular, the study aims to examine financial limitations on SMEs, a major skills shortage in the employed population, organizational resistance to transition, and infrastructural complications of marrying new technologies with old systems.

1.4 Research Questions and Hypothesis

Study focuses on the following research questions and hypothesis:

RQ1: Will technological upgradation and digitalization affect the export competitiveness of the Indian HVAC industry?

H_0 : There is no statistically significant impact of technological upgradation and digitalization on the export competitiveness of the HVAC industry in India.

H_1 : There is statistically significant impact of technological upgradation and digitalization on the export competitiveness of the HVAC industry in India.

Dependent Variable: Export competitiveness.

To assess the competitiveness of exports, the study use the proxy indicator, "Exports of Goods and Services(% of GDP)," which offers the useful macroeconomic lens in which the HVAC industry can be located within broader trends in trade and technical advancement.

Independent Variables: Technological upgradation and digitalization.

"Medium and High-Tech Exports (% of Manufactured Exports)" is a proxy for technological upgradation, which reflects the sophistication in the manufacturing output of a country. While the indicator "Fixed-Broadband Subscriptions (count)" is being used as a

proxy indicator of digital infrastructure which forms the basis of smart manufacturing and online trade platforms relevant to HVAC firms;

Control Variables: Firm size, market situation, and regulatory situation.

Firm size is controlled to account for structural differences in industrial capacity, as larger firms typically exhibit greater economies of scale, technological absorption, and export capability.

Market situation is included to capture macroeconomic conditions such as market size, growth, and trade openness that influence production dynamics and export performance.

Regulatory situation is controlled to reflect the quality of institutional and policy frameworks that affect technology adoption, compliance standards, and international competitiveness.

RQ2: What strategies can be developed to promote technological adoption in the Indian HVAC industry by identifying key barriers and challenges?

To meet this research, a qualitative research approach was followed using thematic analysis informed by grounded theory principles as guiding. This method was chosen for its power to produce theory from empirical data in a situation where any given theoretical model might be problematic or inadequate. Data has been collected through 50 semi-structured interviews with key stakeholders of the Indian HVAC industry who are directly or indirectly involved in the decision-making process for technology adoption. These stakeholders will include Business leaders and executives in HVAC companies, Managers and engineers responsible for production, operations, and innovation, Industry consultants and experts.

The interview instrument was designed to probe the different barriers to the adoption of technology like financial constraints, skills gaps, challenges with infrastructure and compliance issues and the strategies organisations are currently putting in place to mitigate this.

Data were analyzed by means of open coding in order to obtain the original themes, axial coding to relate categories (challenges and strategic responses), and selective coding to produce a central theoretical framework. This iterative research process allowed the birth of a conceptual structure based on the realities of the industry. Based on these aspects, formulation of the framework relevant with strategies to be developed in terms of technological adoption in Indian HVAC industry by identifying the key barriers and challenges was attempted qualitatively.

1.5 Nature of the Study

This study is based on a mixed methods approach and investigates the impact of technological upgradation and digitalization on export competitiveness of the HVAC (Heating, Ventilation and Air Conditioning) industry of India. The research is organised in two phases, a quantitative one, analysing data at a national level to understand the macro level indicators of technological and digital advancement, and a qualitative one, exploring the firm level realities, to identify the barriers and enabling strategies for technology adoption. Together, these phases are designed to create a full and context rich picture of how technological changes impact the position of the HVAC industry within global trade.

1.5.1 Quantitative phase

At a quantitative level the research has made use of secondary data sourced from worldwide reputable experts, namely the World Bank's World Development Indicators (WDI) and the UNESCO ITU Data Hub. These databases offer credible and consistent measures to

determine long-term changes in trade performance and technological infrastructure among countries. Covering 51 low- and middle-income countries between 2000 and 2022 this data set allows us to explore a very robust longitudinal analysis. This means that India's HVAC industry can now be benchmarked against global trends. To assess export competitiveness, the study has adopted the measure "Exports of Goods and Services(% of GDP)" as a proxy indicator, although not ideal it can provide a good macroeconomic overview, placing the HVAC industry in the wider context of trade and technological development. This choice can be informed by the common practice in the export competitiveness research where sector specific export data are not directly available (eg for HVAC). As the HVAC industry is a critical part of overall manufacturing exports, this proxy will allow benchmarking in the face of the larger context of national trade performance.

Two independent variables are taken into consideration as technological and digital progress. First of all, the "Medium and High-Tech Exports (% of Manufactured Exports)", which is a proxy for technological upgradation, reflects the sophistication of a country's manufacturing output. Second, the indicator "Fixed-Broadband Subscriptions (count)" is used as an indicator for digital infrastructure, which is basic for adopting smart manufacturing and online trade platforms relevant for HVAC firms. While these indicators are not beneficial for the HVAC sector specifically, they provide a comparative framework to establish India's position with respect to global trends in technology and trade for the HVAC sector. This macro to sector approach is particularly useful in emerging markets such as India that are often limited in their sectoral disaggregation. By finding patterns and correlations among these variables, the quantitative phase helps to establish the ground for exploration of causal factors and industry specific dynamics in the qualitative phase.

1.5.2 Qualitative Phase

The second phase of the research will be carried out by complementing the results of the quantitative data with qualitative data that is gathered via semi-structured interviews with key stakeholders in the Indian HVAC ecosystem. This includes heating and ventilation air conditioner (HVAC) manufacturers, exporters, technology providers and policy makers. The qualitative phase was especially helpful in determining practical challenges and firm level strategies associated with the use of advanced technologies and digital solutions.

The interview framework was developed based on a set of key themes such as financial constraints, workforce skills gaps, organizational readiness, infrastructural bottlenecks and regulatory limitations, which are often mentioned in both academic and industry literature. These interviews were also conducted to understand the strategies to overcome these barriers companies are implementing such as participation in government schemes, investment in employee training, the involvement of R and D platforms and the use of public certifying labs.

To analyze these interviews a thematic coding procedure based on the thematic analysis informed by grounded theory principles methodology was created. It involved open coding to identify preliminary themes, axial coding to identify contacts between barriers and strategies, and selective coding to synthesize the research findings into a conceptual framework expressive of the dynamics of the real world. The interpretive nature of this analysis enables the research to tease out patterns that may not be apparent by using quantitative research data.

1.5.3 Theoretical Grounding and Analytical Frameworks

In this work, two major theoretical frameworks were developed based on the literature review and conceptual analysis. The first framework is an exploration of the role of technological upgradation and digitalization in improving productivity, cost efficiency, innovation capability and overall export competitiveness. It shows how internal

technological developments lead to better performance measures and improved positioning of companies in the global market. The second framework focuses on identifying the important barriers and challenges that hinder technology adoption in Indian HVAC industry such as financial constraint, skill shortness, infrastructure limitation, quality compliance and the strategies that can be developed for their accomminess. Through this model, in order to promote the adopting of technology, the federal policy is being used with the team work among companies and the investment into training the workers all aimed towards meeting the needs in every industry.

These frameworks are used during development of hypotheses and interview tools and provide a means to structure the interpretation of any outcome. The results gathered from the quantitative part are analyzed in terms of technology export linkages, while insights are analyzed in terms of maintaining the strategy adjustment and innovation in companies.

1.5.4 Contributions

Blending the knowledge acquired from the macro and the industrial field, with this method, we can appreciate better the contribution of the technological field to the HVAC export potential of the country. In the quantitative part, we get a impression of general patterns and comparisons from the rest of the world, but in the qualitative phase we see what is going on in people's lives and working places. Such joint research enables to derive trends, also to clarify its causes and action in India. The approach allows to construct a strategy encompassing both general strengths of industry and company specific actions, which can be used to guide those in manufacturing, the industry and policy.

In the end, the research results should contribute in shaping academic deliberations, industry choices and policies so that the Indian HVAC industry can fulfill the goal of becoming world competitive and technology focused.

1.6 Assumptions

This study makes methodological and analytical assumptions to ensure coherence and validity in addressing the research objectives. These assumptions serve both the quantitative and qualitative phases and are systematic to address the rationale of the mixed methods design used in the current study. Since disaggregated HVAC specific export data is not available, the research uses national level indicators as is common practice in competitiveness of business studies (OECD, 2023). These proxies, based on internationally accepted databases such as the World Development Indicators (WDI) compiled by the World Bank and the ITU Data Hub by UNESCO, allow for a macro-level analysis of the correlation between export competitiveness and both technological upgrading and digitalization in the Indian setting.

Although these indicators are broad and not HVAC specific, they are widely used in comparative trade research as credible stand-ins when sector specific data is unavailable. HVAC is embedded within the broader manufacturing and high-tech exports domains and as such, national level proxies reflect macro trends that are relevant to the sector. The use of longitudinal data spanning 23 years (2000-2022) across 51 low- and middle-income countries helps position India's HVAC industry within global benchmarks, thereby reinforcing the validity of the comparative framework.

These are the macroeconomic proxies supported further with qualitative data enabling the study to triangulate (placing 2 variables against the third variable) with the sector specific insights and the macro level trends. This hybrid approach is an effective way of countering the problems of relying solely on national level data, as sectoral nuances will be adequately captured through stakeholder perspectives.

1.6.1 Assumptions for RQ1: Quantitative Analysis

The quantitative analysis performed for RQ1 is based on a number of assumptions which are used to select the indicators and the type of dataset. To represent export competitiveness, the study adopts "Exports of Goods and Services as a % of GDP" as a proxy in representation of export competitiveness. Although it captures export performance at a macro level, this measure is considered appropriate because it is based on how actively a country participates in international trade an arena in which HVAC exports are embedded. For evaluation of technological advancement, the study assumes that "Medium and High-Tech Exports as a Percentage of Manufactured Exports" is a good measure of the level of technological development in a country. This is indicative of the ability of the economy to produce and export technologically sophisticated products which is important in the HVAC industry. In the assessment of the digitalization, the number of "Fixed-Broadband Subscriptions" is used as an indicator of digital readiness. This measure is assumed to reflect the basic digital infrastructure needed to have the capabilities to support advanced manufacturing processes, remote system monitoring, digital marketing and engagement of customers through online platforms, which are becoming fundamental in the HVAC sector.

The time period of the dataset covers 23 years between 2000 and 2022 and covers 51 countries. It is assumed that such a temporal and spatial extent is enough to provide significant comparisons and discover significant global patterns. The inclusion of low and middle-income countries is deliberate because it will be possible according to India to judge its performance against the background of countries with a similar developmental experience. Lastly, the study assumes that occasional values missing in the dataset will not distort significantly the overall trend analysis. The rationale here is that having a longitudinal dataset of this scale helps to tend to short-term inconsistencies so that it will be possible to find reliable long-term patterns, despite slight drops in data.

1.6.2 Assumptions for RQ2: Qualitative Analysis

The qualitative analysis performed for RQ2, which is based on interview with industry stakeholders, is also based on a number of underlying assumptions. For this reason, it is assumed that responses from participants, business leaders and executives in HVAC companies, managers and engineers with the responsibility for production, operations and innovation, industry consultants and experts will be honest, reflective and based on their professional experiences. The accuracy of the discovery of the study depends on how real the narratives are because they throw light on what is going on to those taking part in technology adoption and export. It is further assumed that the sample of 50 participants represent a judicious mix of views in the various roles, company sizes and regions of India. Gathering feedback and insights from different stages in the process of HVAC, for example, production, research, policy and export, the study will give a clearer picture of the sector. Moreover, by linking the large-scale statistical information to the small-scale information, it is believed that the paper can help to explain the causes of export competitiveness in the HVAC industry. This assumption is supportive of the research's mixed methods design, in which system wide patterns witnessed in data analysis are enriched and contextualized by firm level experiences and strategies shared during interview. Together, these assumptions guarantee that the research are deal with effectively. While the qualitative information collected is from a specific sample, it is assumed that the information elicited from the selected samples is representative of wider patterns in the Indian HVAC industry. Given their representative roles (across different value chain segments), the insights can affect the strategies and policies to deal with and perhaps inform practical strategies and policies beyond the immediate sample. At the same time, the study recognizes that the generalization at sector level is inherently limited due to factors such as regional diversity, policy variations and firm maturity differences.

However, a combination of representative sampling and thematic saturation and grounded theory analysis looks to add to the robustness and credibility of qualitative outcomes from this study.

1.7 Scope and Delimitations

1.7.1 Scope of the Study

This article reviews the impact of technological upgradation and the digitalization phenomenon on the export competitiveness of the Indian HVAC (Heating, Ventilation and Air Conditioning) industry. Although a number of studies have been conducted related to the impact of technology and digitalization on global trade in general, their specific effects on sectors such as HVAC especially one with high growth potential but limited research still need to be researched in more detail. The Indian HVAC industry is selected as the point of focus as it is growing at a fast rate, is based on energy efficient technologies and is further responsible for ever-growing exports in emerging economies such as India. As a technology intensive sector embedded within a broader ecosystem of manufacturing, HVAC is very sensitive to changes in innovation, infrastructure and policy dynamics. Thus, understanding technological adoption and influencing the digital readiness has important implications in shaping its export competitiveness, industrial growth, trade policy and sustainable development.

On the methodological perspective, the study mobilises both quantitative and qualitative data in order to generate a multidimensional insight on such relations. The quantitative part is based on macroeconomic information derived from authoritative international sources such as the World Development Indicators (WDI) offered by the World Bank and the ITU Data Hub operated by the United Nations Educational, Scientific, Cultural and Sports Organization (UNESCO). Since HVAC specific export data is not available separately, the

study has used national level indicators including exports of goods and services (% of GDP), medium and high tech exports (% of manufactured exports), and Fixed Broadband Subscriptions (count) to represent trends associated with competitiveness, technological sophistication and digital infrastructure, respectively. These proxies are grounded to consumption practices in known research on competitiveness and enable analysis over time and also across countries.

The empirical sample is, in accordance with the World Bank classification, the 51 low-/middle-income countries between 2000 and 2022. This makes it possible to undertake a robust 23 year trend analysis to use as a benchmark for where India stands as compared to the world. These proxies help to find wider patterns in mislabeling, especially if there is a connection between countries who are higher in levels of digital or technological readiness if they show better materialized outcomes on export a pattern that may be reflective of sectoral tendencies, including HVAC. The qualitative phase complements the macro level analysis incorporating insights from the industry stakeholders through semi structured interview and surveying responses. Participants include HVAC manufacturers, exporters, technology partners and policymakers, all of whom are actively involved in strategic or operational decisions around technology adoption and export development. Their inputs help to identify barriers, enablers and strategies, which are not easily gathered through secondary data.

1.7.2 Delimitations of the Study

The study is delimited in some boundaries and limitations although the approach is comprehensive:

First the use of national level proxies has a limitation on capturing sector specific nuances. While HVAC is enhanced within the larger manufacturing and high tech export categories, these proxies don't isolate the performance of the HVAC. However, this limitation is

overcome by the incorporation of qualitative data, which gives more in-depth perspectives specific to the HVAC sector. This mixed methods approach helps to overcome the dangers of hyper broad indicators, but also contributes to more informed sector specific interpretations.

Second, the qualitative data is provided through a selected sample of industry participants self-reported insights. While these stakeholders have been purposively selected for their relevance and experience, their responses might be subject to subjectivity, strategic interests or recall-bias. Nonetheless, the sample size and diversity, together with the thematic analysis approach, ensure that thematic saturation is reached and increase the credibility of the findings.

Lastly, this research provides insights that are specific to the sector and that help to understand the role of technological and digital transformations in the context of export competitiveness in developing country contexts (acknowledging that findings might not be generally generalizable beyond the HVAC sector). By setting a clear scope and recognizing its boundaries, this research brings certain insights concerning the impact of technological and digital change on export competitiveness in developing country circumstances. It places the Indian HVAC industry in the market as a case from which broader policy and strategic lessons can be unbiasedly defined whilst remaining cognizant of the shortcomings of proxy-based information as well as participants. The findings therefore contribute value to the academic literature as well as for policy formulation in improving technology led trade performance for the highly competitive industrial sectors.

1.8 Limitations

This study identifies four key limitations as follow:

Firstly, in the quantitative analysis for RQ 1, the study uses export competitiveness as a variable, using data from the World Bank (2023). However, export performance depends on many factors that may differ greatly across countries. These factors include domestic industrial policies, trade agreements and geopolitical considerations, which are not explicitly accounted for in this study. The omission of such variables may set limits on the precision of the results in order to know the full extent of export competitiveness.

Second, in the qualitative analysis for RQ 2, the development of a strategic framework for technological adoption in the HVAC industry is based on the analysis of documents and survey responses. While qualitative coding promises a systematic and structured approach, some causative biases might arise because of differences in the views of the respondent or selective reporting in industry reports. These biases may cause a limitation of the generalizability of the findings since the results may not reflect the full range of experiences in the HVAC industry. Thirdly, the quantitative analysis for RQ1 for this research does not consist of analysing specific HVAC firms in India. Even though it is useful to work on the sector wide trends, case studies of specific firms might have provided us with more detailed information on how being up-to-date affects their competitiveness in export markets. There are fewer case studies to examine the issue in depth as there may be issues, problems, opportunities, and challenges specific to particular companies that will not have been covered in sector data.

Fourth, in the case of RQ1, the quantitative analysis of the effects of upgrading versus digitalization on the position in export markets of 51 countries in the low- and middle-income range. Still, the research may not fully describe the circumstances in the Indian HVAC industry. The differences in economy, regulations, government help, and ways of which businesses develop can also impact the relationship between technology and the success in which a country exports goods. So, while this analysis is interesting in providing

some useful viewpoints, its impact on India's HVAC sector could be of low strength. To overcome these problems, whenever it was possible, we examined quantitative trends in addition to qualitative feedback from players in the industry. This makes the study conclusions more credible and proves a more subtle picture of the impact of technology and digitalization on export competitiveness.

1.9 Significance of the Study

The research is informative towards the correlation between technological upgradation, digitalization and the export competitiveness in HVAC industry in India. The results will have the potential to inform both practice and academia by addressing the important gaps in the knowledge about the impact of the technological changes by sector on trade performances.

Academically, this study is relevant in supplementing the literatures, which already exist regarding international trade, technology adoption. Although past research has focused on the role of digital transformation, in general economic terms, there is less research on what effect digital transformation will have on the HVAC industry in its immediate effects especially in developing economies such as India. By incorporating the theoretical frameworks presented in the literature review, this study contributes toward the addition of new knowledge to the academic debate surrounding this concept in relation to the question: How does the availability of technological innovations contribute to trade competitiveness? From the industry perspective, the results have ramifications for practitioners of the HVAC industry, exporters, and policy makers in India. The study identifies some of the key technological barriers and digital adoption challenges affecting global competitiveness and gives stakeholders data-led information to support strategic interventions. Understanding the importance of technology as it relates to export performance can help businesses to

ensure the value of their investment decisions resonate with the demands of the global market, and enhance their productivity and supply chain efficiencies.

For policymakers, this type of research provides them with insight on how to formulate the policy for the promotion of digitalization and technology upgradation in the HVAC sector. Given the thrust of the Indian government towards "Make in India" and export driven industrial growth, the findings of the study can be used as evidence in policy formulations towards uplifting the global position of the sector. Furthermore, the examination of India with 51 other low and lower middle-income countries provides useful information to guide the policymakers in the use of international comparisons in the HVAC field.

In addition, this study engages in the larger debate about how emerging economies can use technology to make their industries more sustainable. By clubbing the information gathered through the two research frameworks used in this research, the research stresses on innovation, infrastructure, and regulatory support affecting the future flow of Indian manufacturing exports. They explain the relation between modernization, the digital advancement, and trading activities to have a better view about the way companies are competitive in the international market.

1.10 Chapter Summary and Transition

This work examines the impacts of digitalization, and the improvement of technology on India's HVAC sector in regard to export. A combination of statistical and professional opinion is helpful to the analysis in exploring why and how India's presence changes in the world market. The research utilizes credible second-hand information expected to be valuable in other areas of the industry. At the same time, it knows that there may be data missing and that what survey inputs are received may be subjective. The research attempts to explain the implications of technology for the outcomes of trade so as to inform research

and government policies. Irrespective of the current trends, the major goal is to create beneficial suggestions that would accelerate India's growth and development in the global HVAC sector.

The next chapter 2 gives an explanation of the existing literature on technological upgrading, digitalization and export competitiveness. The research identifies helpful theories, models and knowledge on how technology influences the global trade results. This chapter represents gaps in current research and provides the basis for the theoretical framework and methodology of this study. By studying the past research, it paves the way for the analysis of Indian HVAC industry current challenges and opportunities in the global market.

CHAPTER II: LITERATURE REVIEW

2.1 Introduction

The ability of companies and industries to adopt innovative technology and digital solutions has now proven to be pivotal to remain relevant in the context of extremely competitive business environments in the modern world. While the general importance of exports in achieving national economic strategies has been established; it is equally important to understand the internal enablers that support export performance in specific sectors that matter such as Heating, Ventilation, and Air Conditioning (HVAC). The HVAC industry, due to its technical complexity, cross sectoral linkages and fast evolving demand for energy efficient systems, is very much sensitive to technological advancement and integration with digital technology.

The present chapter forms conceptual underpinnings for an exploration how technological upgradation and digitalization are internal capabilities affecting export competitiveness. Rather than reiterating the macroeconomic objective or general industry growth patterns, the following discussion deals with the underlying theory of capabilities generated by innovation and how it initiates performance results in international trade. Existing academic and policy literature has frequently addressed digitalization and upgrading of technologies as disconnected fields. However, there are still few studies that model comprehensively their combined influence in export success, particularly in the context of a developing economy with structural constraints coupled with diverse enterprise capacities.

Against this background, the chapter makes a theoretical and conceptual framework specific to India's HVAC sector with two questions posed first is, will do these twin transformations improve their export competitiveness and second, what are the strategies needed to maintain their adoption? This framework is based on existing theories of international trade, innovation systems and digital capability maturity, while also incorporating empirical learning on industry specific developments and comparative global benchmarks. In this light, the chapter puts in context a more extended discussion of the channels via which digitalization and technological modernization can cross over with export oriented consequences. In the process, it provides a frameworked foundation for the analysis and empirical research that follows which anchors the study within a well founded conceptual framework that is aligned with both academic rigour and practical application.

2.2 Theory

2.2.1 Proposed Theoretical Framework on Technological upgradation and digitalization effect on the export competitiveness of the HVAC industry in India.

"Digitalization as the use of digital information and technologies to change business processes has become a driving force changing industry around the world". At its most basic digital transformation is more than just the modification of operations, it can fundamentally alter the nature of business itself. Digital technologies can be defined as the type of devices, systems, and tools as well as other resources that are used to produce, store, or process data. OECD (2019) explains that digitalization has implications not only of the deployment of these technologies but also of the interconnection facilitated, leading to new or substantially altered business activities. Matt and Rauch (2020), Ferrantino and Koten (2019), and Tjahjono et al. (2017) also point out a multidimensional and fast-changing

nature of digitalization, which features platforms, industry 4.0, electronic data exchange, and digital marketplaces.

Further inculcating this change, Society 5.0 is a concept with its base in Japan's innovation strategy that lays emphasis on the integration of digital tools for social advancement. Aqmal 2024 refers to four main areas of influence of this revolution for business sectors: shifting expectations of the customer, improving product quality based on data, development of new operational modes in digital format, and new cooperation. The International Energy Agency (2017) backs up this view with the understanding that the digital and physical worlds are converging through three key aspects: data (digital information), analytics (drawing insights) and connectivity (human and machine interaction through digital network).

Technological advances, especially since the 1980s, have greatly lowered transportation and communication costs, which in turn has enabled the fragmentation of production at the global level and facilitated international trade. As World Bank (2020) explains such advancements have led to the development of complex cross-border value chains, where countries specialize on the basis of their comparative advantages. Digitalization gives further strength to such structures, by creating new opportunities for innovation, efficiency and inclusion (Digital Progress Report, 2023) which have resulted in benefits for organizations, countries and individuals.

Building on the basic knowledge of digitalization, the researcher also discussed research on the connection of digital transformation with other economic aspects of an economy. These include relations between digital technologies and internationalization (Cassetta et al., 2020), economic growth (Liu et al., 2023), technological innovation and productivity (Babina et al., 2022; Micallef and Gupta, 2021; Mishra and Pani, 2021) and employment dynamics (Autor et al., 2022). However, many of these studies, though valuable, are often

about isolated relationships, often abstract and oftentimes iterative without giving a holistic picture of the joint impact of digitalization and technological upgradation on export competitiveness.

In order to fill this gap, the author has made a detailed competitive intelligence and market research report on the HVAC sector in India, where an investment of \$5,000 (Rs. 5,000 crore) is highlighted for the emerging technologies (Markets and Markets, 2023). The report focused on major questions within the industry: the impact on demand for HVAC, the leading areas with impact, and how it influenced other adjacent industries such as construction, manufacturing, energy and technology. The forecasted 5-year results are increased energy efficiency, sophisticated product development, demand and expansion in the market, and profit-earning eventually reflecting the transforming waves of digitalization on global trade dynamics (Pol & Hara, 2025). Given the insights discussed above, digitalization evidently plays a transformative role in terms of operational efficiency, customer engagement and international competitiveness. Likewise, technological upgradation comes out as a catalyst in terms of innovation, sustainability and global relevance. These finds are the basis for the conceptual framework (see Figure 1) that is the visual model for the hypothesized relationship between technological advancement, digital integration, and export competitiveness in the Indian HVAC sector.

Figure 1 suggests that technological upgradation and digitalization play a role in improvement in cost efficiency, product quality, innovation capacity and workforce competency. These internal improvements then flow through to enhanced export competitiveness which in turn drives a wide range of other outcomes including economic growth, industry development, environmental sustainability and employment generation. This model is based on competitive intelligence pulling 2023 market research blog and World Bank datasets (2016, 2021) that provide both relevance and validity through

integration of empirical and theoretical evidence. It is a logical representation of the study's first research purpose which is the examination of the influence of digital and technological changes on export competitiveness in the face of global market changes.

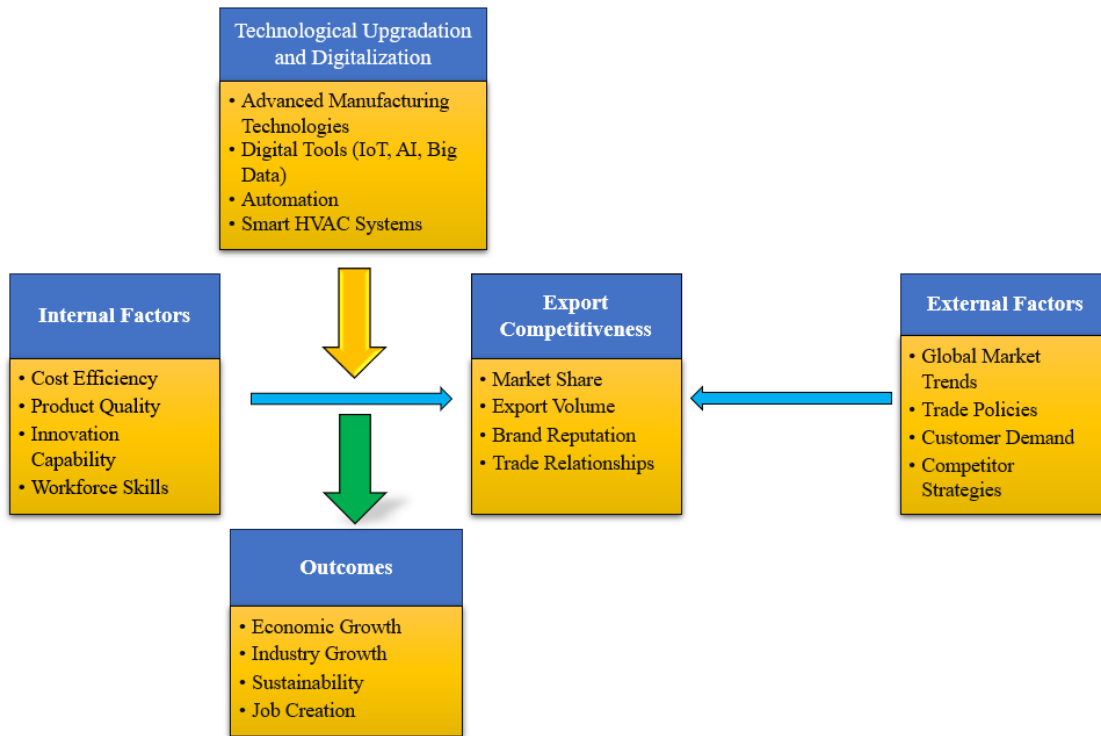


Figure 1: Conceptual framework of Technological upgradation and digitalization effect on the export competitiveness of the HVAC industry in India.
Source: Based on Pol & Hara (2025, p. 205), author revised.

2.2.2 Proposed Conceptual Framework on Strategies to be developed to promote technological adoption in the Indian HVAC industry by identifying key barriers and challenges.

There are two key paths available to countries for developing their digital sectors; export-oriented and domestic market-oriented. Although they do have their own unique

prerequisites, they complement and enhance each other. While a lack of the domestic digital sector may not be a key determinant of success in the digital sector, local digital capabilities may be useful in many low- and middle-income countries. This successful domestic digital market is more capable to address domestic demand, generating more economic spillovers and, ultimately, stimulating innovation and growth (Keller, 2002; Sampson, 2023). In these economies, the export led digital pathway can be a transition to connect with the internal value creation. As the number of native digital companies increases, they begin to internationalize and this continues to boost the export performance of the industry. In the short term, countries need to identify their comparative advantages in various areas of digitals and prepare targeted responses. It is generally more feasible to many low and middle income countries to use tailored pathways to use current strengths to their advantage (Digital Progress and Trends Report, 2023).

Aqmala (2024) carried out an exploratory qualitative research aimed at ecofriendly digital transformation in MSMEs for enhancing global competitiveness. The study, which included primary data from 425 MSMEs in DKI Jakarta, Bali, Java, Borneo, and Sumatra, concluded that digital transformation improves competencies, optimize operations and increase international competitiveness. This transformation occurred in four phases: institutional and production improvements, market expansion, digitalization and access to finance, and lastly, exports market entry.

Similarly, Dixit and Bhasin (2022) noted that the HVAC sector is complex and fragmented and operates in globally distributed value chains and includes a broad range of technological applications. They identified that SMEs in the HVAC sector have a number of innovation-related challenges. These include lack of skilled human capital, financial barriers and limitation in internal R&D and certification facilities. Many SMEs find it difficult to afford new equipment and further hinder the process enhancement and

competition. Quality assurance is another major challenge, especially where domestic, low value products are given precedence over export standard products. Moreover, poor design capabilities limit the capabilities for tooling, machining, and production efficiencies, which limits the quality and marketability of HVAC products.

In addition, Dixit and Bhasin (2022) noted specific policy measures and trends in the industry that could facilitate technological upgrading in the HVAC sector. Recommendations are needed on improved vendor development, capital supports for technology up-grade, access to affordable public certification labs, and R&D collaborative platforms. These measures are aimed at overcoming some of the fundamental challenges and empowering SMEs to better align with global quality and performance standards.

Building on these insights, Figure 2 presents a theoretical framework to help address the second research purpose, which is to identify important barriers to technological adoption in the Indian HVAC sector and to outline strategies for overcoming them. The framework is based on the work of Dixit and Bhasin (2022) and Aqmala (2024) and is consistent with the status of India's HVAC supply gaps (as reported by CEEW).

As illustrated in Figure 2, major obstacles, monetary limitations, capability gap, infrastructural limitations, design flaws and quality compliance issues start the framework, which then proceeds to identifying the obstacles as well as financial, technical, and infrastructural limitations. It also goes a step ahead and proposes certain actions to resolve these issues, such as providing financial support, establishing learning and growth programs, collaborating in the research and development process, and making certification labs more available. This third phase of promotion of technology integration gets additional investment, changes in the company and trained teams and in the end it leads to smooth functioning of advanced solutions. Ultimately, the end result of such efforts is expected to

lead to vital outcomes including better efficiency, competitive advantage, sustainable growth and export competitiveness.

The link that it draws between the barriers, strategies, pathways, and outcomes in the industry, gives this framework a strong and a practical foundation for policy recommendations and business actions to support the growth of the HVAC sector in India's world markets.

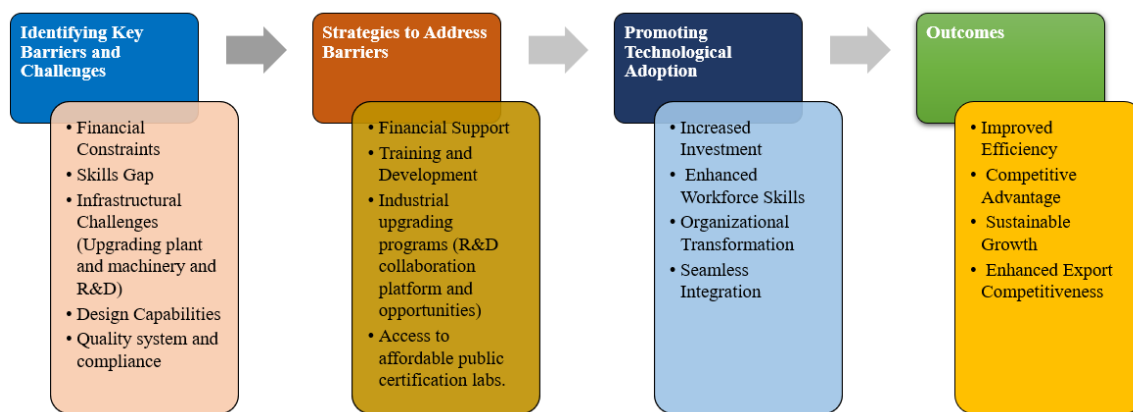


Figure 2: Conceptual framework of Strategies to promote technological adoption in the Indian HVAC industry by identifying key barriers and challenges.

Source: Author's own illustration.

2.3 Literature Review

2.3.1 India's HVAC Landscape: Contrasting with Global Players amid Improved Business Environment:

India is progressing as a major supplier of HVAC machinery parts and components. The availability of qualified personnel in the fields of manufacture and engineering in India is making it a favorable location for manufacturing of HVAC components. The government in India has initiated efforts towards promoting manufacturing and exports in various

fields; one such field is HVAC. Investing in the industry supports these initiatives, and the industry shows quick maturity in India, which means more demand for products manufactured in India. How you make your items helps with your reputation overseas. Since now Indian manufacturers are exporting HVAC related pieces, they are seeing more increase and scope in the international market, according to ET2C blog(2023). Further, report also reveals that China and Turkey have become global manufacturing hubs of HVAC machinery and components, which have played pivotal roles in supporting the growth of the market. China's vast manufacturing capacity ensures economies of scale, competitive pricing, and technological advancements, making HVAC equipment accessible worldwide. Turkey's strategic location facilitates access to European and Asian markets, supported by high quality manufacturing and a focus on innovation, strengthening its role as a vital trade hub in the HVAC supply chain.

In fact, China is major manufacturing centers of HVAC equipment but when literature discusses the story of business environment, China lags behind countries like Malaysia, Thailand, Vietnam, Mexico and India who are targeting manufacturing investment to come their way rather than China. According to EIU, Asia Outlook (2023), India's business environment is now competitive for both China and South-East Asia and the country may receive even more foreign investment. The business environment is improving in India and bilateral trade accords are being made which makes India a quite possible investment destination. Moreover, report indicates that India business environment showed an enhanced score in most parameter which consists of Macroeconomic environment score 6.1 to 6.9 and Market opportunities score 7.1 to 7.9 in Q2 2022-23. In addition, India has jumped to the 52nd position in the EIU rankings of business environment in the whole world, five years ago, it was placed at the 62nd position and is now perceived as ahead of China. According to TOI news report (2022), Greater political risk in the Southeast Asia

will provide India an opportunity to gain more attention by global manufacturers. Ground happenings also appear to confirm India as a lucrative investment destination. Investment has gained high momentum in the electronics industry, which is being facilitated by the government intervention through the production linked incentive scheme. Electronics exports by India increased about 50 percent to about \$14 billion in 2021 and had already caught up with that level through the first nine months in 2022. One of Apple suppliers, Foxconn, based in Taiwan, is considering substantial growth in India, because the company wants to expand its production volume out of China. Additionally, report pointed out that focus on 2023 India G-20 presidency and the high likelihood of the succeeding bilateral trade negotiations between the country and both Australia and UK will also serve to help demonstrate opportunities in investment in the country, the report said.

The EIU Asia Outlook report is not the only optimistic report of India. Global and Morgan Stanley report that India may surpass Japan and Germany to grow to be third largest economy in the world according to S and P. Whereas the forecast made by S and P is premised on the estimation that the nominal gross domestic product growth rate of India will be averaged at 6.3 percent per annum until 2030, Morgan Stanley believes that the growth rate of India is likely to have more than doubled compared to the current rate by 2031. Moreover, the report emphasizes on real income per capita that is expected to record high average growth of 5.3%, and Indian households are expected to be the highest spenders among G20 economies. These projections are based on the assumption that structural reforms continue, such as trade and financial liberalization, and investments in infrastructure and human capital, and in the labor market. The policy actions announced by the Government of India make India a destination of foreign investors and manufacturing powerhouse. The introduced in 2020 Production Linked Incentive (PLI) Scheme is likely to become the key driver of manufacturing and export growth. The scheme

provides inducements to local and overseas investors, such as tax rebates, license offenses, and other incentives (Morgan Stanley, 2022; S and P Global, 2022). Based on the opinions of S and P Global (2022) the government seems to be counting on the PLI Scheme to transform the Indian economy into an export sock and party of global supply chains. The PLI project has been adopted with the air-conditioning manufacturing industry in the country, covering technology issues and creating a manufacturing ecosystem of air-conditioning parts and components. (Dixit and Bhasin, 2022). So far, nearly INR 5,000 crore worth of investments have been made to access the PLI incentives, which are estimated to bring INR 81,000 crore in incremental production and approximately 44,000 direct jobs in the industry (GOI, 2021).

Make in India is another major initiative under which the government aims to grow manufacturing by 12–14 per cent per year, creating 100 million manufacturing jobs and increasing the contribution of manufacturing to GDP to 25 per cent by 2022 (Government of India, 2014). The government is systematically trying to improve ease of doing business and competitiveness rankings to make India a place that global manufacturing firms view favorably to set up shop. This initiative focuses on 25 priority areas. According to Morgan Stanley, global offshoring, the digitalization and transformation of energy are the new contexts to drive unprecedented economic growth in India. According to Desai (2022), India is becoming increasingly influential on the global scene, and we believe this right-sided transformation would mean one-in-a-generation change and a chance of profits to investors and businesses. As the policies of the president Xi Jinping have contributed to an increasing rift between the East and the West, the prime minister Narendra Modi is promoting India as a location where multinationals can cut down on their excessive reliance on Chinese supply chains. Global investors have slashed out of China this year with net outflows of more than US\$187 billion, which compares very brutally to their US\$17 billion

outflows from India. India, according to the World Bank (2022), was in a better position than the other emerging economies of the world to sail through the global headwinds. The economy of that country had shown resilience in spite of difficult external environment, it said in its India Development Update.

2.3.2 Competition and economic growth are closely intertwined ideas:

In today's globalized world, the close connection between competitiveness and economic growth is key for countries. Consequently, as Ruzekova (2020) recognizes, the competitiveness of national economy and business environment is important to economic, political, social, and international economic growth of the country. Competitiveness is one of the factors which encourage foreign investment and increase the level of exports which are major contributors to economic growth. Competitive countries are most likely to attract more foreign investment, thereby providing companies with valuable capital, technology, and knowledge, which can improve their performance. It can also lead to an increased volume of goods being exported, which might contribute to economic growth in the country (Cekmeova, 2016; D southern border Greece, 2017). National competitiveness is significant to all countries. Although it has been an area of perpetual interest, national competitive advantage remains elusive. competitiveness of the country can be interpreted as the capability of country to sell its own goods to other countries (Rodriguez and Rodrik, 2001; Carvalho et al., 2012), or the capability of country to: earn money, to adjust to global changes in the external environment, or to gain access to scarce resources. The ability of the national economy to deliver a better standard of living can be referred to as competitiveness whereas the term competitiveness only has the meaning of national productivity as Porter simply states (Huggins and Izushi, 2011). Virjan et al. (2023) claim that economic growth and competitiveness are closely intertwined and reinforce each other; as a result, the higher the level of competitiveness, the greater the economic growth, and

the greater the economic growth, the greater the competitiveness that can be achieved. Competitiveness is the force that drives economic growth as it encourages enterprises to improve their production, invest in innovation, research and development, and improve the quality of their goods. Nevertheless, the opposite point of view is also suggested, i.e. the fact that competitiveness may take place in the detriment of an economic growth, and, vice versa, an economic growth can be accompanied by defeat in the competition (Porter, 1990; Reich, 1990; Krugman, 1994). Conversely, WEF (2017) defines the competitiveness of a country as a collection of 12 pillars which are organized in three categories. The first category has to do with the minimum needs of (i), institute, (ii), infrastructure (ii), macroeconomic stability, (iv), health and (v), primary education. The second group is efficiency sources, (vi) higher education, (vii) efficiency in the commodity markets (viii) labor market efficiency (ix) finance market development (x) technological readiness, size and sophistication of the financial market. Group three has variables of (xi) innovation and (xii) business sophistication. (Gama et al, 2020) use data from the World Economic Forum (WEF, 2020) to show how economic growth and competitiveness are connected. They explain that a country's competitiveness doesn't happen all at once but progresses through three stages. Initially, it relies on its resources like labor and natural assets. Then, as it improves basic indicators of competitiveness, it moves towards being more efficient and innovative. They stress that each stage builds on the previous one, so to move forward, a country must strengthen the pillars of each stage. Global technological division was first introduced within the concept of competitive growth.

In order to make a practical distinction between growth stimulated by innovation and growth stimulated by technological transfer, Maric et al. (2021) identifies three interconnected mechanisms driving economic growth. The first is efficient resource allocation through market competitiveness and a sophisticated division of labor. The

second is capital accumulation, where increased national savings boost per-employee output. The third and most important mechanism is technological development, without which sustainable economic growth and enhanced living standards are not possible. According to (Thierer, 2014; Broughel and Thierer, 2019; Caseiro and Simoes, 2019), technological innovation drives economic growth in the long-term. Innovative products spawn more innovative products, and this stages a ripple effect that fuels economic advancement. It has empirical evidence, as advanced economies with highly technological products and services are enjoyed as far as growth is concerned since the year 1830, with minimal reduction in growth rate (Gordon and Jackson, 2016).

By paying attention to the appropriateness and deployment of the e-business technologies that allow firms to exchange the information throughout the supply chain, Cassetta et al. (2020) investigating how digital technologies can contribute to the internationalization of Italian SMEs. They consider the possibility of heterogeneities in digitalization routes and find that e-business technologies affect positively the internationalization only when they have been incorporated into the innovations of processes and organizations and investments in the skills of digitalization were already made.

They identified how technology leads to the growth of the economy based on the facts that in order to increase economic growth, it seems that diffusion and adoption of digital technologies are equally important as their invention (Liu et al., 2023). It is only through and when new technology is diffused and utilized that the contribution of the new technology to economic growth will be achieved. They identified how technology leads to the growth of the economy based on the fact that to enhance economic growth, it seems that the diffusion and adoption of digital technologies are as important as their invention (Liu et al., 2023). The contribution of new technology to economic growth can only be achieved through the diffusion and use of new technology. possibilities of digital

technology were widely and deeply proclaimed by highly qualified and educated professionals as well as leading corporations, which are usually found in high income economies, and they got substantial profits because of their technological knowledge. Babina et al. (2022) discusses the use of AI technologies and their effects on economic growth by introducing a new measure of firm-level AI investment. Their research found that investments in AI were on the rise in various sectors and that companies that invest in AI show greater growth in sales, staffing, and company valuations. They have observed that this expansion has been majorly due to growth in product innovation. The results of the current research supported the claim that the new technologies including AI may fuel growth and give rise to superstar companies due to novel products. The importance of technologies, their dependence on competitiveness and economic growth were brought to the fore in many studies. Most of these studies show that investing in digital technologies has increased product development, workforce, revenue, profitability, net operating efficiency, and market capitalization (Babina et al., 2022; Micallef and Gupta, 2021; Mishra and Pani, 2021; Mishra et al., 2022). The use of new technologies often increases employment and creates new and better-paid jobs. Autor et al. (2022) underscore the quantitative magnitude of this phenomenon, showing that in 2018, thirteen years after entering an era of slow workforce growth, more than sixty percent of all employment in the United States was held by job titles that did not exist in 1940. Such new positions may be superior to other positions of ancient origin because new knowledge and expertise are initially scarce and premium (Digital Progress and Trends Report, 2023). Another fascinating direction in this matter is studying the impact of competitiveness and innovation on economic growth in some European states (Terzić S., 2021). The countries examined are the leading ones, among which there are Switzerland, Sweden, and Germany, and the following ones, which are the Czech Republic, Poland and Romania. The study

implemented various approaches and found out that augmented economic growth per capita is correlated with the Global the Competitiveness Index 4.0, the Global Innovation Index, and GDP growth rates per capita will be higher. It points out that the economic growth of Europe is based on competitiveness and innovation. Macroeconomic stability through strong institutions, excellent infrastructure, good financial system, opportunity to spend on improving skills, thriving businesses and capable innovation of such countries are believed to be the reason behind their competitiveness and innovation. The literature claims that global competitiveness can be used to measure the economic growth of any state and is also essential in recovery and enhanced economic growth. This is because; it explains that economic growth is closely related to the competitiveness of a nation.

2.3.3 Dynamics and Growth Trends in the HVAC Industry from Global Insights

The HVAC industry shows diverse regional trends and promising growth projections. According to a report by the Statista Research Department (2024) on the worldwide HVAC industry statistics and facts, regional regulations and differences are a massive driver in the HVAC industry. It was observed that the size of the HVAC market is large in Asia and air conditioners are used more in this region than in other parts. At the same time, Italy was also identified as one of the European markets that had the largest heat pump markets in 2020. Similarly, a report published by the Statista Research Department (2024) on the global revenue forecast of heating and cooling from 2018 to 2028 by region indicates significant growth forecasted for all regions by 2028. Across the globe, the 'Heating and Cooling segment's revenue ranking in the DIY and hardware store market is forecasted to be led by the Americas with 150.34 billion U.S. dollars. In contrast, Australia and Oceania trails with 2.73 billion U.S. dollars, showing a difference of 147.61 billion U.S. dollars compared to the Americas. Furthermore, among the 16 countries and territories from the Asia Pacific included in this ranking, China had the highest revenue in the heating and

cooling segment of the DIY and hardware store market, followed by Japan with a revenue of 7.1 billion U.S. dollars. Conversely, Kazakhstan ranked at the other end of the spectrum with 283.22 million U.S. dollars, indicating a difference of 67 billion U.S. dollars to China. In 2022, the demand for air conditioners in China was higher than in any other region. That same year, North America and other Asian countries, excluding China and Japan, demanded more than 20 million units. The demand for such devices in Europe reached a new high point of 9.5 million units, representing an increase from the previous year. In general, the demand for air conditioners has remained stable in most regions (Sherif, 2023). It is estimated that total demand will increase approximately eightfold in terms of aggregate tonnage of refrigeration (ToR) by 2037-38 (Ozone Cell, 2019). The report also offers a more detail picture of the growth potential of the sector which is reflected in Figure 3 that shows threats of growing demand over various segments of the HVAC sector. Among these, the need for cooling in buildings by space is expected to experience the greatest growth and increase to 11 times the demand in the reference year (2017-18). These projections are based on a sound analysis of the important variables, such as economic development, increasing incomes, the growth of the aspirant class and the pace of urbanization. This trend growth of these variables provides us ultimately what the growth in cooling demand should be.

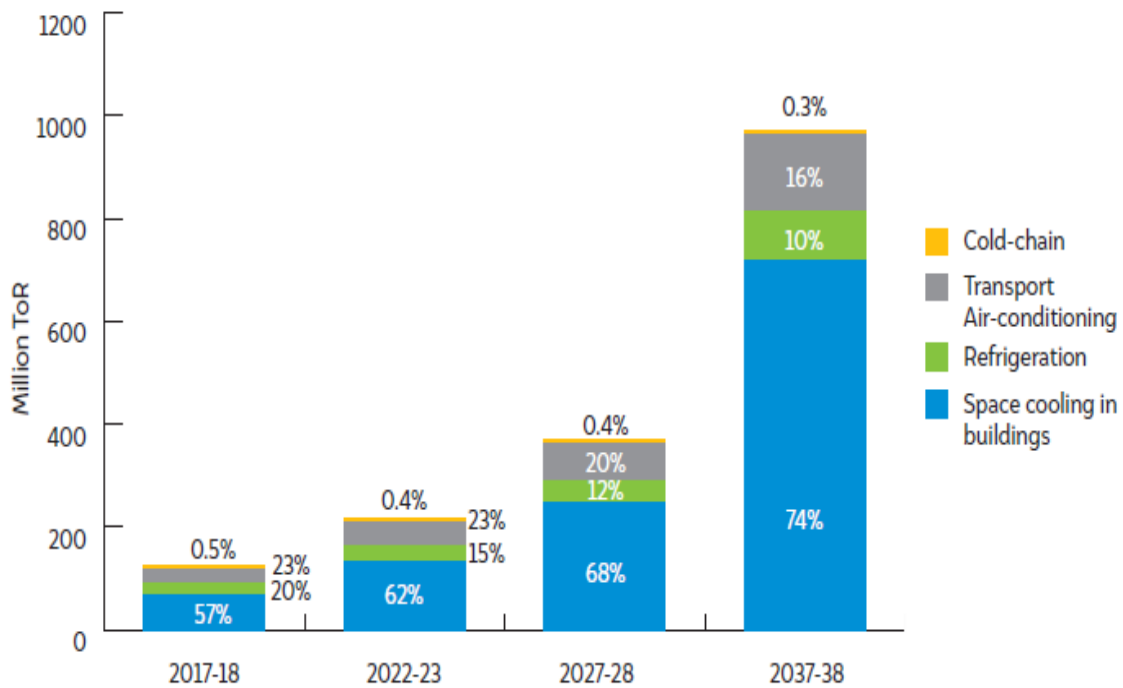


Figure 3: Sector-wise projection of cooling demand over 20 years.
Source: Ozone Cell (2019, p.11).

In the cooling space of buildings, the primary HVAC products are: a) room air conditioners, b) chiller systems, c) variable refrigerant flow (VRF) systems, and d) packaged DX systems. Room air conditioners dominate in aggregate tonnage and are expected to grow at a 9-10% CAGR in a low-growth scenario, and up to 15% in a high-growth scenario. Chiller systems are projected to grow at 5-10% CAGR (Ozone Cell, 2019), with low-efficiency models being replaced by high-efficiency ones. VRF systems, requiring advanced controllers, are anticipated to grow at about 15% CAGR over the next decade due to their energy efficiency and rising popularity in certain segments. The packaged DX market is expected to see modest 5% growth (Ozone Cell, 2019). Figure 4 illustrates the projected market size of these product types in terms of aggregate tonnage of refrigeration over the next two decades.

Product types	Stock in 2022-23 (130 million ToR)	Stock in 2027-28 (245 million ToR)	Stock in 2037-38 (720 million ToR)
Room AC	85%	87%	88%
Chiller system	7%	6%	5%
VRF system	4%	4%	5%
Packaged DX	4%	3%	2%

Figure 4: Tonnage of refrigeration-based HVAC equipment stock.
Source: Ozone Cell (2019, p.12).

The available literature suggests that Indian consumers will purchase over 150 million room ACs over the next 10 years, representing a conservative retail value of approximately ₹510,000 crore (Basith, 2021). In parallel, TechSci Research report (2023) highlighted on India HVAC industry that has experienced remarkable growth and transformation which has been attributed to factors like rapid urbanization growth, increased incomes levels, and heightened awareness of indoor air quality since the early 2000s. This growth has created the demand for sophisticated systems in different sectors, such as high end, leading to huge investments from both domestic and international players. this investments resulted India HVAC market to USD 9.1 billion in year 2023.

Moreover, Dixit and Bhasin (2022) argued an interesting paradox of the Indian HVAC Sector is that, despite the size and growth potential of Indian market, not having scale is often used as a major excuse against countering the dominance of imports. This issue can be attributed, to a major extent, to the fragmented manufacturing base in India. The sector includes a high number of small-and-medium sized enterprises (SMEs), and even the bigger ones are not similar to the scale of their Chinese counterparts. These structural constraints within the sector lead to different technology related challenges. Additionally, Dixit and Bhasin (2022) discussed one important facet of this technology challenge is that

it doesn't focus on cutting-edge, state-of-the-art technologies which are hard to acquire and not available in India. The existing literature shows a huge gap in the exploration of why the Indian HVAC sector, despite having a large market size and growth scope, is struggling to find the scale and counter the dominance of imports. The available literature also lacks studies of detailed understanding regarding the precise nature of these technology-related challenges and the identification of potential solutions to address them effectively. Available literature also reveals initiatives taken by government for growth of Indian HVAC market. In 2020, the Indian government imposed a blanket ban on the import of air conditioners with refrigerants. Approximately 35% of the 7 million ACs sold in India are imported as fully built units, mainly from China (Basith, 2021). Moreover, the recent Director General of Foreign Trade (DGFT) order is expected to eliminate the import of Chinese fully built units into the country, creating a supply vacuum that will need to be filled by locally manufactured units. However, this decision is likely to have a short-term disruptive impact on the Indian industry, forcing a significant number of the 40 local brands that depend on the trading of fully built units to recalibrate their supply chains. Report reveals that Indian AC OEMs now have a robust domestic electronics supply chain, allowing them to shorten lead times, reduce inventory holding, develop technology differentiators, and most importantly, eliminate a key point of friction that has been holding back the expansion of the ecosystem. MVIRDC's report on India's Export Competitiveness in 2022 finds out the proactive measures taken by the Government of India to encourage export growth. Initiatives like Refund of Duties and Taxes on Exported Products, Rebate of State and Central Levies and Taxes schemes, an Interest subvention scheme for Micro-Small and Medium-sized Enterprises (MSME) exporters and Transport and Marketing Assistance Scheme have been implemented. Notably, the recently announced Production Linked Incentive (PLI) scheme for 14 sectors is set to give a boost to the output of

manufacturing and boost the global competitiveness of local MSMEs. Further Kumar (2022) mentioned active role of Central Government in enhancing India's exports, it is also essential role for the State Governments to actively strategize their industrial policies to achieve more significant exports. As India looks to enhance its share in the world trade, states emerge as relevant players in the trade through forming the manufacturing backbone of the country. The improving export competitive states might also improve their wealth and standard of living which is expected to minimise the regional disparity across states. He added, top five states in India i.e. Maharashtra, Gujarat, Karnataka, Tamil Nadu & Telangana contribute 75% to India's overall export. However, there is no doubt there is a gap in understanding aspects such as the impact on market dynamics and the competitiveness of domestic manufacturers. More substantial is the gap on the subject of extent of technology innovation, and the growth angle of entire Indian HVAC industry.

2.3.4 Fostering Innovation through technological upgradation and digitalization in HVAC industry:

The literature on digitalization and technological innovation is full. Digital technologies are transforming the modern industry and creating a paradigm shift in the manner of conducting business. In the modern landscape of the industry, technology is changing the way in which information is collected, distributed, and used to make technological advancements. Digital technologies are increasingly becoming a part of the industrial environment by using foundational technologies like big data, cloud computing, data lakes, sensors, actuators, mobile technologies, networks, storage, and computing capabilities (Chui et al. 2013). This technological advancement allows organizations within the industry to move away from conventional ways of information gathering and sharing to make it easier to visualize business ideas and establish value creation in collaboration (Westerman, 2017). As all parameters of the industry landscape change, the framework for

cooperation and problem-solving changes which requires suppliers to adapt to these new environments (Manyika et al. 2015). Gartner says, "Digitalization is the use of digital technologies for change in business model to deliver new revenue and value-producing opportunities; a process of moving to a digital business." Development has entered a new era in which digitalization is greatly changing our economies and societies. Significant advances in digital technologies have driven dramatic changes, from the way we communicate and access information to how we conduct business and interact with the environment (Digital progress and trends report, 2023). Based on World Bank (2016) digital progress and report presented that digitalization has opened new avenues for innovation, efficiency, and inclusion, bringing tangible benefits and new possibilities to individuals, organizations, and nations as shown in Figure 5.

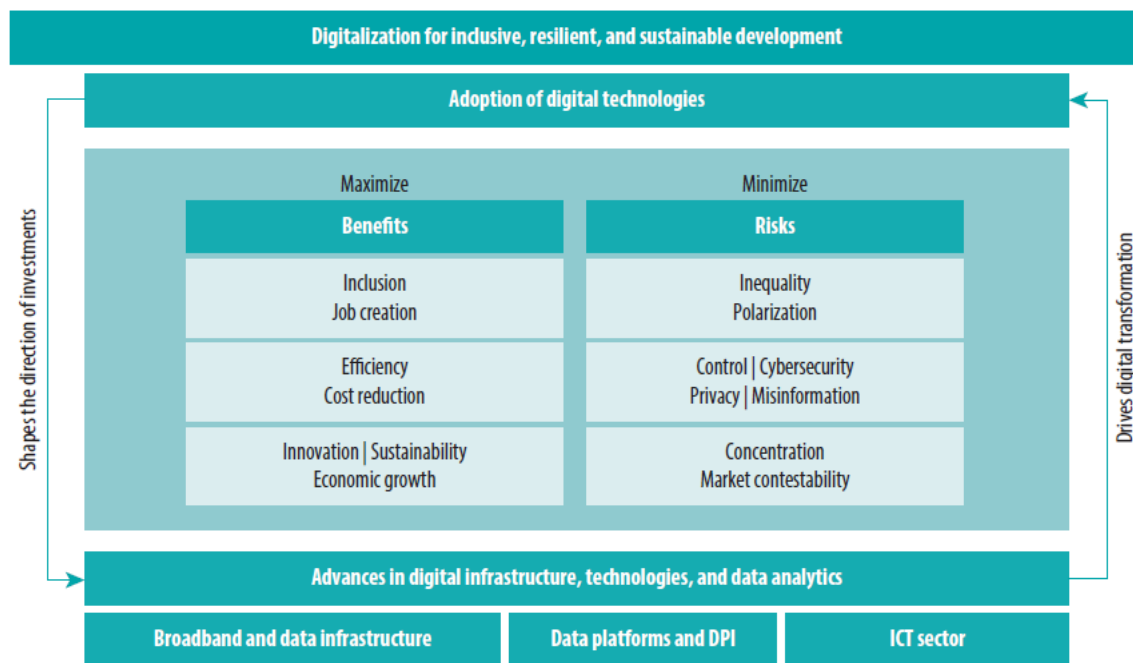


Figure 5: Digital technologies and their interactions.

Source: World Bank (2016 p. XV).

Note: DPI = digital public infrastructure; ICT = information and communication technology.

Report also reveals that embracing digitalization is no longer a choice but a necessity, as it holds the foundation and potential to shape a more inclusive, resilient, and sustainable world for generations to come. It is now the moment for countries to fast track the construction of new digital infrastructure, such as IoT along with AI, in addition to the hastening of vital projects and major infrastructure construction that's already included in countries' financial stimulus plans (WEF, 2020). Focusing on necessity of digitalization researcher found two important elements Digital Public Infrastructure (DPI) and Digital Adoption Index (DAI). To begin with, DPI has been brought out in the last 20 years by different governments and international organizations, which has been a paradigm shift to a national style of digitalization. The digital progress and trends report (2023) exemplified the general representation shown in figure 6 that can be used to relate to any aspect of DPI. The adoption of any or all components of DPI will likely work through multiple avenues to enhance individual wellbeing, support civic services and efficiency, and support commerce and innovations.

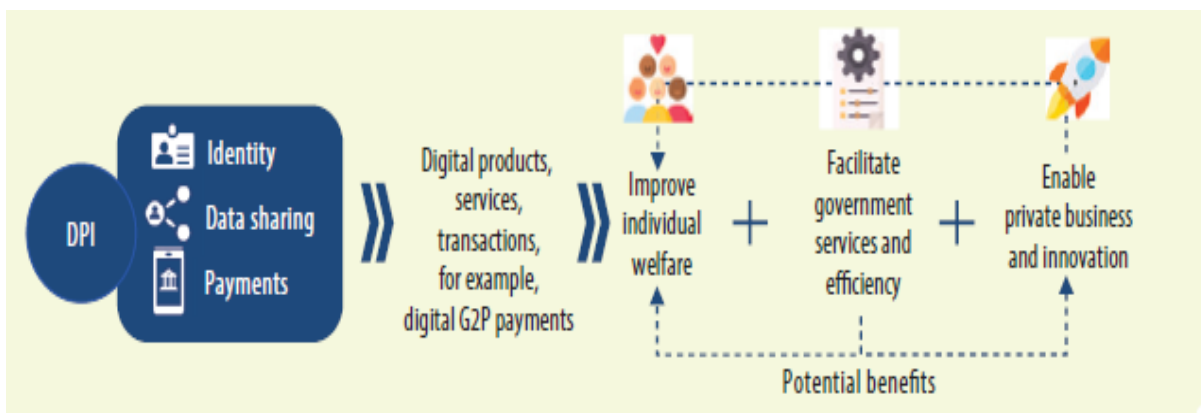


Figure 6: Theory of change.

Source: World Bank (2018., p.72).

Note: G2P = government-to-person

The report also highlights how DPI can reduce the cost of doing business: first, India. The cost of incorporating a typical firm in India is around Rs 1,500 (US\$23), which is expected to drop to Rs 10 (US\$0.15) with greater scrutiny, digitization, and interoperability of the Aadhaar system (World Bank, 2018) and second, Singapore. Financial service providers save up to US\$50 by getting each customer online through the use of SingPass (Cooper, Marschel, & Chan, 2022). Second is Digital Adoption Index (DAI) that is an indicator of the ability and readiness of any country to embrace and explore digital technologies to support development: it shows how India gradually improved in digital adoption according to the World Bank. DAI consists of three subindexes which are found on three dimensions: households, the government and business. World Bank (2021) report highlight significant improvements in India's digital adoption. Specifically, the DAI for India increased from 0.44 in 2014 to 0.51 in 2016.

Veldhoven and Vanthienen (2021) performed a developmental survey of 41 digital transformation models and listed four research prospects. Their new and holistic framework points to major shifts in business, society, and technology, which allows them to more accurately predict the manner of unfolding and interdependence of these shapes. The main goal is to combine research from business and society, so a better understanding of how society functions in business can be achieved. In their study, Veldhoven and Vanthienen (2021) explain how digital transformation greatly affects businesses, society, and technology and highlights how these areas are all interrelated and interact with each other.

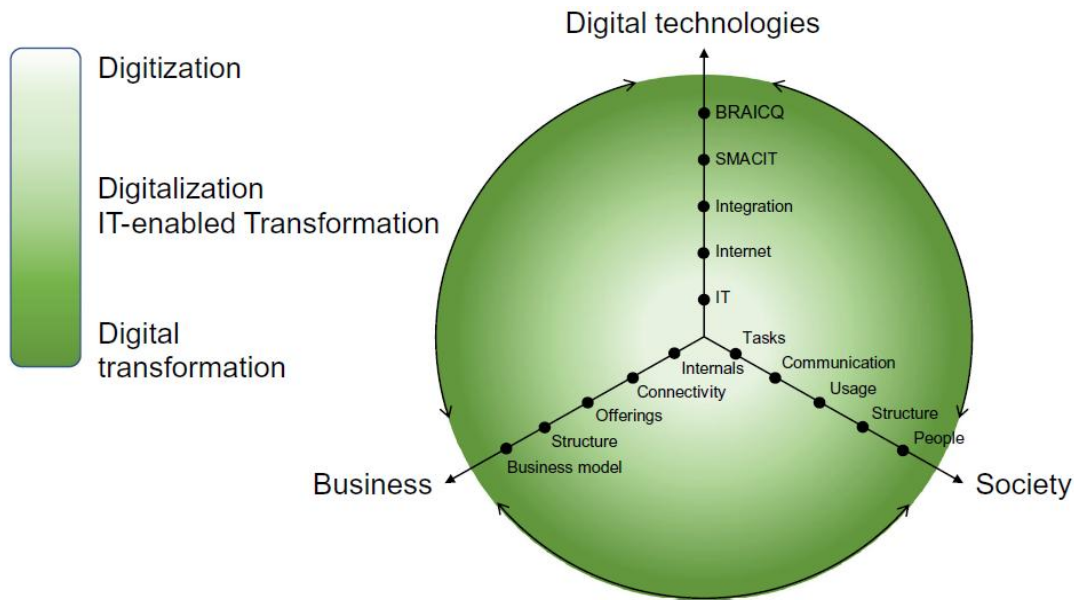


Figure 7: The evolution of Digital Technologies
Source: Veldhoven and Vanthienen (2021 p.639).

There is not much literature discussing digitalization and technological progress in Heating, Ventilation, and Air Conditioning (HVAC) industries. For residential, commercial, and industrial areas, regulating indoor air is largely achieved by the HVAC industry (Asim et al., 2022). Air conditioners and heating devices are used to provide pleasant temperatures, proper humidity levels, and clean air for everyone inside. In order to solve the problems of using less energy and caring for the environment, we need to have focus on the innovative HVAC systems that are energy use efficient (Vujanovic et al., 2021). Using VRF, smart thermostats, and heat pump systems is helping the HVAC industry minimize energy wastes, thus resulting in more cost savings and a better environment. Digitalization could make a difference in heating and cooling alone, as it is an exception when it comes to other parts of the energy sector. Digitalization is good as long as the energy saving is higher than the energy consumption. Digital technologies hold immense possibility to save energy through more efficient heating and cooling, as well as

helping to resynchronize or reshape loads of consumers and save money while preserving or even enhancing comfort and indoor air quality.

Vishnuraj (2023) stated that technology is transforming the HVAC field fast and making it more sustainable and easier to control by introducing new innovations. As the development seems to be understood, there may be even more innovations of the future. HVAC technology began by working on making machines better and make them more efficient. Still, people are now more concerned with sustainability, better living conditions, and energy efficiency, due to global warming and stronger needs for well-working heating and cooling systems. Furthermore, Mahurkar (2023) pointed out that the combination of artificial intelligence and machine learning is a leading development that allows HVAC systems to handle additional information, achieve better performance, predict system failures, reduce bills, and increase system life span. AI and machine learning have helped the HVAC industry by making data study, performance boosting, and future maintenance prediction possible. With IoT, energy management and making the indoor climate more convenient have been made possible for HVAC systems. Now, you can manage HVAC units on your mobile phone and they feature smart tools for cooling, checking the outside temperature, and watching the patterns of those in the building. IoT brings new opportunities to the energy sector, with businesses increasingly adopting smart HVAC systems to compete in the changing commercial and energy demanding market. Operational visibility is a key benefit of IoT in HVAC systems, allowing for data analysis, automation, maintenance, planning, and optimization, driving the industry towards more cost-effective and efficient goals (Vishnuraj, 2023 and I-link digital blog 2021).

Chandra (2020) indicates that digitalization of buildings (smart buildings) is important when it comes to HVAC. The smooth interconnection and interfacing of building management systems and the HVAC systems can also improve the process reliability and

safety as well as efficiency, and eventually decrease the overall building energy costs. Going forward, the application of digitalization in the HVAC sector will continue to grow increasingly important powered by technology advancement, encouraging further innovation and enhancements in system efficiency and functionality.

However, most of the literature is focused on how digital technologies are revolutionizing the HVAC industry internally and there is a limited source in the literature on how these advancements affect international market penetration and competitiveness. Specifically, how do digitalization and technological upgradation in HVAC systems influence a company's ability to compete in global markets and what are the strategies needed to promote this technological advancement. Additionally, there is also need of addressing technological gaps and issues with Indian HVAC industry.

The Technology and Innovation Report (2021) emphasizes the role of technological change and innovation expressed in product and process innovations. These technologies have the potential to transform the way individuals work and the way goods and services are produced, thereby changing wealth creation and distribution processes. Technological change triggers long chain reactions throughout the economy, creating, destroying, and transforming jobs, resulting in winners and losers. These effects can be transmitted between countries through international trade. Additionally, technological change influences wages and profits, widening the disparities between and between wage earners and capital owners as can be seen in Figure 8.

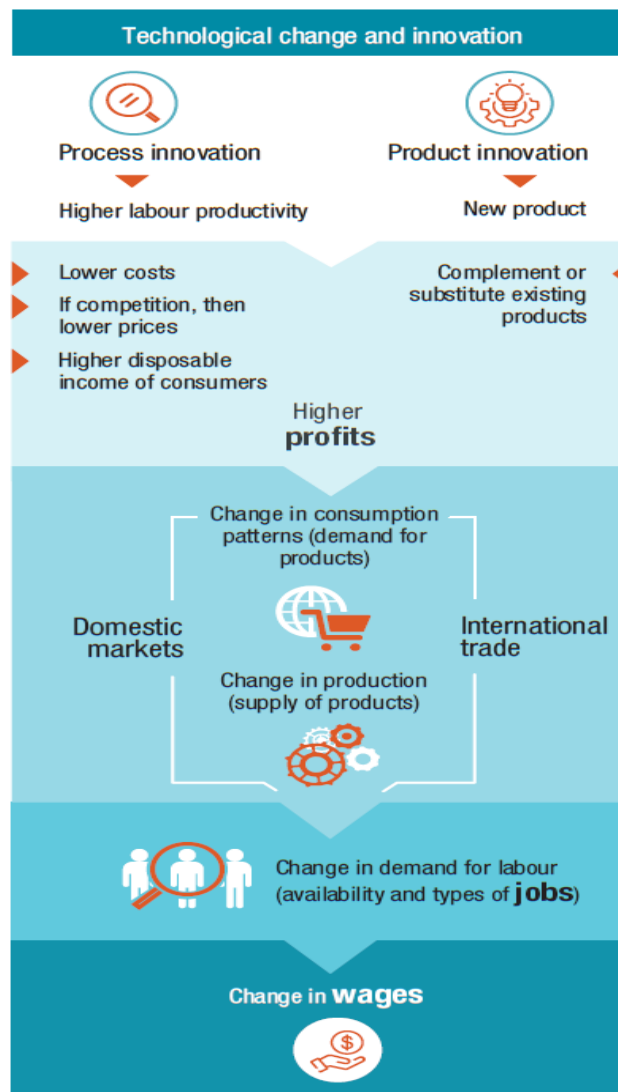


Figure 8: Innovation affects profits, jobs and wages.

Source: United Nations Conference on Trade and Development (2021, p. 35).

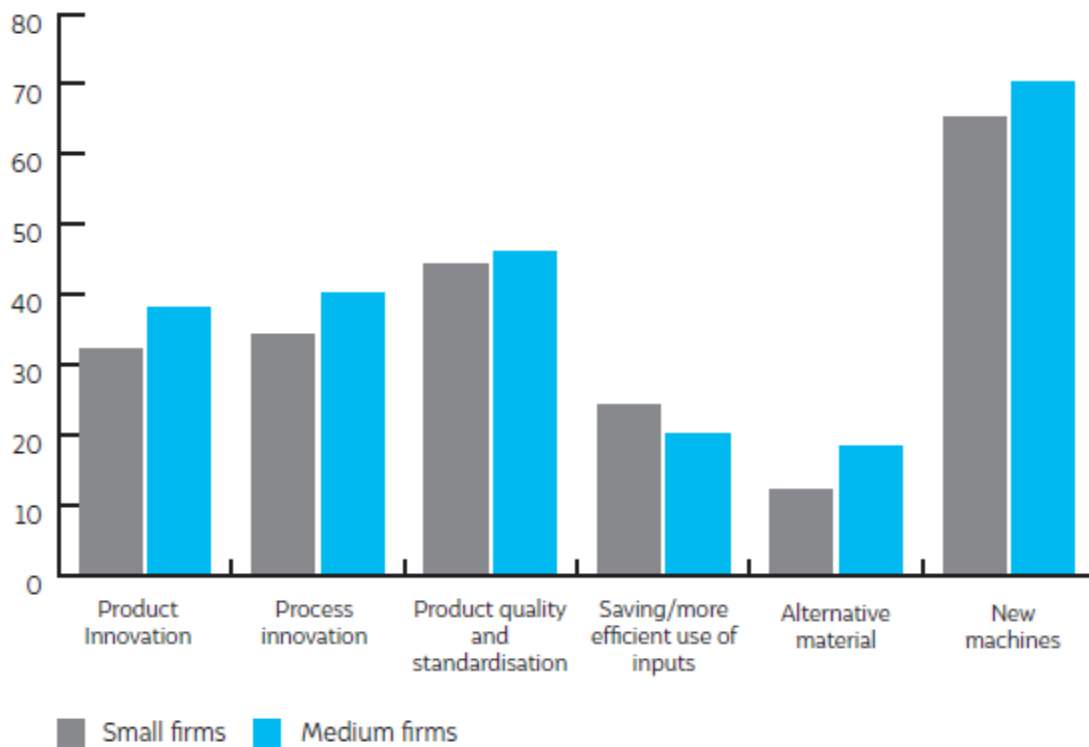


Figure 9: Percentage of innovative SMEs pursuing different innovations
Source: Dixit and Bhasin (2022) Technology Gaps in India's Air-conditioning Supply (CEEW, p.27)

Figure 9 depicts the percentage of innovative companies undertaking various forms of innovative practices and this indicates that most of the technology gaps that SMEs are required to bridge which is of vital essence to the supply chain, are indeed incremental. These differences mainly revolve around product quality and standardization and keeping pace with new machines and manufacturing techniques. Rather than differentiating themselves in the market, these measures will enable SMEs to remain competitive in the changing manufacturing technology environment. These efforts also involve balancing quality and cost to market standards. Dixit and Bhasin (2022) identified technical challenges that are more pronounced in AC manufacturing compared to other sectors, including industrial design capabilities, quality systems and compliance, and the

upgradation of plant and machinery. Apart from these broad challenges, they summarized key technology issues with basic AC components in Figure 10 and created a capital technology matrix in Figure 11 to identify components that heavily rely on capital investment and technology.

Component	% of imports	Technological and other Issues
Compressors	More than 85%	• High investment needed • Process know-how layered, complicated, IP dependent • SMEs not involved even in subsystems or components that go in compressors
PCBs & drives	90%, manufacturing started recently	• Complex supply chain • Circuit design skills absent • Miniaturisation a growing challenge • Quality systems need improvement (EMS vendors) • Scale needed in procurement of chips
Motors (BLDC + non-BLDC)	80% Imported	• Raw material and magnets • China is too competitive • Other technological bottlenecks not clear
Heat exchangers (finned tubes)	Assembled in-house	• Expensive raw material aluminium and copper • Coating facility for copper and aluminium not available • MSME design capabilities lacking
Fans and blowers	20% imported	• Design capabilities in India-manufactured fans and blowers • Help in advance tooling development • Performance testing facilities needed
Grooved copper tubes	100% imported	• Manufacturing competitive due to high price of raw copper • Process know-how difficult to obtain and operationalise • Quality concerns due to recycled copper • Duty structure of India vs FTA with few countries that have matured manufacturing base

Figure 10: Technology issues identified for different components

Source: Dixit and Bhasin (2022) Technology gaps in Indian air conditioning supply (CEEW, p. 29).

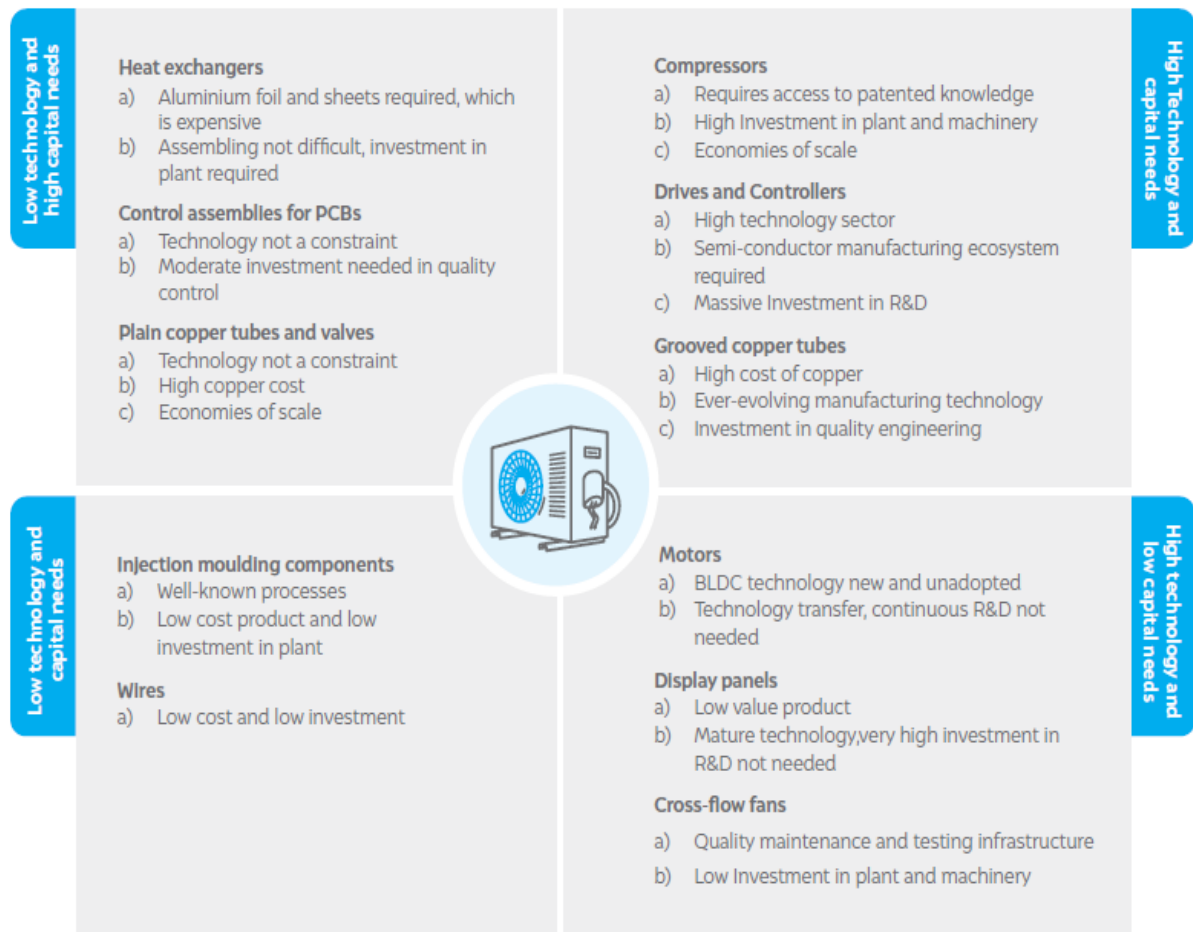


Figure 11: Technology-capital nexus in AC Components

Source: Dixit and Bhasin (2022) Technology Gaps in India's Air-conditioning Supply (CEEW, p.30).

Technological and capital-intensive components include compressors, drives and controllers and grooved copper tubes. These elements are costly to set up competitive manufacturing capabilities, substantial financial investments in R and D is needed to internalize the required technical expertise and standards, and they must have technology transfer and intellectual property sharing agreements with top players in the industry. Such aspects render them hard and costly to manufacture. Conversely, modules like motors, display panels, and cross flow fans are capital intensive, but not technology intensive. The

main hindrance to these elements is technology. It is important that manufacturers upgrade to new manufacturing process and technologies in order to improve their cost and quality. Certain parts have high capital requirements to establish competitive manufacturing plants, and low technology requirements. Examples are aluminium finstock (foil and sheets) heat exchangers, copper tubes and PCB control assemblies. Lastly, there exist low-value elements such as sheet metal, injection moulding, and wires, which do not present serious challenges in terms of technology and capital. The capital-technology matrix enables it to give priority to the desired segments of manufacturing and technology assistance. The latter priority is necessary as not all components are eligible for intervention as there is a considerable knowledge gap between Indian and foreign firms. Also, we have capital requirement which is also a big factor, as the SMEs can hardly take the risk and invest. This way, the support can be given in the areas where it is most likely to achieve success and where it is most needed.

2.3.5 Comparative Analysis of Digitalization in the HVAC Industry: India and Global Benchmarks

The global heating, ventilation, and air conditioning (HVAC) industry is undergoing a paradigm shift driven by the digital revolution. Technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), Building Information Modeling (BIM), cloud computing, and digital twins are redefining the design, implementation, and management of HVAC systems (IEA, 2022; McKinsey and Company, 2023). In leading economies, also using AI enabled systems is enabling predictive maintenance, real time performance optimization and energy savings. For instance, the shipment of AI driven HVAC controls at 45 Broadway in Manhattan by Brainbox AI has led to substantial tractory energy and carbon emission reductions (PRE, 2025; DOE, 2025). Smart building integration is another characteristic of sophisticated HVAC ecosystems. Countries such as Singapore and

Germany have even implemented intelligent energy management system and digital compliance requirements in their building standards to smooth the efficiency and sustainability (IEA, 2022; European Commission, 2021). Globally, there also is a trend towards mandatory digitization in the form of Building Information Modelling (BIM). As can be seen by the mandates from around the world, the US, UK, Germany, Singapore, Australia and various European countries have BIM enforced for all public infrastructure projects (Frost & Sullivan, 2023). The US mandates BIM in public projects with over \$5 million since 2003. Similarly, Singapore and Australia mandate BIM for projects over certain size and cost of projects. These mandates not only result in an increase in digital adoption, but drive innovation and efficiency in the HVAC design and maintenance sectors. In contrast, India is by the time of writing having no formal BIM mandate at the national level, which is leading to slow adoption of the digital construction practices dictated by the HVAC industry and the building space. Within this backdrop, India is still in nascent stage of digital maturity and smart and AI enabled HVAC systems are mostly limited to high end commercial developments. Nevertheless, some vital trends are starting to affect the Indian HVAC industry. A 2025 survey from TechSci Research showed that people's need for convenience, cost savings, and easy remote use is boosting the usage of smart HVAC systems. Green and smart buildings these days feature these types of solutions that offer app controls, smart diagnostics, and cooling based on the number of people present. At the same time, there is rising support for HVAC systems that use renewable energy, mainly solar-powered heat pumps and air conditioners. The use of solar technology is growing due to its falling costs and moves by governments to reduce carbon emissions. The National Institute of Solar Energy (NISE) and the Bureau of Energy Efficiency (BEE) are contributing significantly to this transformation. In this era after COVID, indoor air quality is given more attention for its health effects. Newer HVAC

systems tend to have HEPA filters, UV-C technology and VOC purifiers to clean air more effectively and comply with the rules set by green building organizations. To address these recent developments, India's laws and policies now focus more on saving energy and promoting sustainability in the HVAC industry. Planning to increase the manufacturing of high quality air conditioners and their components inside India, the government has allocated ₹6,238 crore for the Production Linked Incentive (PLI) scheme (PMO India, 2021). Along with this, the Energy Conservation Building Code (ECBC) implemented by the Bureau of Energy Efficiency (BEE) is now a major driver for using energy efficient HVAC technologies in new as well as updated buildings. At the same time, by focusing on performance in LEED and GRIHA, India's green building movement is helping more people appreciate advanced HVAC systems for their energy efficiency, positive impact on IAQ, and sustainable approach to design. More and more, such certifications are being added to large commercial and institutional work, promoting the growth of low carbon cities. All of these efforts show that India supports climate goals and aims to introduce digital and efficient solutions to HVAC.

Even though there has been advancement, the HVAC sector in India does not keep pace with the industry's digital adoption. As more people live in cities, focus on the environment increases, and the middle class uses more goods, the market for real estate grows. Yet, digital developments are only occurring in luxury projects. In comparison to the global leaders who are using AI and BIM to optimize the entire chain end to end, in India, deployments still rely heavily on the conventional system. Acknowledging this deficit the Indian government has introduced a number of structural interventions to modernize the sector. These include regulatory programmes such as BEE's star ratings and labelling standards, which have helped to raise energy performance benchmarks and the ECBC

which has encouraged the adoption of efficient HVAC designs across the built environment.

In order to both tackle the growing need for cooling, as well as environmental pressures, India, in partnership with the World Bank, is working on a comprehensive national project to build the HVAC ecosystem. This includes investments in capacity building, R and D support for super-efficient air conditioners which are 30% to 40% more efficient as exists 5-star models and increasing access to affordable cooling technologies (Economic Times, 2023). With air conditioning penetration standing at only 5% in India currently compared to the global average of 30% these efforts are vital to reducing the projected increase in cooling related energy consumption.

In addition, the increasing demand from Tier II and III cities is making manufacturers diversify in terms of product offerings in terms of modern comfortable HVAC offerings. Technological advancements within the industry are also on the rise, with the increase in the use of Variable Refrigerant Flow (VRF) systems, IoT enabled controls and remote monitoring tools (ITA, 2024). These are part of country-wide programs that include Smart Cities Mission, the National IoT Policy and the Digital India initiative. Nonetheless, there are challenges that are encountered at the systemic level. The high upfront cost of energy efficient and smart HVAC systems are a big deterrent for cost sensitive residential consumers in spite of long term savings. Moreover, due to unavailability of skilled technicians requirement of design, installation and maintenance of HVAC system suffer from service quality especially in non-metro areas, while with increase in demands from compliance by energy efficiency norms, small and medium manufacturers are under pressure. Furthermore, limited consumer awareness in regards to benefits of energy efficient and green certified H.V.A.C technologies slows down the transformation in the market.

India's regulation environment also lags in terms of the digital enforcement of regulation that has become the norm in many developed economies. For example, the UK, US, Germany, Singapore and Australia have BIM as mandatory for public infrastructure projects. In India, there is no national BIM mandate which is hindering the integration of digital design, simulation and lifecycle monitoring across HVAC and construction projects (Frost & Sullivan, 2023). While the potential of digital transformation, sustainability driven innovation and market expansion are considerable, addressing these structural, regulatory and capacity related constraints will be necessary for India to harness its full competitiveness in the global HVAC ecosystem.

While it has made significant gains in policy formulation and market stimulation, a lack of mandate digitally accelerants like BIM continues to limit this behavior of integrating final digital work flows at system levels. In countries where BIM is specified by law, implementation of BIM has become fundamental building to optimize the HVAC lifecycle and export competitiveness. The fact that India is overly dependent on conventional construction and HVAC practices, without having digital standards across the nation, means that their ability to scale innovation and meet global expectations is weaker. It is notwithstanding, a major research gap remains in that existing literature has not been able to properly discuss the intersection between digitalization and technological upgradation and export competitiveness in the Indian heat ventilation air conditioning (HVAC) industry. Most studies are based on energy performance or acceptance among consumers, without addressing the effects of digital capability on India's global positioning in the HVAC manufacturing and trade. Moreover, the role of national digital policies, incentive schemes and regulatory gaps, in particular an absence of BIM mandates, in enabling or constraining the digitalization of the HVAC environment in India are seen as being

insufficiently explored. These unexplored dimension provides the basis for inquiry of this study in terms of systemic levers for India's HVAC transformation in a global context. In order to systematically capture such differences, a comparative benchmarking of key digitalization and policy parameters between India and selected leading global HVAC markets is shown in Figure 12. It brings out some important gaps in areas like IoT integration, AI based predictive maintenance, energy efficiency standards and skilled workforce readiness. While India has taken some supportive measures in the form of PLI scheme and BEE ratings, global counterparts have implemented advanced incentives, R and D eco-system and regulatory mandates such as BIM compliance and LEED certification in their respective digital HVAC strategies. This comparison forms the base for strategic focus areas that India needs to intervene quickly to attain global competitiveness.

Parameter	India	Global Benchmarks	Source
IoT Integration	Limited to premium segments and commercial projects	Widely adopted across residential and commercial sectors	CEEW (2022); George Oliver (2024); Trade.gov (2024)
AI and Predictive Maintenance	Emerging, with pilot projects in urban areas	Standard practice in energy optimization	Financial Express (2023); Johnson Controls, Schneider Electric practices (Oliver, 2024)
Energy Efficiency Standards	ECBC, BEE star ratings, PAT scheme	EPBD, LEED, ENERGY STAR, national building codes	IMARC Group (2025); George Oliver (2024); TechSci (2025); BEE Guidelines
Smart HVAC Systems	Growing adoption in urban markets and smart cities	Embedded in most modern building projects globally	TechSci (2025); Smart Cities Mission; Trade.gov (2024)
Skilled Workforce	HVAC skill shortage in Tier II & III cities	Structured vocational certification systems	Financial Express (2023); HVAC workforce programs in Germany, Japan, US
Government Incentives	PLI, ECBC, energy audits, R&D support via World Bank	Longstanding subsidies, tax breaks, and R&D grants (DOE, EU funds)	PMO India (2021); Economic Times (2023); Trade.gov (2024); DOE (2024)

Figure 12: Comparative Analysis of India and Global Benchmarks on Key HVAC Digitalization and Policy Parameters
Source: Author's own illustration.

2.4 Summary of the Literature Review

The literature review provides a detailed look at the many aspects of the Indian HVAC industry in relation to global competition and how the economy is growing. It points out that India is now a major part of the global market, thanks to its workers' abilities and initiatives from the government supporting manufacturing and exports. Even though China leads in manufacturing, India's new and favorable business setting makes investors more likely to choose it, since it is expected to soon take the third place as a world economy. After all, scaling up domestic production is important to address the issue of dominance by imports and deal with technological difficulties. Import bans are one of the government measures used to support local industries, but they may cause some problems in the short run. Besides, the efforts such as the Production Linked Incentive (PLI) scheme motivates to increase domestic production and exports. Materials here also analyze how being more competitive and promoting growth influence each other within the industry, along with the role of innovation and up-to-date technology for developing efficiency and sustainability. Although digital advancements may help improve energy efficiency and systems, little is known about how they change global market competition. Yet, the industry's recent changes show that India could lead HVAC development and influence the future scope of the industry due to global economic changes.

Around the world, the HVAC business is undergoing a transformation using IoT, AI, cloud technology, digital twins, and BIM, which is a crucial component in boosting energy efficiency, predictive maintenance, and greenhouse emission reduction. The US, UK, Germany and Singapore have made these changes formally and offered incentives for

digitalization to be integrated throughout the HVAC process. Meanwhile, India's digital side is seen as patchy because it's mainly used in premium businesses rather than on a large scale, due to no Building Information Modelling (BIM) rules, not many people aware of digital construction, the high price to get started and lacking skilled people for big projects. Although many Tier II and III cities and several smart and eco-friendly buildings are improving, there are still challenges with training people, enforcing laws, and using technology everywhere.

Even so, India has introduced various policies to keep up with global trends, for example, Energy Conservation Building Code (ECBC), BEE star ratings, and offers economic incentives for HVAC products that use less energy. Institutions such as the Bureau of Energy Efficiency and the National Institute of Solar Energy are actively promoting renewable integrated HVAC solutions., collaborative initiatives with the World Bank aim to improve R and D capacity and affordability of super-efficient air conditioners. Yet, India's HVAC industry still falls in its race with the global benchmark with respect to end-2-end digital integration, automation and enforcement of regulations. While the world leaders are using BIM and AI as standard practice, India's lack of transitioning to modern methods in construction and HVAC practices and the reliance on traditional construction practices still limits scalability and export readiness.

Given these gaps, the literature highlights the need to conduct further research into the long-term consequences of governmental policies, the practical problems of adopting technology and the specific manner of how digitalization can improve global market competitiveness. This aspect seems to form the foundation for this study that aims at addressing these shortcomings and gaining in-depth knowledge of the transformative potential of technological modernization and digitalization in the Indian HVAC industry. Given these shortcomings, the researcher chooses India as a case study to arrive at a better

understanding of the evolution of the HVAC industry in a key emerging economic market. By this choice the researcher opens the door to exploring in the study the specific mechanisms and strategies that Indian manufacturers are using to increase production and reduce the dependence on imports. This plan will give an indication on how India will take a better place in the global market and even dominate the HVAC industry irrespective of the occurrence of shifts in the economy.

2.5 Identification of Study Gaps

After reviewing the literature it is obvious that there are significant gaps in the research work for the HVAC sector concerning technology upgrading, digitalization and export competitiveness in the Indian context. While there is a growing global understanding about the strategic importance of technology driven transformation, academic research in the implications of the same for export performance, particularly in emerging economies such as India, is limited and fragmented.

Initially much lesser research found regarding the precise impact of technology and digitalization on export competitiveness in the context of global competition and its long term implications were found from the previous studies. Indeed (Vishnuraj 2023 and Mahurkar 2023) highlight the transformative potential of technologies for redefining the way HVAC operations are done, e.g. Artificial Intelligence (AI), Internet of Things (IoT) and cloud-based analytics, while it fails to delve into technological innovations turn into significant export and export outcomes. Existing research tends to emphasise improvements in operational efficiency or in saving energy at the level of local markets, but tends to ignore important aspects of global competitiveness such as export volumes, diversification into new markets or adherence to international product standards.

This leaves a large void in the literature in regards to the measurable, implications of digital capability on performance in international markets. Therefore, there is a definite demand for quantitative studies to specifically measure the effect of technology and digitalization on export competitiveness. Thus, this gap in the studies should be filled.

Second, much less research on understanding the strategies needed to promote the technological adoption in the Indian HVAC industry by identifying the key barriers and challenges. While advanced economies have institutionalized digital transformation by making it mandatory through force of law, providing financial incentives and creating human capital, India's journey appears to suffer from a number of structural challenges. The sector has massive barriers to entry to digitalization, especially small and medium size enterprises (SMEs), as they have limited financial resources, not to mention the access to state-of-the-art technologies nor the available qualified personnel who are trained in smart HVAC systems. Organizational resistance to change, fragmented supply chains and infrastructural mismatch between the legacy systems and modern technologies adds to the problem. Despite the interventions by the government in the form of Production Linked Incentive (PLI) scheme and Energy Conservation Building Code (ECBC) the adoption of smart and efficient technology is sporadic with a lot of transformation taking place in high end urban projects.

These identified gaps in existing literature offer good opportunities for other research and explorations within the field. Collectively, all these gaps indicate that the area of research needs to better explore the larger structural issues playing a supporting or spoiling role in the digital and technological evolution of India's HVAC industry. In addition, there is little information about how to avail this transformation to enhance the position of India in world economy. The research presents an effort to connect these concepts by providing a fact

based and policy related understanding of improving technology benefits to Indian exporters of HVACs.

2.6 Study Purposes

Using the primary assumptions identified in the literature review, this research aims to accomplish some of the research goals that are significant for the Indian HVAC industry, in educational and actual practices.

The intention would be to investigate how enhanced technology and digital solutions can shape the country's accomplishments in terms of exports relative to other countries in the world. Even as these new technologies like AI and IoT gain more attention, people are still not sure how they directly or indirectly influence export performance metrics such as opening new markets and meeting world standards. The purpose of the study is to clarify the key role that digital tools play in increasing the visibility of the Indian HVAC industry worldwide.

Secondly, the aim is to discover what hinders the adoption of new technologies in the Indian HVAC industry so that necessary strategies can be created. In particular, the study aims to investigate financial issues that SMEs encounter, the absence of certain workforce skills, difficulties companies have when adapting to change, and issues in connecting old and new systems.

Despite the fact that people understand the benefits of digital HVAC systems, small and medium-sized enterprises are still taking up these options slowly.

Therefore, this study looks for problems facing digital transformation, for example, the shortage of funds to invest in advanced technology, gaps in technical and digital abilities that many people have, strain against changes in organizations, and obstacles to making new technologies work with old systems. The study intends to discover practical guides for

both stakeholders and policymakers, in order to support the inclusion of more AAC users in new digital developments.

In simple words, the objective of this study is to examine the impact of innovations and new technology on exports and to find out the issues that hinder the Indian HVAC industry in adopting them. By doing this, the publisher wants to fill existing gaps in literature and play a role in the current discussion on setting up a competitive and future-ready industrial space underpinned by digital technologies.

2.7 Research Questions

Besides exploring how advancements in technology affect international competitiveness, the researcher looks for the obstacles limiting wider use of these technologies in the sector. Given the eager ambitions of India in the global manufacturing and export markets in particular witnessed in India's Make in India as well as Digital India, addressing these dimensions becomes timely and strategically important.

RQ1: Will technological upgradation and digitalization impact the export competitiveness of the HVAC industry, India?

The first research question has to focus on the relationship between technological upgradation, digitalization and export competitiveness. While there is a spate of innovations such as IoT enabled systems, AI driven controls, energy efficient designs and other such developments which are increasingly being integrated into HVAC products globally, there is limited empirical evidence of how these developments affect the positioning of the Indian industry in export markets. Therefore, it is the intent of this study to quantitatively determine if technological modernization and the adoption of digital applications contribute to the positive achievement of important export measurements such

as export volume, market reach, product compliance and overall competitiveness in an international market.

RQ2: What strategies can be developed to promote the adoption of technologies in HVAC industry in India by identifying the key barriers and challenges?

The RQ2 adopts a more internal perspective for the industry by the attempt to find strategies that are effective in promoting the adoption of technology. Although talks around Industry 4.0 have picked up, deployments of advanced technologies in the Indian HVAC sector have been sporadic and the adoption of these technologies is not very regular, particularly for small and medium-sized enterprises (SMEs). This study explores the financial, organizational, and infrastructural barriers in digital transformation at the sector. By finding these constraints, the research aims to develop evidence-based strategies that target the broader and more inclusive adoption of technologies, to develop a more inclusive, and therefore better prepared sector as a whole for the digital transition.

Collectively, the research questions are aimed at providing a holistic insight into the extent to which digitalization and technological advancement act as both enablers and a product of enhanced export competitiveness. At the same time, they attempt to solve the structural challenges which will need to be overcome in order to positively leverage these transformative processes in the Indian HVAC industry.

2.8 Chapter Summary and Transition

The literature review thoroughly deals with the relation between technological upgradation, digitalization and export competitiveness especially in the context of HVAC industry in India. It opens with a comprehensive position of Technological upgradation as an important enabling factor for industrial growth and making the country internationally

competitive. According to studies, investing in R and D and creating new products with energy-saving techniques greatly assists companies in following fresh global standards. Green features appear in the HVAC industry through the use of green refrigerators, energy efficient products and adhering to green building rules. Such developments enable companies to make various products, cut energy costs, and remain competitive, as rules for exports become tougher and environmental standards are regularly increasing.

After that, the review discusses how digitalization is changing the entire manufacturing process. The design, observation, and management of HVAC systems have transformed thanks to the Internet of Things (IoT), artificial intelligence (AI), cloud-based ERP, CRM applications, and digital twin solutions. They accelerate operations and predict when maintenance should be done, and they aid in decision making and staying responsive to the needs of consumers. In India, government programs including Digital India, the Smart Cities Mission, and the National IoT Policy have started the digital transformation, but use of advanced technologies is not even within the HVAC sector. Examining other countries reveals that making BIM use obligatory helps accelerate the use of new technology and sense integration of the HVAC systems into smart buildings. Unlike many other nations, India does not have a national Building Information Modelling (BIM) policy, so the use of digital construction and system improvement takes more time. Various studies point out that, to export better, a given country needs to work on price efficiency, elaboration of quality products, acceptance of certifications, maintenance of participation in different markets. If HVAC products conform to standards specified by LEED, they get permission to enter the high value markets. Studies have shown that businesses who use advanced technologies and digital tools have no problem meeting global market needs and changes in regulations which in turn improved the way they do businesses outside their home market. Besides, the addition of the national policies, such as the PLI and the ECBC, are

viewed as important in the development of the manufacturing skills of the country and producing items that are ready for the global marketplace.

In the end, all these works are put together as a conceptual structure where technological upgrades and digitalization are pointed out as important elements for HVAC industry to be competitive on export markets. As a whole, studies point out that while there have been improvements in separate fields, there is still an important gap in understanding how digital and technological strengths together affect India's exporting in the HVAC sector.

CHAPTER III: METHODOLOGY

3.1 Introduction

In order to deal comprehensively with these questions, a mixed method research approach involving quantitative and qualitative methods was employed. The choice of mixed method was the choice construct, to account for the complexity of the phenomenon from both the macroeconomic perspective as well as the firm perspective. The quantitative part involved secondary data analysis in relation to measuring the relation among the technological advancement and digitalization in relation with export performance. Complementing this, the qualitative element included the use of semi structured interviews with industry experts and practitioners to talk about underlying challenges, enablers and strategies to technology adoption for the HVAC sector.

This two fold approach enabled triangulation of findings adding to the validity and depth of findings. The methodology was especially good for the business to business (B2B) where the tech and the operational processes are complex and market competitiveness depends on the strategic and technical aspects (Dixit & Bhasin, 2022).

Through this methodological design the study made a systematic attempt to study the current technological progress in the Indian HVAC industry, understand key barriers for digital transformation and propose practical ways to improve export competitiveness. The outcomes were envisaged to provide actionable recommendations to the industry stakeholders and policy makers aimed at aligning the HVAC industry in India at the international standards of performance, innovation and sustainability.

3.2 Methodology of Research Question One (RQ1)

3.2.1 Research Design and Rationale

Since this study investigates the consequences of digitalization and technology on exports, an explanatory sequential mixed-methods design was selected for the study. This design is useful for the study because it allows researchers to gather and combine information from figures and written descriptions step by step. By doing this, we gain a basic and also detailed look at the issues under study (Creswell and Clark, 2017; Harvard Catalyst, 2023). This phase is important as it helps to discover various patterns, relationships, and trends attributed to technological upgradation, digitalization, and export competitiveness. Following this, the qualitative part is added, where stakeholders' thoughts and feelings are gathered to further explain the main reasons behind the identified trends (Guest et al., 2006). The research starts with a quantitative stage, where information from databases of the World Bank and UNESCO such as the WDI is used. Since HVAC is a basic part of the manufacturing and export industries in general, the development and digital trends of HVAC could be researched through a number of internationally accepted national indicators. This methodology permits the possibility of comparisons in over 50 poor and middle-income countries. In this study, the chosen variables are as follows: Exports of Goods and Services(% of GDP), Fixed-Broadband Subscriptions (Count) and Medium and High-Tech Exports(% of Manufactured Exports). As the data spans from 2000 to 2022, it is also possible for an analysis to be run on how technological and digital growth has affected the ability of Vietnam to export internationally over all these years. To determine the relationship between the variables, we will implement a multiple regression analysis to obtain information on the relevance of digital and technological changes in the country's

exports. With the aid of statistical analysis, it will be possible to find out how each variable affects the export competitiveness.

Once the numbers are analyzed, another phase is done where the results are studied more in depth. To learn about technology's effect on exports for the industry, we will interview manufacturers, exporters, policymakers, and technology providers who have been purposefully selected. In this case, details from the interviews will explain the specific digital strategies companies adopt and discuss the problems they face when trying to implement them, as well as their experiences with government aid (Harvard Catalyst, 2023; Creswell and Plano Clark, 2017).

By following one phase after the another, quantitative and qualitative studies, the analysis explores the ties between adopting modern technologies, digitalizing, and expanding in the HVAC industry. The data found in the numbers will inform the qualitative evaluation and direct researchers to specific points that call for more study.

Should there be a gap between the strong technology and internet access in such countries and their export competitiveness, further reviews will be carried out to discover the obstacles. Some barriers stand in the way, for example, regulation is not up to date, there are not enough qualified workers, making it harder to obtain financing, or lacking infrastructure buildup (World Bank, 2023).

The combination of these facts allows the study to give a full explanation of the impact of technology and digitization on Indian HVAC industry exports and those of similar nations. An examination of data consisting of the interval above 2000 to 2022 in this analysis is giving an useful insights to policy makers and businesses about the successful export policies (UNESCO, 2023). With this design, both statistics and interviews permit researchers to recognize large picture associations within the industry and also detect the genuine understandings of the professionals of the HVAC industry. They help to provide

a complete understanding of the role of digitalization and technology as part of bringing global trade enabling data based advice for all members of the export process.

3.2.2 Methodology

The methodology for RQ1 was adopted in two consecutive phases.

The first phase involved a quantitative analysis involving the use of historical secondary data to analyze the nexus between technological upgradation and digitalization and how they impact export competitiveness, in this case over time.

The second phase was a qualitative study done through semi structured interviews to interpret and put the quantitative study in context.

Integration of both phases took place at the interpretation phase, which ensured the methodological triangulation and consistency between the statistical results and industry level insights.

3.2.2.1 Population

The study covers all stakeholders operating in the Indian HVAC (heating, ventilation and air conditioning) industry and especially those who participate in export activities. These are made up of HVAC manufacturers, exporters, Experts, policymakers and technology providers from India. Besides that, the investigation aims to take the perspective of buyers and partners across the globe to understand how Indian HVAC products compete globally with similar products from different low- and middle-income nations.

For the quantitative part, information is taken from major global databases, such as the World Development Indicators (WDI) from the World Bank and UNESCO's repository, so that the results can be compared worldwide. This way of analyzing export competitiveness uses facts to evaluate the HVAC industry in India with other countries. The research investigates trends over the years between 2000 and 2022 and showcases what contribution

advancements in digital and technology space had in the country's exports (World Bank, 2023).

In the quantitative research, Indian HVAC stakeholders keep getting interviewed in semi-structured conversations, thus detailed understanding about industry needed issues and prospects related to technological improvements and use of digital tools can be achieved. In the qualitative section of the study, information about policy weaknesses as well as technology challenges will be gathered in order to provide more information about why things occur a particular way in the industry (UNESCO, 2023).

3.2.2.2 Quantitative Sampling

To conduct the quantitative analysis, secondary data is collected from globally reputed databases such as World Development Indicators (WDI) and the records of the United Nations Educational, Scientific and Cultural Organisation (UNESCO). As a result, the review can go through the interaction among exporting in the HVAC sector, updated technology and involvement of digital tools on the global market.

A longitudinal trend analysis that covers 2000 to 2022 is used in this study to determine how new technologies and the digital revolution have changed a country's export prowess. This procedure matches the usual ways of conducting trade competitiveness research when there is not much sector-specific data available. Researchers tend to look at official trade statistics from countries to find out trends in different industries (OECD, 2023). To do this, for example, the OECD uses inter country input and output tables composed of regional and national data in its trade in value-added (TiVA) indicators. In addition, the World Bank's SPI indicators judge how well a country produces and shares valid data, which supports the creation of reliable overviews of how the country does in trade (Nature, 2023). With the help of national indicators, the study gives an overview of how the Indian HVAC

industry performs in exporting compared to similar countries. This analysis will show if digitalization and use of new technology affect HVAC export competitiveness.

3.2.2.3 Data Collection

This research analyzes the relationships among export competitiveness, improved technology, and digitalization with the use of three major national indicators: Exports of goods and services (% of GDP), medium and high-tech exports (% of manufactured exports) and fixed-broadband subscriptions (calculated). They help show how strongly a nation is a part of world trade, its advanced production, and how well digital systems support it, all of which shape its success in international competition.

It measures the percentage of GDP that is made up by goods and services exported to other countries, using World Bank's World Development Indicators. In general, a higher percentage indicates that a country's exports are competitive, due to helpful trade rules, modern industries, and taking part in global business connections (World Bank, 2023). Its strength in exporting goods in the future mainly depends on its industrial advances, progress in research and development, and the extent to which it is digitally connected (OECD, 2023).

Enhancing technology is essential for business competitiveness abroad, because it improves the value and quality of output. This indicator is calculated by the World Bank and shows the portion of manufactured exports that comes from medium and high-technology goods. More advanced technology found in exports points to a nation's advanced industries and the ability to compete well. Because of this, firms can generate high-value items without facing tough pricing competition (World Bank, 2023; OECD, 2023).

Relying on digital tools makes exports more competitive by helping manage work more effectively, removing many trading barriers, and opening new markets. This indicator is

based on data provided by UNESCO's ITU Data Hub, and reflects the proportion of individuals with a fixed broadband connection (which enables e-commerce, digital supply chains, and connecting internationally). Where broadband is widely used, economic growth is faster and the country becomes more involved in international trade. As a result, businesses can now serve new customers, collaborate in global manufacturing chains, and make use of automation and artificial intelligence thanks to new technologies (UNCTAD, 2021).

3.2.2.2.2. Time Frame and Geographic Focus

This research review data from the years 2000 to 2022 and uses this information to observe the influence of technological modernization and digitalization on export competitiveness over the years. There are 51 low- and middle-income countries in the data, all listed by the World Bank, which allows for an analysis that puts India's HVAC export field in line with worldwide trends. Researchers in trade competitiveness usually rely on national-level trade indicators that have become established in the field. In the absence of specific industry figures, the macroeconomic data can serve as a good base for judging different sectors (OECD, 2023).

3.2.2.2.3. Data collection strategies

Data collection strategies aim to determine three important variables that can show export competitiveness, technology updates, and digitalization. The WDI (2025) from the World Bank shows that exports of goods and services (% of GDP) lists how much of a country's GDP is comprised of exports of goods and services. This indicator, taken from the WDI (2025), and shows the percentage of medium and high technology manufactured exports to the total manufactured exports, explaining the level of progress and technology in the manufacturing sector.

The Fixed-Broadband Subscriptions (Count) indicator, which is taken from the UNESCO's ITU Data Hub (2025), specifically measures levels of Digitalization in capturing the level of broadband penetration, a growing enabling factor for e-commerce, digital trade and smart manufacturing.

"The dataset is organized so as to preserve comparability over the selected 51 low and middle income countries from 2000 to 2022 aiming at carrying out a long term trend analysis of technological improvements and trade performance." Given the long time frame of the study, missing values within the dataset are not a much of a limitation as the number of observations provided are sufficient for a good statistical analysis. The presence of a longitudinal dataset for more than two decades thus enables an in-depth analysis of structural changes in export competitiveness, digital transformation and technological changes.

3.2.2.2.4 Data Analysis Approach

The quantitative analysis uses several statistical methods in order to analyse the linkage of technology upgradation, digitalisation and export competitive strength. The technique of multiple regression analysis conducted by EViews is used by the study to ascertain the degree of influence of technological upgradation and digitalization on export performance in selected countries. A trend analysis (2000 to 2022) is conducted in order to monitor changes of the export volumes, broadband penetration and high tech manufacturing exports, to see a more clear realization of the long-term changes in the economy. Additionally, a comparative assessment across 51 low and middle-income countries is done to benchmark India's HVAC export sector against an overall global market, which maps out structural gaps, competitive advantages as well as opportunities for strategic industrial growth.

Combining these ways of analysis the study will be able to put forward analytically based information regarding the influence of technological change and digitalization in making the HVAC exports in India competitive in the world. The findings will serve as a guide for the policymakers, industry leaders, and trade strategists to determine the structural changes needed to consolidate India's position in global HVAC markets, which matches the industrial policies the emerging global trade dynamics.

3.2.2.3. Qualitative Sampling:

Participants were chosen using a purposive sampling method to get a broad range of knowledge, expertise and views to be able to have the ability to understand the research topic broadly. The final sample was 50 participants from major stakeholder groups from the Indian HVAC industry, comprising top exporters, policy influencers, industry leaders and technology experts.

This sample size proved sufficient to produce rich and meaningful insights while being manageable from the point of view of detailed data collection and analysis purposes. All the participants were active in the export and technological fields of the Indian HVAC industry, ensuring the relevance and accuracy of the qualitative data. The group consisted of people representing manufacturing, export management, policymaking, industrial associations, and technological services sectors, which is consistent to achieve a balanced and multidimensional understanding of the explored issues in this study.

3.2.2.3.1. Participant Selection Criteria:

The participants for this study will be selected based upon their knowledge and experience of the HVAC industry. Those participating in the selection process will try to select those who have worked for five or more consecutive years in the profession and who shoulder management positions such as project managers, senior engineers, or department heads due to the influence on choices and direction of the industry. A balance is attained on this study

by including members involved in manufacturing and also in service sectors as well. Additionally, people from the West India will receive more attention because the research involves ensuring that this area is covered.

3.2.2.3.2. Rationale for Sample Size:

To get clear insights and having a feasible study of 50 people were involved. Many experts say researchers reach the point of thematic saturation when no new information is being processed that allows them to come up with new themes or insights (Guest et al. 2006). In this way, the opinion of people represents lots of individual point of view in the industry without being too much similar. In the majority of the mixed methods research situations the number of qualitative participants is fewer than the number of people involved in the quantitative element of the project, since the motive is to obtain thorough and sound evidence rather than striving for broad generalizations (Creswell and Plano Clark, 2017). If the study is not very complex, you can use between 20 and 40 participants, Mason (2010) says.

With the focus of 50 people, the participants can be diverse enough to discuss the main topics on technological advancement, digitalization, and competitiveness in exports of Indian HCV products. Since the study has interviewed 50 people representing manufacturing, policy, and technological background, it gets ideas from people in different jobs and sector. With this approach, professionals with necessary experience are included, which goes along with the standards of qualitative sampling (Patton, 2002).

3.2.2.3.3. Recruitment Methods:

The research will involve different outreach methods to make sure that the recruited sample is both diverse and qualified. This means reaching out to HVAC trade organizations, contacting experts through LinkedIn using certain profiles, and pulling in referrals from those you start out with to continue gathering well-matched experts.

3.2.2.3.4. Ensuring Diversity:

Participants will be chosen in a wide variety of ways to give a thorough view of the HVAC industry. It should include people involved in design, set up, maintenance, and the sales sides of the business. It will ensure that different business sizes are represented by including big businesses as well as small to medium-sized companies. Geographic representation will be secured by choosing West India as the location and trying to include delegates from many states or regions there. Maharashtra and Gujarat in West India are selected because the region greatly shapes India's industrial and economic future, and plays a major role exporting goods. Both states have a notable impact on India's industrial exports, since HVAC suppliers, manufacturers, and exporters operate there in significant numbers. What's more, they have excellent infrastructure, vibrant research labs, and mechanisms that allow for easy digital trade, making them the perfect spots for further study. Because of its main economic centers, Mumbai and Pune, Maharashtra is pivotal for the HVAC industry. Housing the corporate headquarters of India, many of which need air conditioning, Mumbai is known for its HVAC demand, whereas Pune, promoting IT, manufacturing, and education, showcases more kinds of HVAC applications. Gujarat is known for welcoming businesses, excellent infrastructure, and producing many products. Because it is rapidly growing and industrialized, Pune takes on an important role in manufacturing, exporting, and sets a good context to see patterns of HVAC use. In the past five years, India's two leading exporters, these two states, have accounted for almost 50% of the nation's total merchandise exports. Out of India's industrial GDP, Maharashtra contributes 15%, and Gujarat gives 8%, and both states are major contributors to the HVAC export market. Because these regions are studied, the research can efficiently collect specific data on trade and new technologies and maintain the importance of local perspectives. Moreover, the industrial diversity and technology patterns West India seem

to teach to other industrial centres of the country, this makes it a perfect environment to examine the interconnections between the concepts of digitalization, export performance and technological advancement.

The qualitative method fits well with the research objectives that focus on understanding the ties between technology, digital changes, and export competitiveness in the HVAC industry of India. The study seeks to give a complete overview of the industry's trends, problems, and possible opportunities by recruiting a group of people with a lot of experience.

3.2.2.4 Sampling and Sampling Procedures

3.2.2.4.1 Quantitative Analysis

During the quantitative phase, researchers select and study households from each of 51 low- and middle-income countries, to ensure that the data reflects all differences in export competitiveness, technology and digitalization in the region. As it is difficult to collect data on HVAC for companies, the study depends on national-level information obtained from the World Bank WDI and UNESCO Caps sources. Studying the trade condition and changes in the technology for the economy provides a broad scope to consider the change in export competitiveness of Indian HVAC with the other countries. The study was conducted for 23 years, which helps to get the clear picture of technology and trade performance trends. The longer one has a period of data, the better one can see trends, and can reduce the influence of swings that were caused by surrounding events or policies.

This approach though is consistent with known methodologies in the trade competitiveness research, using longitudinal data to measure industrial transformation and global market integration (OECD, 2023). Because there are 51 countries, all low- and middle-income countries are included, it is possible to measure differences in export capacities, use of technology, and changes with regard to digital transformation among countries. Since

every nation's export and economic development are different, by seeing the several nations we can learn the effect of technology on exports the countries which the industrial system is similar to India. Authors adhere to the misuse of economic surveys to deduce trends about different sectors in cases of insignificant data about actual industry (UNCTAD, 2021; World Bank, 2023).

3.2.2.4.2. Sampling Process

Data is gathered and designed and checked against the select criteria through a detailed process to get a representative sample. The initial part is to identify main variables in the study using the following goal of the study to test the association of technological upgrade, digitalization and how competitive is a country in exports. The World Bank and the UN's Education, Science, Sports and Culture Organization (UNESCO) datasets (2000 to 2022) were used to collect these indicators that were the major sources for quantitative researches. All these instruments ensure that the most vital points of the study related to trade and industry are measured in a thoughtful and precise manner.

It is necessary during the second stage to put the data in an order so all the countries and years can be compared. In this format, data on 51 low-and middle-income countries are available for 23 years, so one can follow changes and trends in both technology and exports. It makes it possible to conduct the study based on a focus on sectors since, at the national level, it can gather data on the trends of each sector if there is no data at the industry level. In the third stage, both the verification and validation are performed on the data taking special attention to the missing values of the data and maintaining the data set consistency, in an effort to maintain the reliability of the data set. This manner of sampling has a good basis in quantitative analysis and makes the findings of the study more credible. At this fourth step, the site of analysis is each and every country (51 countries of low and middle income), when it comes to the quantitative phase. Given that trade data for firms is

not available, the research looks at data from the economy as a substitute for technological advancements, digitalization and export competitiveness. Thanks to the eight years of data starting in 2000, the study looks at many countries and finds common trends in the adoption of technologies, making policies and trading similar to that of India's industrial sectors. This way of collection of data helps this study to examine the link between digitalization, technological progress and export competitiveness from a strong macroeconomic angle. The results of the study are sure to give valuable information about the global trends in trading of HVAC for the formulation of suggestions to the government and industry of India with an aim of improving its performance in the export of HVAC.

3.2.2.4. Qualitative Analysis:

During the qualitative phase, the techniques of purposive and stratified sampling were used to ensure that various points of view were represented from each stage of the HVAC value chain. Participants were from three main stakeholder groups: (i) manufacturers and exporters involved in doing business internationally and using modern technologies; (ii) policymakers and industry experts involved in trade and regulatory and policy development; and (iii) digital consultants and technology providers involved in supporting innovation and digital integration within the sector. Each group presented distinct yet interlinked insights into the voices of enablers and barriers observing the Indians practicing exporters of advanced technology solutions and digital solutions in the market.

The selection process involved adherence to carefully defined inclusion criteria to obtain the credibility, relevance and richness of insight gathered. A minimum of five years of working experience in the industry was given provided, in order to guarantee that respondents ensured they had adequate contextual understanding and professional maturity. In addition, the research participants all had direct involvement in either export-

oriented operations or technological issues that ensured the data reflected current industry practices and trends.

Efforts were made to try to capture a cross-section of the strategic and operational and technical roles, thus building a multidimensional understanding of the phenomena under investigation. The results were strengthened through triangulation of multiple stakeholder perspectives that allowed an all-round and accurate interpretation of the role of technology in export competitiveness in India's HVAC industry. This strategy was conducive to the valid and deep nature of the results in line with the main exploration goals of the research.

3.2.2.5 Procedures for Primary and Secondary Data Collection

3.2.2.5.1 Quantitative Analysis

In this study the initial step is centered on a national level analysis, and the analysis aims at pinpointing general trends, patterns, and associations regarding the technological upgradation, digitalization and the export competitiveness. Since no national level trade data exist with regard to HVAC alone, this paper utilizes macroeconomic indicators to proxy technological transformation and export performance within economies that have industrial structures similar to that of India. The selected input variables, exports of goods and services (% of GDP) (export competitiveness), medium and high-tech exports (% of manufactured exports) (technological upgrading), and fixed-broadband subscriptions (computing) (digitization) are published on the World Bank's World Development Indicators (WDI) and UNESCO's ITU Data Hub and have a globally standardized database.

The dataset covers 51 low- and middle-income countries from 2000 to 2022, allowing us to explore how trade and technology have changed over time. Since national indicators are used to measure sectoral performance, the method in this study is based on the same model used in research on trade competitiveness and industrial development (World Bank, 2023;

UNCTAD, 2021). Both multiple regression analysis and trend analysis are used to explore the relationships that exist between improving technology, digitalization, and export competitiveness. This way of analysis offers explanations for how technology and digital solutions lead to more exports and allows India's HVAC sector to be seen against the backdrop of global trade.

3.2.2.5.2. Qualitative Analysis (Semi-Structured Interviews):

For the second qualitative part, using interviews, primary data were gathered which were focused on insights seen in the statistical part. Careful selection of experts and leaders in the study area such as major exporters, policymakers, and providers of advanced technology were involved in the study. A total of 50 people were recruited to ensure variety in terms of experiences and roles included. Participants recruited from ISHRAE, ASHRAE, industry networks and LinkedIn connections. The sample was split according to different parameters such as safety management experience, company size, geographical location etc. to ensure representativeness. The interviews were conducted both virtually and in person between June and September 2025 and the availability of the people.

3.2.3. Instrumentation and Operationalization of Constructs

This phase of the research is quantitative, and structured framework helps in ensuring the international data-sources are collected and sorted with a complete structure. The WDI and the ITU Data Hub from World Bank and the UN's education agency (UNESCO), respectively, are the principal resources for most indicators on national export competitiveness, improvements in technology and digitalization. These Indicators have been selected Exports of goods and services (% of GDP) Medium and High tech exports (% of manufactured exports) Fixed-Broadband Subscriptions (Count) From 2000 to 2022, a period of 23 years, this dataset took into consideration the data that was collected from a

total of 51 low and middle-income nations. This explains how over the years technology and digital transformation have brought about change in export performance. The method ensures that data is presented, analysed statistically and compared with other countries in a similar manner. Since the dataset is based on a series of accepted trade and technology indicators, they are essentially a reflection of agreed-upon macroeconomic procedures, so it provides good input for use in regression modeling and trend study (OECD, 2023; World Bank, 2023). The standardization of data has been measured in a single form which has made the study analyze the impact of technology and digitalization on export performance of HVAC industries in India when compared with other countries.

Semi-structured interview guide is the dominating mode through which data will be collected during qualitative phase. The method of the study is conducted through the use of open-ended questions in the interview, addressing the main themes in uncovered during the analysis which will help us to investigate the influence of the application of updated technology and digital tools to export competitiveness. The interviews will focus on two Indian states (Gujarat and Maharashtra), which are among the largest centre of the HVAC industry and exports in India. The meeting will bring together industry experts, policymakers, and technology providers, so there is a broad range of opinions on the main research topics. This research targets three main topics: modernization of technology, digitalization, and being competitive in exports. Technological upgradation is viewed as an independent variable and denotes the amount of R & D spending and new inventions in a country. The indicator used to determine this is medium and high-tech exports (% of manufactured exports), taken from the World Bank's World Development Indicators. The amount of this indicator represents the share of medium and high-tech goods among a country's exported manufactured products, which is taken as a measure of its technological level, industrial progress, and efforts toward innovation. It suggests that heavy technology

integration allows a country to be part of valuable global supply chains and boost its industrial development in the HVAC sector (World Bank, 2023). Digitalization is considered on its own as a choice to use digital tools in the facilitation of trade and within industrial activities. Data comes from the Fixed-Broadband Subscriptions (Count) indicator that is found on UNESCO's ITU Data Hub. It shows us how much digital infrastructure is being used, especially concerning the access and use of broadband technology around the globe. As more people and businesses have broadband access, it helps improve the country's export performance, automation in factories, and reach to world markets. Good digital connections fuel the rise in trade because they back the growth of online sales, make it easier for countries to trade, and help Industry 4.0 advancements that raise industry and market competition (NCTAD, 2021; ITU, 2023).

Export competitiveness is what we measure when we look at how well a country can keep and advance its international participation. The information is taken from the exports of goods and services (% of GDP) indicator, which originates from the World Bank's World Development Indicators. It shows the direct relation between the trade of a country and its economy, which identify how well it has to be passed into the global economy, increasing manufacturing and export chances. The paper considers how the HVAC sector in India can take advantage of the opportunities offered by technology upgrading and digitization in order to determine the impact of these policies on the country exports in this sector (World Bank, 2023). Using these tools, this study relies on hard data for making its judgement regarding the competitiveness of Pakistan's exports using worldwide measures of trade and technology. The consideration of data from 2000 to 2022 across 51 countries with low- and middle-income countries provides a perspective to look into the HVAC sector of India against the global framework of trade.

The main objective using a panel data analysis model is to connect the variables (technological upgradation and digitalization) with the variable export competitiveness.

$$Y(\text{Exp_Comp}) = X_0 + X_1 (\text{Tech_Upgrad}) + X_2 (\text{Digital}) + \epsilon$$

Y(Exp_Comp): Export Competitiveness (dependent variable).

X₀: Constant term (intercept).

X₁: Coefficient for technological upgradation (reflecting its impact on export competitiveness).

X₂: Coefficient for digitalization (reflecting its impact on export competitiveness).

ε: Error term, accounting for the variability not explained by the model.

The model tests the statistical significance and strength of the relationship between technological upgrading, digitalization and export competitiveness and provides empirical evidence on the trade performance affecting countries based on tech and digitalization. The combination of quantitative and qualitative methods ensures that the statistical findings are backed up with insights from industry which adds to the overall validity of research findings.

3.2.4 Data Analysis Plan

The data analysis strategy is designed to address the research objectives by integrating quantitative and qualitative insights. The sequential mixed methods approach will be used, starting with quantitative analysis, followed by qualitative analysis.

3.2.4.1. Quantitative Analysis Plan

Secondary data will be used in the quantitative analysis to identify patterns, links and trends about improvements in technology, digitalization and being competitive in the export.

Using data in 51 low and middle income countries over a period of years from 2000-2022, the analysis attempts to discover in what way technology and digital changes may have an effect on the international trade. The first important task is to clean, organise and structure the data in order to set it proper for statistical analysis. The World Bank's WDI and Data Hub from ITU of the United Nations Educational, Scientific, and Cultural Organization (UNESCO) will supply the data, and these would be prepared to ensure that all statistics will be the same for analysis purposes. In the second step, harmonisation of the methods of measuring the progress in technology, digitisation and international competitiveness is done to enable comparisons between countries and over time. By making the comparisons more standardised, the differences in the collection of data in different countries can be reduced and cleaner statistics showing the links between the different variables can be produced. In step three, a panel data analysis technique is used to examine the link between the digitalization and upgrading of technology in a country and export. Panel data analysis works well with longitudinal data in that it makes sure that we can see the country variation as time passes. This model enables us to check our research hypothesis and find out regarding the relationship between upgrading of technology and digitalization and the export competitiveness. The insights will be useful in explaining how technological progresses have enhanced the performance of the HVAC sector in India in the global trade market.

By using this econometric approach, the study will come up with results that would explain how the advances in technology and digitalization help make a country of some sort stand out in the global trade. The investigation will recommend steps that will increase India's HVAC export and also comply with the international best practice guidelines.

3.2.4.2. Qualitative Analysis Plan

In such explanatory sequential design, moving from quantitative to qualitative is important and expected which develops a more in-depth understanding of the issue that is being researched (Creswell and Plano Clark, 2017). At the beginning, researchers apply quantitative analysis to identify patterns and interrelations between the development of technology, digitalization and the success in exports. Despite imparting insights on the primary trends, the statistics fail to describe the situation context that brings the situations into play. In the qualitative phase, researchers probe what occurs to the stakeholders and learn about the industry-specific elements for what these trends are (Guest et al., 2006).

Quantitative analysis gives us broad knowledge but the qualitative one enables to take closer look into the problem and consider how the new technologies impact on the export competitiveness of HVAC firms. As long as data confirms that digitalization is an aid in exports, it is possible to acquire more understanding by way of qualitative interviews about the practices and difficulties faced by those involved (Mason, 2010). Mixing both types of data enables the research to come up with more reliable and useful findings considering that the findings come with the support of practical experience (Creswell and Plano Clark, 2017).

During the qualitative phase, activities were conducted in order to analyze data obtained from the interview in order to identify the key themes that came out in relation to the data obtained by the quantitative phase. The interviews helped in gaining in-depth knowledge about the relationship between the technological advancement, digital transformation and the position of the HVAC industry in the export markets of India. To facilitate the sharing of information, each interview was fully transcribed, and participants' responses were captured totally. All research procedures followed high ethical standards so that the personal data of participants were protected through anonymization and confidentiality

standards. All the data collected were securely kept and protected throughout the research process to ensure participant privacy and data integrity.

A method appropriate for understanding the qualitative results was a thematic analysis by NVivo 14 that supports the discovery of patterns and the systematic structuring of data. A structured analytic method was developed which was a combination of deductive and inductive coding techniques. The results of the quantitative analysis helped to guide the deductive coding to ensure a match between the two phases of the study, while inductive coding enables the emergence of themes and new knowledge from the narratives of the participants which could also be considered in a broader sense than could have been imagined.

After completion of the coding process, the main themes and subthemes were identified and categorized to get more understanding on technological upgrades and digitalization trends in the Indian HVAC sector. This categorization brought valuable information on the daily challenges of the industry as well as its strategies for exporting. To increase the credibility and validity of the findings, qualitative findings were compared and triangulated with the quantitative finding and ensured that the interpretations were rooted in multiple sources of evidence.

Integrating the qualitative and quantitative components allowed for the whole story of patterns and trends to be understood. The study thus captured the multidimensional influence of the technological advancement and digital transformation on export performance by merging both forms of data. Finally, the qualitative findings were compared with existing theories and industry practices in order to put the results into context with models and actual market conditions. This methodological integration enhanced the explanatory power of the study and increased the practical relevance of this work for policymakers, industry practitioners, and stakeholders in the Indian HVAC sector.

The explanatory sequential mixed methods design therefore not only enhanced the scientific robustness of the research process but also provided insights for actionable research on how to further develop the export competitiveness in the industry.

3.2.5 Threats to Validity

3.2.5.1 External Validity

Using indicators from the World Bank's WDI and data on the country from the ITU Data Hub to examine the topic of upgradation, digitalization and competitiveness for exports in the HVAC sector might lose some of the details of activity in different sectors and companies. The contribution brings together data from up to 51 low- and middle-income nations spanning 2000 to 2022 in order to provide a better and inclusive picture on the impact of technology and the digital sector on economies.

Changing technology and the way digital trade is done can mean whether or not the outcomes of the research are still applicable in the future. Therefore, the details of the research include the period of time covered (2000-2022) and focuses on how both digitalization and industrial modernization have changed over time. In addition, adopting internationally recognized trade and technology indicators is useful to ensure that the findings will be useful in areas besides HVAC. Future investigations will point toward recent technological advances, new strategies in trade and switching focus of exports of countries, which will keep this study relevant for the longer term.

3.2.5.2 Internal Validity

The possible threat to the internal validity of the research is selection bias and in this case the results might be impacted by countries, which have superior technologies and digital infrastructure. To solve this issue the paper incorporates 51 nations from the low- and middle-income category which allows them space to shine despite their differing technology, internet access, and stats on exports. Because of the fact that the panel data

analysis operates in both countries and time, this helps to curb bias in comparing nations and ensures that the results are stable (OECD, 2023).

Accuracy and the proper use of large concepts such as technological upgradation and digitalization is a second concern about internal validity. To deal with this, the research exploits the global standards and methodologies advised and monitored by World Bank and UNESCO Caps to measure and report the extent to which a country depends on R and D, the level of readiness of a country to enter the digital age, and the performance of the country in the export. Furthermore with industry reports, study results on trade competition and policy reviews, the study ensures that the relations found between numbers in the statistics in practice are real. The better level of reliability is achieved in the study, it applies strict statistical tools, and matches the country with economic results, and also with trading results at the global level.

3.2.5.3 Construct Validity

Validating the construct means there have to be precise definitions and coherent ways of measuring important study variables. The study keeps a good approach to concepts and precise results by using a following framework for operationalization: One way of taking note of Technological Upgradation is by looking, through the Medium and High Tech Exports (% of Manufactured Exports) figure, which comes from the World Bank's World Development Indicators. It provides an idea of development and innovation in economic growth by referring to what percent of goods exported by the country use leading technology (World Bank, 2023).

A figure of the number of fixed broadband subscriptions is used to measure digitalization, which is from the ITU Data Hub by the United Nations Educational, Scientific and Cultural Organization. It measures the maturity of digital infrastructure and digital activity in trade

by measuring broadband access, e-commerce growth as well as technology adoption in sectors (according to ITU in 2023 and UNCTAD in 2021).

The World Bank's World Development Indicators are used to get exports of goods and services (% of GDP) indicators for measuring export competitiveness. This helps to show the performances of the trade of the country with its economy shows how the country and the trade is doing in globally, it is making exports as a country and competing in the global market as the nation (World Bank, 2023). This study ensures that measurement is accurate and meaningful in terms of utilizing widely accepted trade and technology measures that can be used to benchmark countries against each other. Using this structure, the study makes the findings more accurate as it ensures that they actually demonstrate how technological upgrading, digitalization, and export competitiveness actually work together in the context of global trade.

3.2.5.4 Ethical Procedure

All the individual people will be shown the background of the research and the reason why their data is collected. The researchers will ensure that the participants' confidentiality is maintained, and all their personal information will be kept anonymous. Using this method, the research is performed in an ethical manner, guaranteeing everyone's rights and safety during the study.

3.3. Methodology of Research Question Two (RQ2)

3.3.1 Research Design and Rationale

The study would be conducted in a qualitative manner through exploration and in-depth investigation of challenges, barriers, and solutions to stimulate advancements in Indian HVAC industry. This is an appropriate model as it allows the researchers to have different types of discussions with the industry professionals, allowing them to better understand

what is impactful on the adoption of technology and what factors are aiding and halting its advancement.

3.3.2 Methodology

3.3.2.1 Population

The people who are to take part in this study will be main stakeholders in the HVAC sector in India taking part in the selection or decision making regarding use of new technologies. Some of these people include Business leaders and executives, managers and engineers responsible for production, operations and innovation, consultants and experts in the industry. For a vast population that is so diverse and the goal of finding out the barriers, challenges and strategies, a higher sample size of 50 participants is ideal to record a wide range of views across the industry. This will be distributed as follows:

1. Business Leaders/Executives: 10 to 15 nos.
2. Managers and Engineers: 15 to 25 nos.
3. Industry Consultants and Experts: 8 to 10 nos.

The western part of India, particularly the states of Maharashtra and Gujarat, plays a very important role in the industrial and economic structure of the country. Mumbai, the capital city of Maharashtra is the financial hub of India located in a high concentration of corporate offices, commercial complexes and luxurious residential buildings. This urban landscape generates a significant demand for the HVAC systems (India Business Trade, 2023). Another major city of the State of Maharashtra is Pune famous for its vibrant IT industry, charter academic institutions and large industrial areas, a composite of modern technological advancements and traditional manufacturing requirements.

The role of Gujarat state plays an essential role in the manufacture with the advantage of favourable place and top infrastructure and business-friendly policies for investors (Manufacturing Today, 2024). The state covers more than 500 million tons of container traffic annually, which is a testament to the strength of logistics. Furthermore, Gujarat's priorities for the growth of industry can be observed in the New Industrial Policy which aids in expanding the core industries and supporting emerging and growth sectors in such a manner so that the economic growth becomes sustainable and new innovation comes into picture (India Business Trade, 2023). The HVAC industry in Gujarat is very strong because the state has diverse industries and is growing rapidly. According to previous research, these areas have greatly boosted technology and helped with industrial advancement in India (Gupta, 2021).

3.3.2.2 Sampling and Sampling Procedures

Only those individuals with plenty of knowledge and insight about overcoming technological adoption obstacles will be chosen by purposeful sampling. There will be 50 participants involved, and they will be picked due to their work role, their experience with technology, and their willingness to give insights. The team will come from various places and companies to give a wide range of viewpoints.

3.3.2.3 Procedures for primary data collection

Semi-structured interviews will help to obtain primary data to have a better sense of what people are going through. It's appropriate for figuring out what stops, challenges, and strategies are present in the technological adoption in the Indian HVAC industry, where stakeholders may include business leaders and experts. A set of open-ended questions will be posed in the interviews to answer the questions on exploring emerging technology, barriers, challenges in the use of these technologies as well as solutions to them. This type of interview is flexible because the interviewer changes questions in response to

participants' answers, allowing them to get a lot of detailed information (Kallio et al., 2016).

Thematic analysis is the main way in which we will study the data. Following an orderly approach, it uses different stages to guarantee an in-depth and structured interpretation of the collection. It improves the dependability and clarity of the outcomes and adds to the link between the information, the analysis, and the conclusions. This way of organizing the process helps maintain accurate analysis and reduces the possibility of bias (Naeem et al., 2023). Since the main objective is to uncover important insights from the interviews, making use of thematic analysis is a good option.

To begin, thematic analysis makes it simple and easy to highlight, study, and present the main topics that appear repeatedly in qualitative data. You can use thematic analysis informed by grounded theory principles to study and solve a large range of research questions (Braun & Clarke, 2006). Also, this method improves the examination of answers by placing participants' statements within the perspective of previous studies. When connecting these insights to wider theoretical ideas, thematic analysis reveals where academic research is lacking, points out what's new, and shares new views with colleagues. Moreover, thematic analysis presents research findings in an organized manner which enables both scholars and industry players to comprehend how the study can be put into practice. Thanks to its approach, data analysis results in sound recommendations used for both developing policies and making important decisions (Vaismoradi et al., 2013; Nowell et al., 2017).

3.3.2.4 Instrumentation and Operationalization of Constructs

The research will be based on semi-structured questionnaire to examine a variety of topics that are relevant to the use of technology in the Indian HVAC industry. The participants will be asked about their opinions on latest technological trends, what major problems

companies meet when trying to adopt new technologies, the difficulties they meet in using them, possible solutions or tests they perform to address problems, and their perspectives on making technology adoption widespread among similar companies.

This first construct examines stakeholders' views and understanding of evolving technologies in the HVAC industry, such as using advanced production, technology that relies on data such as AI, IoT, or big data, and the switch to energy-saving and smart HVAC systems. The second concept, Barriers to Technological Adoption, means the internal and external reasons that prevent the adoption of technology. Such problems are found in little financing, not enough skilled employees, weak items, employees' unwillingness to accept change, and insufficient infrastructure.

The third construct looks at the obstacles that crop up when implementing new technologies. Some challenges include staff training, merging of system functions with old processes, doubt about getting a return on the company's investment, and doubt about strategic impacts in the future. The fourth construct looks at the active measures businesses may adopt to handle the issues they face. Some of these steps are upgrading employee skills, following a budget plan including searching for support from the government or outside sources, joining research and development collaborations, and using public resources to obtain certificates affordably.

In the end, Recommendations for the Industry provide suggestions that support technological improvement on a large scale. Such support could consist of fostering healthy startup ecosystems with the help of businesses and governments, setting up ways for information exchange through groups or communities, and allowing for subsidies, less taxation, and investments from the government. All of these form specific guidelines for the interview questions and analysis of information, guaranteeing that the findings match the goals of Research Question 2.

3.3.3 Data Analysis Plan

RQ2 concentrated on the study of the strategies to overcome technological adoption barriers; as such, the qualitative data were analysed using the thematic analysis approach. This method allowed for flexibility and was especially well-suited to finding patterns and deriving meaningful insights from the data (Braun & Clarke, 2006; Nowell et al., 2017). The aim of the analysis was not to support existing theories, but to discover new and emergent understandings from the perspective of the participants, and therefore, thematic analysis was the most suitable method of analysis for the research.

The qualitative data were organised and coded via NVivo 14 software that is widely known as efficient tool for managing unstructured and semi-structured datasets and to carry out systematic qualitative analysis (Woolf & Silver, 2018). NVivo's tools supported the identification of core ideas, organisation of data and visualisation of conceptual relationships consistent with the goals of this research.

The use of NVivo facilitated the process of themed analysis because it allowed for the responses from participants to be categorised into major and minor themes. Through the Node feature, related codes were aggregated into meaningful categories such as cost related barriers, strategic implementation challenges and influence of external incentives. This classification allowed for the identification of repeating patterns and relationships of the data. Ultimately, this approach supported a holistic response addressing Research Question 2 with convergent and divergent perspectives of the participants and a nuanced understanding of efforts to overcome the barriers associated with adopting technology.

Based on the methodological structure presented since Naeem et al (2023), a systematic six-step thematic analysis was carried out. First, audio recordings of all interviews were transcribed verbatim (to provide an accurate account of participant accounts). Second,

initial coding was done through the assignment of labels to text segments associated with barriers, challenges, and strategic responses. Third, codes were grouped into larger thematic groupings that were similar to participants. Finally, themes were being interpreted and conceptualized to come up with the insights about the significant obstacles and the strategies practiced by Indian HVAC firms in technological adoption. This process culminated in the elaboration of a conceptual framework that describes savings processes in organizations in order to overcome barriers and achieve successful strategies for modernization in the HVAC industry.

3.3.4 Threats to Validity

3.3.4.1 External Validity

By concentrating on the industrially important regions such as Maharashtra and Gujarat, the study captures important information that could represent the landscape of technological adoption in other such similar regions as well. Although the results are not intended for the Indian HVAC sector as a whole, they provide significant pieces of information that can be enhanced and elaborated on by venturing into different areas.

3.3.4.2 Internal Validity

The study will aim at ensuring credibility in qualitative research through some processes, for example, checking the accuracy of interview questions and information with respondents, checking the results from different angles, organizing interview process carefully. Participants will be able to review their transcripts and make sure that the information included by them is right during the interview. Member checking refers to the opportunity offered to the respondents to reflect on the findings and ensure that their reactions and ideas are appropriately displayed in the research (Birt et al., 2016). To enhance the level of how reliable the findings are, triangulation is carried out by checking information from various participants and sources. This method of data gathering

emphasizes some trends and topics in commonalities which in turn makes the results obtained more convincing with the usage of multiple opinions (Patton, 1999; Denzin, 2012).

Questions during the interview will be made neutral and open so that everyone can express their opinion without being influenced and guided by specific questions. This way of interviewing makes sure that people give honest answers, and collects valuable and important data (Castillo-Montoya, 2016). The study takes these efforts that assure that the findings created about the barrier and strategies in the adaptation of HVV technology are credible, equal to the truth, and not affected by influencing factors.

3.3.4.3 Construct Validity

To make sure the questions are proper and effective, they will be written by experts and professionally tested. At first, a team of skilled experts in HVAC technology will make and review the planned questions. Experienced senior engineers, managers, or consultants from the industry will give helpful comments on how understandable and important each question is. They will determine if the survey reviews essential topics including obstacles such as expenses and staff qualification, and does not influence the results. As a result of review, the questions are designed to encourage sincere and useful replies that match the aims of the research project. Ensuring this will help the interviewers understand major issues in technology, and accurately mention them during conversational parts.

3.3.4.4 Ethical Procedure

All participants will be told in detail about the research and how their information will be processed. All information about the participants will be safeguarded since their identities will be anonymized. Following this approach, the study remains ethical, and those involved are treated with respect and their rights are protected.

3.4 Conclusion

This chapter presented the methodological framework followed for studying the impact of technological upgradation and digitalization on export competitiveness of Indian Heating, Ventilation and Air Conditioning (HVAC) industry. The methodology of the research design was designed in such a way that it provides the study with some measure of methodological rigor and analytical depth, afforded by the research objectives and questions of the research.

A mixed method of approach was adopted to answer Research Question One to include the quantitative analysis of historical secondary data and a qualitative interpretation through interactions with industry stakeholder. The quantitative phase based on the panel data from internationally recognized sources to examine the macro level against the technological advancement, digital infrastructure, and export competitiveness and time. This was supplemented with qualitative interviews, which provided firm level explanation and understanding into the context of how technologies and digital initiatives were affecting export performance in the industry. That the two phases were combined this allowed for triangulation, and added strength to the validity of the findings.

Research Question Two has been answered by qualitative research design with the key concern on identifying the main barriers in adopting technology and mitigation measures to overcome them in HVAC sector in India. Semi structured interviews with some of the stakeholders in the industry enabled in depth examination of the role of the organisational, financial, human resource and structural factors in the adoption and modernization of technology.

Appropriate sampling techniques, data collection procedures and data analysis tools were used in respect to both research questions. Panel data regression techniques and diagnostic testing were the quantitative analysis methods and thematism along with NVivo software

for qualitative interpretation. Ethical considerations were taken carefully throughout the research process, in terms of maintaining confidentiality, informed consent and the responsible handling of data.

CHAPTER IV:

RESULTS

4.1 Introduction

This chapter shows and interprets the empirical results that are obtained from both quantitative as well as qualitative phases of this research on the overarching research objective of understanding the effect of technological upgradation as well as digitalization on export competitiveness in Indian on Heating, Ventilation and Air Conditioning (HVAC) industry by addressing the research issues discussed in Chapter 1 and Chapter 2. The analysis is based on the mixed methods research design outlined in the preceding methodology chapter, combining the econometric modelling and the thematic interpretation in order to capture where trends can be measured and where there are understandings of context.

The results are organized according to the two main research questions for this study are:

1. Will technological upgradation and digitalization affect the export competitiveness of the HVAC industry in India?
2. What strategies can be developed to promote technological adoption in the Indian HVAC industry by identifying key barriers and challenges?

The first section (RQ1) brings together and combines quantitative and qualitative results and presents an integrated evaluation of the contribution of technological sophistication, digital infrastructure and innovation practices on improving export performance. The quantitative part uses panel data regression analysis assisted with diagnostic testing to find the most suitable econometric model for robust and reliable estimation. The qualitative

component, using the six phase thematic analysis approach of Braun and Clarke (2006) complements these statistical findings in order to gather insights from study participants in the industry, to illustrate patterns, perceptions, and strategic practices that help comprehend a technological transformation.

The second section (RQ2) is a qualitative only analysis, that is addressed by financial, organizational as well as the structural factors as well, which give or improve technology adoptions and modernization in the sector. Used NVivo 14 in data management and coding, we can see the theme key, including modification of the modernization, development of the workforce skills, competitiveness, organization barriers, capacity to innovate and advanced system integration.

4.2 Study Results for Research Question One

4.2.1 Quantitative Analysis

To inspect the effect of technological upgradation and the digitalization over export competitiveness in the India's HVAC industry, panel regression data analysis was performed. The panel structure of the data, comprising both regional and temporal dimensions, allows for the examination of variations across different regions while also capturing changes over time. This method provides a more comprehensive and statistically reliable estimation by accounting for unobserved heterogeneity that may influence export performance but remains constant within each region. As emphasized by Baltagi (2005) and Wooldridge (2010), panel regression techniques minimize omitted variable bias and enhance estimation efficiency, making them particularly suitable for analyzing regional competitiveness dynamics.

To determine the most appropriate panel data specification, three regression models Pooled OLS (POLS), Fixed Effects (FEM), and Random Effects (REM) were estimated and

compared through diagnostic testing. The Pooled OLS model served as the baseline estimation, assuming homogeneity across regions. However, the Breusch Pagan Lagrange Multiplier (BP LM) test produced the p value of 0.0000, that is less than the 0.05 threshold, confirming the existence of significant panel effects. This result implies that variations across regions are not random noise but contain meaningful structural information, rendering the simple pooled model unsuitable.

Following this, the Hausman specification test was done to see whether the Fixed Effects Model the (FEM) or the Random Effects Model the (REM) would provide the most consistent and efficient estimates. The test showed a p value of 0.9555, well above the conventional 0.05 significance level. This result indicates that there is no systematic correlation between the unobserved regional effects and the explanatory variables, confirming that the Random Effects Model the (REM) is the suitable specification for this dataset. In other words, while regional characteristics do influence export competitiveness, these influences are random rather than correlated with the technological or digital indicators included in the model.

The results of the three models are shown in Table 1, which presents the comparative coefficients and goodness of fit statistics. The constant term remained positive and statistically significant across all models, suggesting a stable baseline level of export competitiveness in the HVAC sector. The coefficient for technological exports (X2) was consistently positive highly significant in all estimations 0.2471 (p=0.000) for the Pooled OLS, 0.3209 (p=0.000) for the Fixed Effects, and 0.3186 (p=0.000) for the Random Effects model (REM). These results collectively demonstrate a strong and statistically robust relationship between technological upgradation and export competitiveness, confirming that regions with higher levels of technological sophistication experience superior export performance.

Conversely, the coefficient for broadband count (X1), which served as a proxy for digital infrastructure, remained statistically insignificant in all three models ($p > 0.9$). This suggests that digital infrastructure alone does not directly enhance export competitiveness unless complemented by strategic technological adoption and integration. The improvement in R squared values, from 0.088 in the Pooled OLS to 0.148 in the Random Effects model, further indicates that accounting for regional level effects increases the explanatory power of the regression. Additionally, the Durbin Watson statistic improved from 0.088 to 0.501, suggesting that autocorrelation issues were reduced once the panel structure was appropriately modeled.

The Random Effects Model (REM), identified as the most suitable specification based on the diagnostic tests, shows that a 1% increase in technological exports corresponds to approximately a 0.32% increase in export competitiveness (as a share of GDP). The model's F statistic (39.17, $p < 0.001$) confirms its overall statistical significance, implying that technological and digital indicators jointly explain a meaningful proportion of the variance in export performance across Indian regions and over time. For clarification, the part of the REM results was previously reported in Pol and Hara (2025, p.211). The present dissertation extends the analysis by additionally reporting POLS and FEM estimations for completeness and robustness comparison.

Table 1: Combined Findings of Test applied

Variable / Statistic	Pooled OLS	Fixed Effects (FEM)	Random Effects (REM)	Interpretation
C (Constant)	25.2694 (p=0.000)	23.1457 (p=0.000)*	22.9616 (p=0.000)*	Baseline export competitiveness remains consistently positive across all models.
X1 – Broadband Count	5.25E 09 (p=0.976)	8.41E 09 (p=0.941)	1.03E 08 (p=0.928)	Insignificant in all models broadband infrastructure alone does not significantly impact export competitiveness.
X2 – Technology Exports	0.2471 (p=0.000)*	0.3209 (p=0.000)*	0.3186 (p=0.000)*	Strong positive and statistically significant relationship across all models technological upgradation consistently enhances export competitiveness.
R squared	0.088	0.143	0.148	Model fit improves from Pooled OLS → FEM → REM, suggesting the inclusion of panel effects strengthens explanatory power.
Adjusted R squared	0.084	0.139	0.144	Indicates better model efficiency when panel effects are considered.
F statistic (Prob.)	21.83 (0.000)*	32.57 (0.000)*	39.17 (0.000)*	All models statistically significant, confirming reliable explanatory power.
Durbin Watson Statistic	0.088	0.421	0.501	Autocorrelation reduces when using panel models, confirming improved specification.
Model Selection Tests		BP LM (p=0.000) → panel effects exist	Hausman (p=0.9555) → REM preferred	Diagnostic testing confirms REM as the most efficient model.

Note: REM results were partially reported in Pol & Hara (2025, p.211).

Source: Author's own analysis using E Views.

Based on the diagnostic outcomes, the Random Effects Model (REM) is identified as the most proper specification for this analysis. The Breusch Pagan Lagrange Multiplier (LM) test confirmed the existence of significant panel effects ($p < 0.05$), indicating that the pooled OLS model is not that suitable for this dataset. Subsequently, the Hausman test shows a non significant p value ($p = 0.9555$), suggesting that the unobserved regional effects are not looking correlated with the explanatory variables. This result validates the assumption underlying the Random Effects framework and supports its selection as the final model. The REM thus provides the most consistent and efficient estimates, capturing both within region and between region variations in export competitiveness. The final estimation confirms that technological upgradation, represented by technology exports, has a strong and statistically significant positive impact on export competitiveness, while digitalization (broadband count) remains statistically insignificant. These findings establish the Random Effects Model as the most robust and reliable representation of the quantitative relationships examined in this study.

4.2.2 Qualitative Analysis

The data was analyzed using Braun and Clarke's (2006) six phase thematic analysis, which is an effective approach for detecting, interpreting, and reporting patterns (themes) within qualitative data. NVivo was used for efficient management and coding of the data. This approach allowed for automated coding to handle the complexity of the dataset while maintaining an in depth analysis of recurring themes and patterns.

Qualitative Analysis Steps

In the initial stage, all responses were organized and reviewed repeatedly to gain a clear understanding of participants' perspectives and to identify recurring ideas linked to technology, digital practices, and export competitiveness.

Initial codes were then generated using NVivo 14 to systematically capture key concepts emerging from the data, such as technological advancement, digital integration, product quality, and innovation impact. These codes were refined through manual review to ensure contextual accuracy.

Related codes were grouped and clustered to form higher level sub themes, allowing patterns and relationships within the data to emerge in alignment with Research Question One.

The sub themes were further reviewed, refined, and consolidated to ensure internal consistency and clear differentiation, resulting in four overarching themes that reflect the core qualitative findings.

Finally, the themes were interpreted and synthesized to explain how technological upgradation and digitalization contribute to export competitiveness, and these insights were integrated with the quantitative results to support triangulation and strengthen the overall analysis.

The qualitative analysis was conducted to explain and contextualize the quantitative findings by examining how technological upgradation and digitalization are experienced and enacted within firms in the Indian HVAC industry. The analysis focused on identifying recurring patterns in participants' accounts that explain mechanisms of competitiveness, rather than detailing procedural steps.

Using thematic analysis, four dominant themes emerged for RQ1. These themes capture how firms translate technological and digital investments into export oriented capabilities and sustained market competitiveness.

Table 2: Main Theme Description

Serial No.	Main Theme	Description
1	Technological Advancement and Innovation	This theme reflects the ongoing modernization in engineering, design, and manufacturing processes through advanced automation, energy efficient systems, and product innovation.
2	Digital Transformation and Export Performance	Focuses on how digital tools, platforms, and data driven systems contribute to enhanced process transparency, operational efficiency, and global reach.
3	Product Excellence and Competitiveness	Highlights the HVAC industry's emphasis on developing high quality, compliant, and energy efficient products that meet international standards.
4	Innovation Effect and Industry Impact	Focuses on the perceived impact of technological and digital innovations on business growth, energy efficiency, and environmental compliance.

Source: Author's own analysis using NVivo 14.

Theme 1: Technological Advancement and Innovation

Participants consistently reiterated that technological modernization was a basic contributor to export competitiveness. Firms reported to be adopting advanced automation, energy efficient systems, as well as to upgrade manufacturing technologies to achieve better productivity and reliability and to meet international standards. These improvements

were seen as critical to achieving international standards of performance rather than optional operation improvements.

Respondents stressed that investments into advanced refrigeration technology, automation and engineering solutions allowed companies to decrease defective products, increase consistency and produce on scale to export markets. Technological upgradation was thus considered a strategic capability strengthening the firms' preparedness to compete in the international market and accommodate changes in the demands of the market.

Theme 2: Digital Transformation and Export Performance

Digital transformation was born as an important enabler alongside technological advancement. Participants presented of the utilization of digital design tools, modelling platforms, digital twins and collaborative systems, in order to increase coordination, transparency and responsiveness in export operations. Digital tools made it possible to perform faster design work iterations, as well as more customized and effective communication with overseas clients.

Respondents further added that digital integration helped to enhance credibility amongst international buyers by permitting traceability, documentation, and visibility for real time projects. As a result, digitalization had a direct impact on exports because by strengthening the trust of clients, the lead times were reduced and an alignment with the global procurement practices was improved.

Theme 3: Product Excellence and Market Competitiveness

A strong accent was put on the quality of products as a point of export success. Participants linked technology and digital investments to betterments in energy efficiency, durability, compliance with regulations and performance in the product. These attributes were

determined to be decisive factors in competing with established global HVAC manufacturers.

Firms that used powerful manufacturing processes and digital quality monitoring accumulations said they found better positioning in the market and repeat export orders. Product excellence was thus not considered to be the result of isolated enhancements, but rather cumulative integrating technological and digital capacities.

Theme 4: Innovation Effect and Industry Impact

Participants perceived the impacts of technological and digital innovation to be more at the organizational and industry level. Firms were able to report measurable improvements in operational efficiency, sustainability performance and competitiveness over the long-term. Innovation was also associated with greater adaptability, so that firms are better able to respond to changing environmental regulations and international standards.

This theme emphasizes the fact that innovation impacts were beyond the immediate export impacts and contributed to the overall modernization and resilience of the Indian HVAC industry. Technological progress and digital transformation were viewed as enabling factors for both growth at the firm level and competitiveness on a sector wide basis.

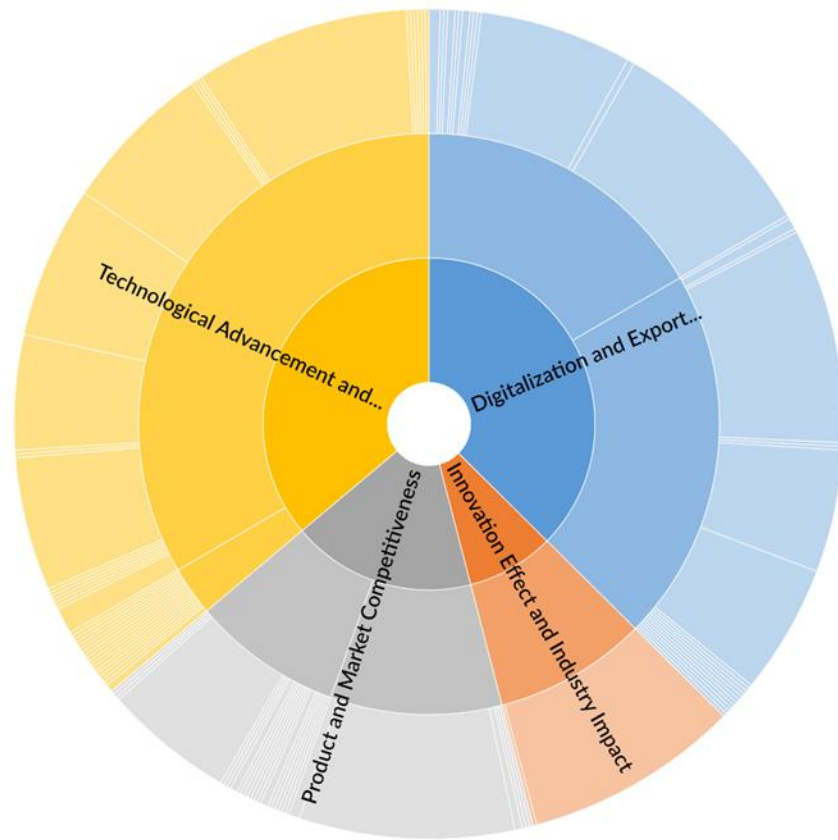


Figure 13: Thematic Map for RQ1
Source: Author's own analysis by using NVivo 14

Triangulated Interpretation

The RQ1 shows clear convergence between the quantitative and qualitative strands on how technological upgradation as well as digitalization shape export competitiveness in the India's HVAC sector. The Random Effects Model, selected through the Breusch Pagan and Hausman tests, demonstrates that economies with higher levels of technological sophistication and stronger digital infrastructure achieve superior export performance, indicating a positive macro level association between innovation capacity and competitiveness. This statistical pattern aligns with the qualitative themes extracted through NVivo, where industry stakeholders describe technological advancement, product innovation, and energy efficient engineering as central drivers of export readiness, and

digital tools, modelling platforms, and collaborative systems as essential for transparency, coordination, and client engagement in international markets. Interview responses reinforce that consistent product quality, compliant design, and the use of advanced digital processes strengthen a firm's credibility in global markets, mirroring the quantitative finding that technology intensive and digitally enabled environments support export growth. Together, both datasets reflect a shared narrative: technological progress and digital transformation operate as interconnected forces that reinforce product excellence, operational capability, and global competitiveness within the HVAC industry, and the statistical relationships observed at the country level are expressed in the lived experiences and operational realities described by industry participants.

4.2.3. Summary of the Study Results for RQ1

RQ1 examined whether technological upgradation and the digitalization influence the export competitiveness of the India's HVAC industry. The findings from the quantitative and qualitative analyses jointly provide clear and convergent evidence that technological advancement and digital transformation play a decisive role in strengthening export performance.

The quantitative analysis, based on panel data regression, demonstrates a statistically significant positive relationship between technological sophistication, digital infrastructure, and export competitiveness. Diagnostic testing confirmed the suitability of the Random Effects Model, indicating that regional and temporal variations in technology adoption and digital capability systematically influence export outcomes. Regions with higher levels of technological upgradation and stronger digital ecosystems exhibit superior export performance, suggesting that innovation capacity operates as a structural driver of competitiveness rather than a firm specific anomaly.

The qualitative analysis deepens this statistical insight by explaining how firms operationalize technological advancement to achieve export readiness. Participants consistently emphasized modernization of manufacturing processes, adoption of energy efficient systems, and integration of advanced automation as critical enablers of productivity, quality enhancement, and compliance with international standards. These technological investments were perceived not only as efficiency improvements but as strategic necessities for sustaining presence in global HVAC markets.

Digital transformation emerged as a complementary and reinforcing mechanism. Respondents highlighted the use of digital design tools, modelling platforms, digital twins, and collaborative systems to enhance process transparency, coordination with international clients, and responsiveness to export market requirements. Digitalization enabled firms to shorten design cycles, improve customization, and strengthen credibility with overseas buyers, thereby directly contributing to export growth and market expansion.

Product excellence and market competitiveness formed a third critical dimension of the findings. Technological innovation translated into improved product reliability, energy efficiency, and regulatory compliance, which participants identified as essential for competing against established global manufacturers. Firms that combined advanced production technologies with digital quality control and monitoring systems reported stronger export positioning and long term competitiveness.

The integration of quantitative and qualitative results reveals a coherent narrative. The statistical association identified through the Random Effects Model is reflected in firm level experiences, where technological upgradation and digitalization jointly enhance operational capability, product quality, and international market acceptance. These findings confirm that export competitiveness in the Indian HVAC industry is not driven by

isolated technological investments but by an interconnected system of technological advancement, digital integration, and innovation oriented practices.

Overall, the results provide a clear answer to Research Question One. Technological upgradation and digital transformation significantly influence export competitiveness by strengthening productivity, enabling compliance with global standards, improving product excellence, and enhancing firms' ability to engage effectively in international markets (Pol & Hara, 2025, pp. 200–216). This convergence of evidence reinforces the study's conceptual framework and establishes technological and digital capabilities as foundational drivers of sustained export performance in the Indian HVAC sector.

4.3 Study Results for Research Question2 (RQ2)

Research Question 2 aims to examine the major enablers and barriers associated with the technological upgradation as well as the digital transformation of the India's HVAC industry. The findings from qualitative analysis are presented thematically to show why firms are different in their ability to take up advanced technologies and maintain competitiveness. Six themes that are interrelated emerged which point to the interplay between the human capital, modernization efforts, organizational readiness, and the structural constraints.

4.3.1 Qualitative Results

Table 3: Main Theme, Sub Theme and Sub Codes

Main Theme	Sub Themes	Sub codes
1. Technological Advancement and Modernization	Upgrades, Technology	Time upgrade, Technology upgrades, Process upgrades, Upcoming technologies, Technological transformation, Energy efficient technologies, Emerging technologies, Eco friendly technologies, Modernization technologies, best in class technology
2. Skilled Workforce and Human Resource Development	Skilled	Skills gap, Skills development program, Skilled workforce impact, Skilled professionals, Skilled manpower, Skill training, Right skills
3. Competitiveness and Market Edge	Competitiveness	Manufacturing competitiveness, Long term competitiveness, international competitiveness, Global competitiveness, Export competitiveness, Competitive word product improvement, Competitive edge
4. Organizational Barriers and Structural Challenges	Challenges, Barriers	Significant challenge, Ongoing challenge, Infrastructure challenges, financial challenges, Complex challenges, Significant barrier, Primary barriers, Key barriers, Critical barrier
5. Technological Adoption and Innovation Capacity	Adoption	Technology adoption grants, Successful technology adoption, Making adoption, Adoption rates, Adoption gap
6. Advanced Tools and System Integration	Advanced	Advanced testing setups, Advanced tools, Advanced manufacturing, Advanced systems, Advanced control strategies, Advanced materials, Advanced components, Advanced design software, Advanced energy efficient, Advanced practices

Source: Author's own analysis using NVivo 14.

Theme 1: Technological Advancement and Modernization

Participants characterised continuous efforts towards technological modernisation as a necessary response to growing global level competition and regulation. Firms reported their practices of upgrading production processes, adoption of energy efficient and eco-friendly technology, and bring their operations to international best practices. However, modernization in the sector was uneven and large and resource rich firms accelerated ahead of the smaller players.

Respondents put greater emphasis on the fact that technology upgrades were often incremental rather than transformative because of budget constraints and riskiness. While the intention of modernization was salutary and pervasive, enduring technological modernization required long term investment planning and strategic prioritization.

Theme 2: Skilled Workforce and Human Resource Development

The access to skilled manpower became an important factor in the success of technology adoption. A central limitation to work had been consistently pointed out by participants, and this was skill gaps especially in using advanced systems, digital tools, and automated manufacturing configurations. Firms where structured training programs and skill development were being done throughout saw an easy adaptation with new technology.

Respondents emphasized the need for technological investments to be accompanied by workforce development, in order to ensure the systems are being utilized properly and they provide greater returns. Human capital was thus seen as a basic capability that had a direct impact on innovation results and competitiveness.

Theme 3: Competitiveness and Market Edge

Technological adoption was closely related to capability of firms to improve competitiveness in both domestic and international markets. Participants observed that modernization led to improved efficiency in production, product quality, and cost control, which helped firms be better competitive with global HVAC manufacturers.

Export oriented firms perceived that technological integration contributed to their positioning in the market regarding compliance, reliability and the response to client requirements. Competitiveness was therefore seen as a result of the cumulative impact of technological, digital and organizational capabilities and not single improvements.

Theme 4: Organizational Barriers and Structural Challenges

Despite intensive motivation to modernize, there were severe organizational and structural barriers for the firms. Financial constraints, poor infrastructure, and rigidities in the operation mode were repeatedly found to be major bottlenecks to technological diffusion. Smaller firms were especially vulnerable because of their limited access to capital and other external support mechanisms.

Participants also noted regulatory uncertainty and lack of coordination among members of the government in regulating them as causes for slow adoption. These barriers led to inequalities in the outcomes of modernization in the sector and perpetuated existing disparity in competition.

Theme 5: Technological Adoption and Innovation Capacity

This theme corresponds to the differences in the readiness and the ability of firms to embrace new technologies. Participants emphasized that the role of leadership commitment, organizational mindset and access to funding played decisive roles in

determining the success of adoption. Firms that had strong leadership and strategic vision showed greater rates of adoption and stronger capacity to innovate.

And support mechanisms such as technology adoption grants and external partnerships were considered to be important enablers, especially for firms moving from traditional to advanced systems. Innovation capacity was therefore shaped by an orientation on the one hand, but also by support structures from the outside.

Theme 6: Advanced Tools and System Integration

The utilization of advanced tools and integrated systems became the indicator of a higher technological maturity. Participants described the adoption of advanced testing facilities, designing software, control systems, as well as energy efficient technologies as an essential part to improve technical actions such as accuracy, quality assurance, and international standards compliance.

Firms that achieved good system integration were mentioned to have chances of better operation control and addition of credibility in export. Advanced tools were thus perceived to be factors of both efficiency and differentiation in global markets.

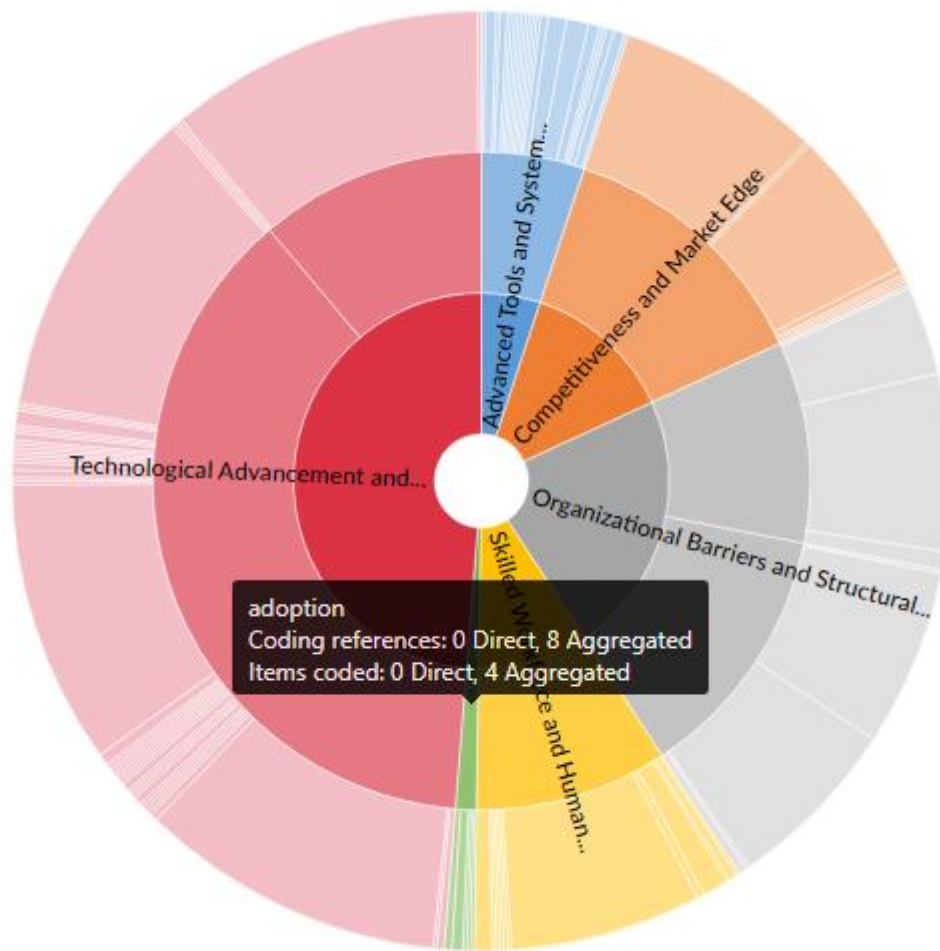


Figure 14: Thematic Map for RQ2
Source: Author's own analysis by using NVivo 14

4.3.2 Summary of the Study Results of RQ2

Research Question 2 examined the key enablers and barriers influencing technological upgradation and digital transformation in the Indian HVAC industry. The qualitative analysis identified six interrelated themes that explain why firms differ in their ability to adopt advanced technologies and sustain competitiveness. For analytical clarity, these six themes were synthesized into four higher order integrative meta themes that capture the underlying mechanisms shaping adoption outcomes.

The first theme, Technological Advancement and Modernization, highlights firms' efforts to upgrade production processes, adopt energy efficient and ecofriendly technologies, and align operations with international standards. While modernization was widely recognized as essential, its implementation varied across firms. Larger and export oriented firms progressed more rapidly, whereas smaller firms adopted incremental upgrades due to financial constraints and risk aversion.

The second theme, Advanced Tools and System Integration, reflects the role of advanced testing facilities, manufacturing systems, design software, and integrated control technologies in achieving higher technological maturity. Firms that successfully integrated advanced tools reported improved operational control, quality assurance, and export credibility, distinguishing them from firms with fragmented or partial adoption.

The third theme, Skilled Workforce and Human Resource Development, underscores the importance of human capital in enabling effective technology adoption. Skill gaps in operating advanced systems and digital tools were widely reported. Firms investing in structured training and continuous skill development achieved smoother adoption and higher utilization of technological investments, positioning workforce capability as a critical enabler.

The fourth theme, Organizational Barriers and Structural Challenges, captures financial constraints, infrastructure limitations, and regulatory uncertainty that slow technology diffusion. Smaller firms were particularly affected by limited access to capital and support mechanisms. These constraints created uneven adoption trajectories across the sector and reinforced competitiveness gaps.

The fifth theme, Technological Adoption and Innovation Capacity, reflects differences in leadership commitment, organizational mindset, and access to funding or adoption support

mechanisms. Firms with proactive leadership and innovation oriented strategies demonstrated higher adoption rates and stronger capability development.

The sixth theme, Competitiveness and Market Edge, links technological adoption to improvements in productivity, product quality, compliance, and export performance. Firms that integrated technology with strategic intent reported stronger domestic and international market positioning.

Overall, the outcome shows that the uptake of technological upgradation and digital transformation in the Indian HVAC industry is influenced by an interhemispheric system by six thematic drivers operating through four integrative dimensions. Successful adoption hinges on the alignment of modernity capability, skilled human resources, organizational readiness and innovation oriented leadership. Firms that manage to achieve this alignment flush have a stronger competitiveness and export performance at firms that are constrained by skill shortages and structural barriers have a slower transformation and weaker market outcome.

Synthesizing and Connecting to the Research Framework

Taken together, the findings for RQ2 show that technological upgradation and digital transformation do not face constraints from lack of awareness, but differences in organizational capacity and structural readiness. Modernization efforts are successful with sufficient backing from skilled human resources, leadership commitment, and enough financial and infrastructural support. On the other hand, firms facing limited ability and structural barriers have a slower adoption speed and less effective competitive performance.

These results are consistent with the conceptual framework of this study that places technological capability, human capital and organizational readiness as interdependent factors in competitiveness. The qualitative evidence lays out the mechanism of operation

of barriers and enablers in detail and helps understand why under similar market pressures, different firms can show different adoption trajectories. Overall, the data proves that any sustained technological transformation of the Indian HVAC industry needs an integrated approach of the technology, people, and organisational support systems.

4.4 Cross Insights between RQ1 and RQ2

This section integrates the findings of Research Questions 1 and 2 to explain how and why technological upgradation and the digital transformation translate into export competitiveness in the Indian HVAC industry. While RQ1 established a statistically positive relationship between technology, digitalization, and export performance, RQ2 provides the underlying organizational and human mechanisms that explain this relationship.

The quantitative results of RQ1 demonstrate that regions with higher levels of technological sophistication and stronger digital infrastructure achieve superior export outcomes. However, regression results alone do not explain variation in performance among firms operating within similar technological environments. The qualitative findings from RQ2 address this gap by revealing that technology does not operate in isolation, but through mediating organizational conditions that determine whether technological investments are effectively absorbed and translated into competitive advantage.

One critical mediating mechanism identified in RQ2 is human capital readiness. Although technological upgradation and digital tools enhance productivity and export capability at the macro level, firms lacking skilled manpower struggle to fully utilize advanced systems. Skill gaps, limited training, and insufficient digital literacy reduce the effectiveness of automation, advanced manufacturing, and digital platforms. In contrast, firms that invested in structured skill development and continuous training were able to operationalize

technological upgrades more effectively, thereby aligning firm level practices with the positive export outcomes observed in the quantitative analysis. This indicates that human capital acts as a transmission channel through which technological investments influence export competitiveness.

A second key mediating mechanism is organizational readiness and structural capacity. RQ2 highlights that financial constraints, infrastructure limitations, leadership commitment, and policy uncertainty significantly shape firms' ability to adopt and sustain technological transformation. Even in regions where digital infrastructure and technological availability are relatively strong, firms facing capital constraints or weak organizational support experience slower adoption and weaker performance outcomes. This explains why the positive relationship identified in RQ1 is not uniform across all firms and regions. Organizational readiness therefore moderates the strength of the technology export competitiveness link identified in the panel data analysis.

RQ2 also clarifies how technological adoption capacity and system integration influence competitive outcomes. Firms that combined leadership support, access to adoption mechanisms, and advanced system integration were able to convert technological upgrades into improvements in product quality, compliance, and export credibility. These firm level capabilities provide the micro level explanation for the macro level export performance patterns identified in RQ1.

Taken together, the cross insights from RQ1 and RQ2 show that technological upgradation and digitalization influence export competitiveness through an interconnected system involving technology, people, and organizational structures. While RQ1 confirms the existence of a positive and significant relationship between technology and export performance, RQ2 explains that this relationship is mediated by human capital development and organizational readiness. Export competitiveness in the Indian HVAC

industry therefore depends not only on access to advanced technologies and digital infrastructure, but on firms' internal capacity to absorb, integrate, and strategically deploy these technologies.

4.5 Chapter Summary

This chapter presented and interpreted the empirical results obtained from both the quantitative and qualitative phases of the study addressing the following two central research questions formulated to study the transformative role of technological upgradation and digitalization in boosting export competitiveness in Indian HVAC industry. The synergy between the analysis of both analytical streams yielded a complex and multidimensional view of the evolving competitive scenario in the industry.

The quantitative analysis, which was based on panel data regression, determined statistically significant positive relationship between technological sophistication, digital infrastructure and export performance. Diagnostic testing by the Breusch Pagan Lagrange Multiplier test and Hausman tests confirmed the most suitable specification of the Random Effects Model (REM) for the data set. The identification of areas and companies with a greater degree of technological development and digital maturity in their processes shows that the capacity to innovate plays a crucial role in the degree of competitiveness in international markets, confirming the importance of the capacity to innovate to the progress of the industrial process.

The qualitative analysis, which was accomplished by Braun and Clarke's (2006) six phase thematic framework supported by NVivo 14 software, added context to this quantitative analysis results. Thematic exploration identified very strategic dimensions like Technological Advancement and Innovation, Digital Transformation and Export Performance, Product and Market Competitiveness, Innovation effect & impact on

Industry. These themes proved the way technological modernization, digital adoption, improvement in product quality altogether boost India's position in an international HVAC market.

The second research question, which was only answered in the qualitative analysis, saw some key enablers and barriers identified with respect to the ability of industry to adopt and sustain technological and digital transformation. Six major themes were thrown up, namely Technological Advancement and Modernization, Skilled Work Force and Human Resource Development, Competitiveness and Market Edge, Organizational Barriers and Structural Challenges, Technological Adoptions and Capacity for Innovation, Advanced Tools and System Integration. On the whole, these themes highlighted the importance of human capital, organizational readiness and financial stability as critical factors in successful technological change.

Overall, the results in both research questions converge in a way that brings out the idea that technological upgradation and digitalization are not standalone developments but part of a wider ecosystem that brings people, processes, and infrastructure together. It is firms that embrace digital tools, sophisticated manufacturing systems and skill development schemes that demonstrate superior competitiveness and those which are handicapped by financial and infrastructural constraints lag behind.

CHAPTER V: DISCUSSION

5.1 Interpretation of Findings

This study aimed to identify the effect of technological upgradation and the digitalization on the export competitiveness in the Heating, Ventilation, and the Air Conditioning (HVAC) industry of India and to look for different enablers and barriers that control the technological transformation of the elite industry. With data presented from quantitative analyses and qualitative contexts, the results give a clear picture of the interaction of these forces for driving competitiveness, innovation and performing outcomes in an emerging industrial scenario.

The mixed methods approach provided both macro level empirical evidence and micro level contextual information. The quantitative analysis, conducted on a quantitative model using the panel data regression model, asserted a significant and strong relationship between technological upgradation and export competitiveness, which proved that technological sophistication is a major factor determining India's performance in exports of HVAC. Conversely, it was evident that the digital infrastructure on its own did not statistically significantly impact and suggests that the contribution of digitalization to competitiveness is dependent on how effectively digitalization is embedded with broader technological and organizational capabilities.

The qualitative results, arrived at through a thematic analysis process in the trusted software NVivo supported the validity and contextualization of these statistical tendencies. Industry practitioners emphasised technological modernisation (automation, energy efficient systems and out of the box design tools) improving product quality, process reliability and the ability to adhere to international standards. Likewise, digitalization

developed as a complementary force which enhanced coordination, transparency and communication across export operations. Participants provided details on how digital platforms, digital twins, and data driven systems helped to build trust in and by the client, cut lead times and enhance global credibility.

The coherence and convergence of these two analytical strands can be seen by examining the concept of export competitiveness as a European competitiveness agenda, Technological upgradation is the main driver of export competitiveness, while digitalization is the capacity building strategy for the implementation of technological and operative effectiveness. Combination of firms that are good at both show greater innovation capability, a higher level of product excellence and greater ability to respond to international market demands.

The results also show that not every part of the industry is affected by technology and digitalization equally in terms of competitiveness. Differences in firm performance are influenced by organizational readiness, human capital capability and structural barriers including financial constraints and poor infrastructure. These mediating and moderating factors all determine whether or not technological investments are translated into export success or underutilized assets. Larger companies with superior capacities, skilled labour forces, and proactive managers had higher technological maturity and greater success in exports. Smaller firms however, often encountered problems in adopting owing to lack of capital and skills, resulting in uneven transformation in the sector.

5.1.1 Research Question 1 Interpretation

The results in addressing the first question of research study “Will technological upgradation and the digitalization effect on the export competitiveness of the India’s HVAC industry”, evidence proves very convincing to suggest that the technological and digital advancements have decisive role to play with respect to the export performance of

Indian firms operating in the business area of the HVAC industry. Both of the quantitative and qualitative results converge to the point of saying that technological upgradation represents the main factor for attaining export competitiveness while digitalization is rather an enabler, complementing efficiency, transparency and global engagement. The mixed method approach of this study shows that the effects of these variables are multidimensional as technological sophistication directly improves productivity and innovation, while digital tools increase these benefits by improving connectivity, reactivity, and integration of operations.

The quantitative analysis provides definite empirical proofs about the important role of technological upgradation. The results of the Random Effects Model showed a significant and positive relationship between technological sophistication and export competitiveness with 1% increase in technological exports resulted in 0.32% increase in export performances. This outcome proves the argument that technology driven innovation plays a major role in the global competitiveness of Indian HVAC manufacturers. The finding is in line with the Resource Based View (RBV) which suggests that a firm's ability to access, develop, and deploy valuable, rare, and inimitable resources is the source of its sustained competitive advantage. In this regard, technology resources including advanced automation, energy efficient systems, and smart control systems are strategic resources that help firms produce differentiated, high quality products that meet the expectations of global customers. The companies benefitting from such technological advancements include those operating in more mature markets such as North America, Western and Eastern Europe, and the Far East articulated about the benefits: "These technological advancements not only improve the reliability and performance of the products, but also improve the compliance with international standards which is a prerequisite to success in the export markets."

The findings also have resonance with the Dynamic Capabilities Theory which has a strong focus on a firm's ability to integrate, adapt and reconfigure the internal and external competencies according to changes in environments. In the HVAC business, where innovation and regulations are evolving at an alarming rate, the firms that are continually improving their technological foundation and processes lie ahead of the curve of those that find themselves in a difficult position. The qualitative evidence offers additional support to this interpretation because participants emphasized their ability to successfully adjust to changes in global demand for energy efficient and environmentally compliant solutions for HVAC solutions based on technological modernization actions such as automation, precision engineering, and sustainable design. Technological upgradation was seen not as an optional upgrading but as an indispensable strategic necessity to maintain competitiveness in international markets that have a pace of constant innovation coupled with a high level of criteria for performance. The firms that made the investments to implement advanced manufacturing technologies and energy optimized manufacturing systems saw real benefits in the return on their investments in terms of increased productivity, cost reduction and enhanced reputation abroad, as an example of how technological sophistication translated directly into export readiness and competitive advantage.

While upscale of technology appeared as an explicit and quantifiable factor of export competitiveness, the contribution of digitalization seemed more nuanced. Effect of Digitalisation As a proxy for digitalisation, broadband infrastructure had no statistically significant direct effect on the export performance, the quantitative results showed. However, the qualitative findings offered a more in depth understanding of this relationship. Industry respondents explained how digitalization in the form of tools like Building Information Modelling the (BIM), digital twins, applications of the Internet of

Things (IoT), and data analytics platforms greatly enhanced design precision, coordination of workflow and decision making in real time. These digital tools particularly found valuable use in export oriented operations where coordination with international partners, documentation requirements as well as quality monitoring requires a high degree of digital connectivity and transparency. Digital transformation thus has a catalytic function in reinforcing competitiveness, not via separated infrastructure, but through its integration with technology and organizations. This pattern overlaps very well with the framework of Technology Organization Environment (TOE) which argues that the benefits of technology are only realized when there is the internal readiness of organizations and support from external actors to realize these benefits. From the experience of the Indian HVAC industry, digitalization alone is not enough for both competitiveness and its value is revealed by combining the application of digital platforms through strategic integration in technologically advanced and organizationally capable organizations.

The findings can also be analysed in terms of the Innovation Diffusion Theory (IDT) and the Technology Acceptance Model (TAM) both of which give the reader a picture of why digital adoption differs from one firm to another. According to IDT, when deciding to adopt, there is a matter of perceived relative advantage, compatibility and complexity. In the current research, while companies understood the relative advantage of digital tools, many were held back by complexity of implementation and the costs to digital transformation. Similarly, according to TAM, perceived usefulness and ease of use are the very important factors that will dictate the success of digital adoption. The qualitative evidence supports this theoretical proposition i.e. those firms that perceived the potential usefulness of digital technologies in terms of improving communication, customization, and client satisfaction showed greater degree of integration and export performance while firms with low technical capacity and digital literacy lagged behind in terms of adoption.

These results point to the fact that digitalization plays a role as a reinforcing mechanism that amplifies the benefits of the technological advancement rather than as a vehicle in itself for determining competitiveness.

Another important dimension that appears from both the statistical and thematic analyses is that of the role that is played by product excellence as a mediating variable. Technological and digital developments come together in order to enhance the quality, energy efficiency and reliability of products all necessary to compete in international markets. Participants always emphasized that thanks to advanced production technologies, supported by digital quality control and predictive maintenance systems, they could comply with the growing global standards when it comes to energy efficiency and environmental sustainability. This relationship between innovation and product excellence is consistent with the Global Value Chain (GVC) Theory, which promotes the need for technological upgrading on the part of firms wishing to upgrade the value chain and position themselves in higher value added segments in international markets. Similarly this logic is reinforced by Porter's Diamond Model as it underscores the interlinked role of factor conditions, firm strategy and domestic demand conditions in defining national and firm level competitiveness. For Indian HVAC manufacturers, various investment in technological innovation and digital integration has become essential not only as a cost competitiveness tool but also as a differentiation and value creation tool in the global trade environment.

In combining these findings, it is clear that the engine behind export competitiveness is technological upgradation and the accelerator is digitalization which increases the speed, transparency, and responsiveness of the engine. Both of the elements work in synergy to produce a modern, innovation based export ecosystem. The firms that have strong technological capability, digital integration and human capital capabilities are always the

top performers in comparison with those that have fragmented or underdeveloped systems altogether. This interrelationship emphasizes the point that competitiveness is not just about acquiring advanced technologies, but about the capacity to absorb, adapt and strategically implement it in line with organisational processes and market requirements. In essence, the findings confirm that the export competitiveness in the HVAC industry of India is the result of an integrated system where technology, digitalisation, human capability, and readiness at the organisational levels interact dynamically. This conclusion is consistent with the study's conceptual framework and elevates the level of the theoretical dialogue by showing that in emerging economies, effective fusing of technological and digital capabilities represents the foundation of global sustainable competitiveness (Pol & Hara, 2025, pp. 200–216).

5.1.2 Research Question 2 Interpretation

The second research question “What strategies can be developed to promote technological adoption in Indian HVAC industry by identifying key barriers and challenges?”, attempted to examine enabling and constraining factors that drive technological upgradation and digital transformation in the industry. The results obtained in the qualitative phase of the study exceeded the purpose of this research work, as it has been found that there is a multifaceted system of drivers and barriers to overcome that despite the general recognition of the need for modernization, the speed of its adoption and success include a degree of variation in the different firms. These differences are functions of differences in organizational readiness, financial capacity, human resource competence and strategic vision and to a great extent, deviations from these differences. The interpretation of these findings highlight that technological upgradation and digital transformation does not suffer due to the lack of awareness and intent but due to the difference in the capacity to absorb and because of the organizational infrastructure and ecosystem level support.

The analysis of the qualitative data, which was carried out with the use of NVivo using the six phase thematic process proposed by Braun and Clarke, came up with six dominant themes, namely Technological Advancement and Modernization, Skilled Workforce and Human Resource Development, Competitiveness and Market Edge, Organizational Barriers and Structural Challenges, Technological Adoption and Innovation Capacity, and Advanced Tools and System Integration. When they are synthesized these themes converge to obtain four meta themes which define the condition shaping up the outcomes of adoption: modernization capability, human capital readiness, organizational support and innovation orientation. Together, these findings present a granular understanding of the ways and reasons by which Indian HVAC firms differ in terms of their capabilities to integrate advanced technologies and digital systems in their production and export processes.

The theme of technological advancement and modernization is the belief that presents a strong sectoral aspiration towards modernization, i.e. due to the pressure of global competition and regulatory requirements. Firms accepted the fact that upgrade to energy efficient and ecofriendly technologies has become a must to comply with the international standards of sustainability. However, the results also reveal that the process of modernization continues to be uneven large and resource rich firms can make sizable technological leaps, while small and medium sized enterprises (SME's) tend to make incremental changes because of capital limitations and risk aversion. These results are consistent with Technology Organization Environment (TOE) model (Tornatzky & Fleischer, 1990), which is propounding that technology adoption is influenced by the interaction between technological preparedness, organizational ability and environmental pressures. In the Indian context of HVAC, in spite of existence of advanced technologies, the small scale firms with less financial and infrastructural capacity are not able to harness

the maximum potential offered by the technologies and this asymmetry has resulted in the development of the HVAC industry varying in the Indian context. This fragmentation highlights that it is not enough to have access to technology available to all as the level of success in adoption is dependent on internal capacity to absorb and operationalize the new technologies.

A critical insight which comes through from the data is that of central importance of human capital as enabler and constraint. Participants will be accustomed to emphasize the point that technological investments matter since long since the skills of the workforce putting it to use. Many companies identified a skills gap with respect to using digital platforms, automated manufacturing systems and modern testing equipment. Companies that have structured training programs, skill development and continuous learning as part of their strategic cultural solutions, achieved smooth and high adoption and usage of new technologies. This observation has echoes in the Dynamic Capabilities Theory (Teece et al, 1997) which suggests that in order to cope with technological change firms must build, renew and re-configure their capabilities on an ongoing basis. Human resource development thus becomes a dynamic capability that assist the firms to convert technological resource into export oriented competitiveness. On the other hand, lack of technical competency among employees often meant as underutilization of new systems and no return on making a technological investment. The implication is that the skill development is not a supporting activity but a strategic lever which will decide the success or otherwise of the technology adoption.

The findings support and highlight organizational barriers and structural challenges as major inhibitors of the technological and digital transformation. Financial stress, lack of infrastructure and regulatory uncertainty were some of the most cited impediments. Smaller firms were especially affected due to lack of access to capital and other support

mechanism from the outside. These barriers correspond with the organizational and environmental components of TOE framework where decision making dimension for accepting technology depends on internal structure (leader support and financial health of the firm and managerial support and external condition (positive and negative finance, incentives policy, availability of infrastructural. Several participants identified disjointed implementation of policies and lack of consistency by the government as delaying modernization efforts. This provides support to the argument that it is not technological unavailability which is a major constraint stopping the industry from achieving a total transformation. Tackling such barriers entails coordinated approaches by the government through incentives for industries and financing mechanisms to assist them and enable digital and technological upgrading especially for the SMEs.

Another major theme, technological adoption and innovation capacity provides intelligence into the differentiating factors of successful and lagging firms. This study found that companies who displayed high levels of leadership commitment, forward looking vision and a culture of innovation resulted in greater levels of adoption and the successful integration of the related technology. These companies likewise took advantage of partnerships, government programs and innovation grants to allow them to do modernization. This pattern is well explained by the Innovation Diffusion Theory (Rogers, 2003) which suggests that the rate of adoption is affected by the perceived advantage, compatibility and complexity. In the H.V.A.C. industry, those companies where technology adoption is seen as a strategic advantage that fits well with existing technology systems will be more advanced more quickly, while those companies scared of the complexity of technology and limited by a scarcity of resources will be less comfortable about technology adoption. Similarly, it is the Technology Acceptance Model (TAM) (Davis, 1989) that supports such interpretation of this theory by postulating that the

usefulness and ease of use of the digital and technological tools is what affect the adoption behaviour. Firms that have leadership that strongly communicates the business benefits of digital transformation and invests in change management are likely to have positive perceptions among employees facilitating adoption.

The results also show that accessing the use of advanced tools and system integration are the hallmark of technological maturity. For instance, firms which implemented the integration of advanced design software, building new testing facilities, implementing control systems, and using energy efficient technologies in a successful manner, saw significant improvements in product quality and accuracy and compliance. These firms became more credible firms in the market to international buyers, to export their positioning. Integration, on the other hand, in many companies was inhibited by the lack of digital infrastructure or cross departmental alignment. This again supports the proposition of the TOE model that adaptation is a function of inner alignment between technological capability, organizational readiness and support in the environment. It is also a case study of Resource Based View (RBV) in action i.e. where new and potent tools and systems, having been successfully integrated, become a resource of value and also hard to replicate that provides the foundations for sustainable competitive advantage.

Means of RQ2 therefore, is that the capacity of technology upgradation against, technological up gradation, digital transformation in the Indian HVAC industry is the combined match of Technology, people and the organization system. Firms that have not only access to technology, but also the readiness humans and the structures have to make the best use of it, they show that they are more competitive, they are more innovative. This helps to attest the general proposition of this study that technological improvement does not in itself ensure the growth of exports, but competition arises as a result of dynamic interaction between technological endowment, human capital, and organizational

capability. The findings underscore the knowledge and appreciation that in order to promote sectoral transformation, it is important for industry stakeholders and policy makers to consider capability building strategies such as skill development interventions, financial incentives and infrastructure investments that enable firms to absorb and implement advanced technologies effectively.

5.1.3 Interpretation Related to Theoretical Framework

The finding derived from this study together with the theoretical frameworks already established gives a complete picture of interplay between technological upgradation and the digitalization and their joint impact on export competitiveness in the India's HVAC industry. The results obtained from both the quantitative and the qualitative analyses support and expand several theoretical perspectives by showing that competitiveness in technologically dynamic industries is not determined by the isolated possession of resources, but rather by the interrelationship between capabilities, behaviours employed to acquire these capabilities and contextual attributes that together allow sustained innovation and improvement of performance across industries. The theoretical synthesis reported in this paper underscores how the current research not only confirms existing models, but also takes them one step forward through their contextual adaptation for an emerging economy and sector undergoing digital industrial transformation.

The strong and consistent relationship between technological upgradation and export competitiveness is in direct line with the Resource Based View (RBV) of the firm (Barney, 1991) which tends to believe that unique and valuable resources act as the base of sustainable competitive advantage. The empirical findings are consistent with the argument that Indian HVAC firms using advanced technologies such as energy efficient technologies, automation tools and smart manufacturing processes demonstrate superior export performance as these resources are valuable and rare and difficult for competitors

to imitate. The results obtained using the Random Effects regression model validate the idea that technological sophistication generates measurable improvements in export competitiveness (0.32% increase in export performance with 1% increase in technological exports), which reflects the tangible performance results of resource accumulation. The qualitative findings provide further insight to deepen this interpretation showing that firms do not see technological innovation merely as an improvement in production, but that it is a strategic asset enabling them to strengthen their brand reputation, customer trust and positioning in international markets for the long term. Hence, the RBV is found to be empirically confirmed in this study, which establishes the technological resources to be the core competitive assets in the HVAC export ecosystem of India.

However, this study also takes the RBV further through the Dynamic Capabilities Theory (DCT) (Teece et al., 1997) which explains how firms constantly adapt and reconfigure their resources in order to remain competitive in changing environments. The HVAC industry, with its inherently fast changing scenario of energy regulation, environmental standards and technological innovation that necessitates the development of adaptive capabilities instead of static assets, requires firms to build adaptive capabilities instead of static assets. The findings reveal that Indian firms with an active culture of innovation and investment in R& D along with constant training of workforce are better positioned to maintain their competitiveness. For example, companies that introduced advanced systems of automation or digital quality control claimed that they felt more productive and internationally credible as a result. These behaviours are examples of “sensing, seizing, and transforming” capabilities the primary building blocks of dynamic capabilities. Thus, while RBV explains what are the resources that drive competitiveness, DCT explains how firms continuously renew and realign these resources to meet the changing demands of global HVAC markets. This study, therefore, empirically validates that the dynamic capabilities are the mediating

mechanisms through which the technological upgradation translates into sustainable export advantage.

The interpretation of findings also bears out strongly in the Technology Organization Environment (TOE) Framework (Tornatzky, & Fleischer, 1990), especially in terms of explaining the haphazard pace and success of adopting technologies and digital technologies in the industry. The TOE framework stresses the fact that adoption is dependent on technological readiness, organizational structure and environmental support. The qualitative results of the study showed that, although technological tools like IoT systems, BIM, and digital twins are becoming more and more commonplace, firms have great variations in their capabilities of implementing them successfully because of varying resources within the company, leadership commitment, and external infrastructure. The existence of financial constraints, skills shortage, and regulatory uncertainties were among the high profile barriers, constraining the adoption, especially among small and medium sized enterprises. These findings support the TOE model's contention that not only do new technologies need to be available but organisations also need to be ready for adoption and the environment needs to be supportive. This insight contributes to the TOE theory by showing how the triadic relationship between technology, organization and environment functions in a high technology sector of industry in an emerging economy. It also stresses that digitalization in itself cannot increase competitiveness without being integrated into supporting organizational systems and the right policy environments.

Complementary insights are given through the Innovation Diffusion Theory (IDT) (Rogers, 2003) to explain the different rates of adoption of digital and technological tools in the Indian HVAC industry. The results conveyed that the perception of the firms are high relative advantage and compatibility of adopting modern technology; the other deterrents include perceived complexity and implementation cost. This pattern of uneven

diffusion lends follow Rogers model of innovation adoption where the early adopters, who have higher financial and technical capacities, lead the transformation while others lag behind due to uncertainty and limitation of resources. The Technology Acceptance Model (TAM) (Davis, 1989) additionally explains this phenomenon by relating the adoption behaviour with the usefulness and ease of use of the technology. In this study, firms that clearly understood the strategic and operational benefits of digital tools (e.g. predictive analytics, digital quality control) had higher levels of adoption. Conversely, when employees viewed new systems as complicated or redundant, systems adoption did not move forward, despite the managerial intention to change. Together, IDT and TAM describe the technological diffusion and acceptance in Indian HVAC industry is not the result of awareness but the outcome of organizational perception, preparedness and the human factor that governs technology user interaction. These theories, consequently, are the behavioural and cognitive background to the quantitative results about adoption disparities.

The findings related to export competitiveness are also strongly related to Global Value Chain (GVC) Theory (Gereffi, 1994) and Porter's Diamond Model (1990). The GVC framework focuses on the importance of technological upgrading and innovation in which firms located in emerging economies can participate in moving up the global value chain by producing higher quality, higher value added goods. The study reaffirms the fact that Indian HVAC firms with cutting edge technologies and digital platforms are having a better capability of meeting international quality and sustainability standards and strengthening their global markets positioning. For example, participants had positive feedback about digital integration, say, traceability and documentation and customer engagement all of which are important qualifications for participating in global supply networks. Porter's Diamond Model reminds us that national conditions such as skilled labour, innovation

infrastructure and domestic demand are important as a catalyst for competitiveness. Results show that the rising energy efficient and climate resilient HVAC system demand in India provided a home ground of innovation for export oriented modernization. Together these two frameworks shed light on how technological and digital firm level capabilities work in interaction with national and global factors in determining the outcome of competitiveness. Hence, the studies bear the testimony that the export competitiveness in Indian HVAC industry is not just a firm level phenomenon but a systemic phenomenon involving the influence of technological sophistication, institutional support, and international value chain participation.

Synthesizing all these frameworks, this study provides a congealed conceptual knowledge of export competitiveness in terms of what can be called the Technology People Organization (TPO) Model. This integrative model makes technological upgradation the basic engine of competitiveness, that is supplemented by digitalization as the amplifier, and mediated by human capital as the transmission mechanism, and is moderated by organizational readiness as the structural determinant of the effectiveness of a technology. The TPO model is a derivation of the theory, which draws together the resource oriented logic of RBV with the adaptive abilities of DCT, the contextual realism of TOE and the behavioural insights of the IDT and TAM. In doing, it reflects its complex interdependencies, a major feature of technological change under industrial conditions during the emerging. This integrated interpretation reinforces that technological upgradation and digitalization contribute to the export competitiveness not in an isolated manner but through systemic alignment among population resources, capabilities, the organization structures and conditions in the environment.

5.2 Practical Implications

The findings of this study have strong practical implications to industry practitioners, policy makers and academic institutions with regards towards enhancing technological and digital competitiveness in Indian HVAC industry.

For Industry Practitioners

The research establishes that the competitiveness of exports is dependent on strategic alignment of technological upgradation, digital transformation and workforce capability.

Firms will want to develop a dual action approach combining investments in cutting edge technologies (such as the Internet of things (IoT), Building Information Modelling and digital twin systems) coupled with structured investment in employee training and upskilling. Companies that integrate modernization with workforce development have a higher product quality, credibility in exports and resiliency of operations.

Large firm management should institutionalize ongoing learning programs, take digital integration audits and assemble innovation task forces to keep the technology going. SME owners and managers, on the other hand, can focus on adopting some modular or shared digital tools in industry clusters or vendor partnerships which will lower the cost of implementation.

Current practice adjustment: Many firms approach the adoption of technologies as a onetime investment; this study advises instead to consider the adoption of technology in terms of building a continuous capability which is driven by senior management and back by digitalized performance metrics and training KPIs.

For Policymakers

The research underlines the importance of policy and institutional support in order to facilitate the diffusion of technology, in particular to small and medium sized firms.

Government ministries (e.g. Ministry of MSME, Ministry of Commerce & Industry) should institute fiscal incentives, innovation vouchers, low interest funds for technology

adoption directly for supporting SMEs to make the transition to smart manufacturing and digital systems

The state level policymakers could support the modernization of industries by sharing state of the art testing facilities, R&D centres and digital infrastructure in emerging HVAC manufacture centres.

To overcome chronic skills problems, public agencies and skill councils should collaborate with industry for providing such certified training in the areas of HVAC automation, energy efficiency, digital platforms, in tall with various national programs such as Digital India, Skill India etc.

Policy adjustment: Current technology promotion schemes are rather generic; according to this study, sector specific technology upgradation schemes should be addressed that take into consideration unique patterns of innovation at higher value add industries such as access heating, ventilation and air conditioning, i.e. HVAC, and similar industries with high precision programming requirements.

For Academia and Industry Associations

The findings highlight the role of academic institutions and professional associations (e.g. ASHRAE, ISHRAE, CII, FICCI) to overcome knowledge and capability gap.

Universities and technical institutes should collaborate with (HVAC) firms in codeveloping applicable research projects, test bed demonstrations and case based executive training programs to encourage real world digital adoption.

Industry associations can develop common digital benchmarking systems, have repositories of best practices online and host annual innovation awards highlighting excellence in technological and digital transformation.

Academic adjustment: Enhancements of academic curricula regarding industrial digitalization and innovation management should be attained with the aim of creating appropriately trained graduates for technology driven export industries.

Industry adjustment: Associations should change from general networking to facilitating capability development, although they should directly support the SMEs in the implementation of the digital tools and performance benchmarking.

5.3 Chapter Summary and Transition

This chapter provided an in depth discussion and interpretation of the study's findings in relation to the research objectives, theoretical framework, and existing literature. The discussion established that technological upgradation serves as the primary driver of export competitiveness in the Indian HVAC industry, while digitalization functions as a complementary enabler that strengthens efficiency, transparency, and innovation capability. The quantitative results confirmed that technological sophistication has a significant and measurable impact on export performance, whereas the qualitative analysis revealed that digital tools enhance competitiveness indirectly through improved coordination, communication, and product quality.

The interpretation of findings for the second research question further highlighted that the successful adoption of technology and digital systems is shaped by organizational readiness, leadership commitment, and human capital capability. Firms with skilled workforces, proactive management, and innovation oriented cultures were more likely to achieve effective technological integration. Conversely, financial limitations, policy gaps, and infrastructure constraints emerged as major barriers to widespread adoption, particularly among small and medium sized enterprises. These insights underscore that

export competitiveness is not determined by technology acquisition alone but by the strategic alignment of technology, people, and organizational systems.

The discussion also integrated the empirical findings with the study's theoretical foundations Resource Based View (RBV), Dynamic Capabilities Theory (DCT), Technology Organization Environment (TOE) framework, Innovation Diffusion Theory (IDT), and Technology Acceptance Model (TAM). Together, these frameworks explained how firms create and sustain competitiveness through the development, renewal, and strategic deployment of technological and digital resources within enabling organizational and environmental contexts. The resulting Technology People Organization (TPO) Model proposed by this study provides a holistic understanding of how resource capabilities, adaptive competencies, and contextual readiness jointly drive export competitiveness in emerging industries.

To wrap up, the chapter discussed the practical implications of the research for industry practitioners, policymakers, and academia. For firms, the findings emphasize the need to pursue integrated technology digital skills strategies; for policymakers, they highlight the importance of financial incentives, infrastructure improvement, and skill development initiatives; and for academic and industry bodies, they reinforce the value of collaboration in driving technological innovation.

In summary, this chapter has discussed the empirical results of the study in light of existing theoretical frameworks, providing both conceptual understanding and practical insights into how technological upgradation and digitalization drive export competitiveness in the Indian HVAC industry. The integration of quantitative and qualitative findings confirmed that technology, human capability, and organizational readiness operate as interconnected levers of competitiveness, embodied within the proposed Technology People Organization (TPO) Model. Having interpreted these findings and outlined their theoretical and practical

implications, the next chapter presents a comprehensive summary of the research. Chapter VI consolidates the study's key outcomes, highlights its theoretical and applied contributions, acknowledges its limitations, and proposes directions for future research to extend this inquiry into broader industrial and policy contexts.

CHAPTER VI: SUMMARY, IMPLICATIONS AND RECOMMENDATIONS

6.1 Summary

This paper analysed the impact of technological upgradation and digitalization in export competitiveness of the Indian Heating, Ventilation and Air Conditioning (HVAC) industry. The reason for researching was that global market competitiveness is increasingly dependent on technological level, digital preparedness and the ability to innovate. Despite the strong growth of the HVAC industry and its central role in the manufacturing and export sectors of Indian economy, very little empirical studies were done to examine the impact of the transformative factors together in the export sector. Therefore, the focus of the study was to understand the extent of contribution of technological upgradation and digitalization in export competitiveness related issues and also to identify the enablers and barriers that influence the adoption of technological upgradations and digitalization in the Indian scenario.

To achieve these goals, a mixed methods research design combined quantitative and qualitative methods was utilized for the study. The quantitative analysis was based on the panel data regression to estimate the statistical relationship among technological advancement, digital infrastructure, and export competitiveness in different regions. Three econometric models (a) Pooled OLS; (b) Fixed Effects; (c) Random Effects, were estimated and compared with the diagnostic test, the Breusch Pagan LM test and the Hausman test, made the Random Effects Model (REM) the best model for the study. The qualitative analysis complemented this by using the responses, that had been collected by taking semi structured interviews, which were analysed using NVivo 14 following Braun and Clarke's (2006) six phase thematic analysis approach. This combination provided the

ability to both numerically establish the validity of relationships and interpret contextually the experience of technological and digital transformation for firms.

The quantitative results showed that the upgrade of technology has a very high and statistically significant positive impact on export competitiveness. Specifically, the output result was that 1% technological exports equalled approximately 0.32% in export performance, highlighting the relative importance of technological sophistication as a contributor of international competitiveness. Conversely, digital infrastructure by itself wasn't found to make a statistically significant impact on export competitiveness, indicating that the value of digitalization is realised mostly when effectively combined, i.e., coupled with technological processes and organizational systems. These results have been in accordance with Resource Based View (RBV) and Dynamic Capabilities Theory (DCT), which argue that the sustainable competitive advantage is attained by firms by developing and continuously renew valuable, rare and inimitable technological resources and capabilities.

The qualitative findings offered more in depth understanding on the mechanisms by which technology and digitalization contribute to export performance. Four major themes emerged, including technological progress and innovation, digital transformation and export achievement; product quality and competitiveness; innovation influence and industry impact. Interviewers told how automation, advanced manufacturing technologies and energy efficient systems improved the quality, reliability and compliance with international standards of their products. They further stressed the complementary role played by digital tools like Building Information Modelling (BIM), digital twins and internet of things (IoT) applications in improving the operational transparency, process coordination and client engagement. Collectively, these insights show that while technological modernization is a foundational factor of competitiveness, digitalization will

act as a strong enabler that multiplies the impact of efficiency, integration and responsiveness in international markets.

The second research question was focussed on barriers and enablers for adoption of technology, digital technology career in Indian HVAC industry. Six major themes were identified which included technological modernization, skilled workforce and human resource development, competitiveness and market edge, organizational barriers, innovation capacity and advanced tools and system integration. The findings showed that the factors that are essential in successful adoption are the fitting of the readiness of the human capital, financial resources, leadership commitment, and the organizational support structures. Firms who invested in training and skills improvement of employees had better ability of operationalization of new technologies, better ability to incorporate new technologies, and were able to increase export performance of firms. On the other hand, small and medium size enterprises (SMEs) were at times constrained with financial constraint, gaps in infrastructure and irregular policy support resulting in lower rate of adoption. These sorts of differences highlight the fact that the key challenge facing the sector is not the lack of awareness, but the unequal capacity to absorb, implement and perpetuate technological change.

When combining the quantitative and qualitative results from the research, in the end, the study concludes that the export competitiveness in the Indian HVAC industry is influenced by the synergetic interaction of technology, digitalization, and organizational capability. Technological upgradation is driving better productivity, quality, and compliance; digitalization is driving better process integration, communication, and reach to markets; and the extent to which these advantages are realized is determined by organizational and/or human factors. This holistic understand leads to a new reinforcement that competition is not driven by technological acquisition, but more effectively by the

alignment of technology, people and processes in favourable organizational and policy contexts.

6.2 Theoretical and Practical Contributions

This study adds to the pool of knowledge both theoretically and in a practical sense of technological upgradation and the digitalization contribution to export competitiveness in the HVAC industries in India. The research synthesises and empirically validates multiple theoretical perspectives such as Resource Based View (RBV), Dynamic Capabilities Theory (DCT), Innovation Diffusion Theory (IDT), Technology Acceptance Model (TAM), Global Value Chain (GVC) Theory, Porter's Diamond Model, Technology, Organisation and Environment framework (TOE) framework and Productivity Theory in a single empirical frame. Through this multidimensional approach, the study pushes the limits of the discussion relating to industrial competitiveness in emerging economies in terms of emphasizing the interaction of firm level technological transformation, digital adoption, organizational capability and policy conditions (external) in driving export performance.

From the theoretical perspective, the study makes several important contributions. First, it reinforces the Resource Based View (RBV) by proving that technological upgradation is a valuable, rare and inimitable resource to compete in the export market. Empirical evidence from the Random Effects Model establishes that regions and firms with a higher degree of technological sophistication have a better export performance. This validates the RBV argument that proprietary technological assets that include automation systems, energy efficient designs and smart HVAC technologies are a sustainable source of competitive advantage.

Second, the findings build on the Dynamic Capabilities Theory (DCT) to demonstrate that the origin of competitiveness is not based on static technological possession, but rather on a firm's ability to continuously adapt, renew and reconfigure its technological and digital capabilities in unequivocal desired response to an evolving market. Firms that invested in training, innovation and modernization performed better on export trades confirming that dynamic capability building (rather than one time technology acquisition) is a sustainable global competitiveness strategy in volatile world markets.

Third, the research aims to give a contribution to Innovation Diffusion Theory (IDT) and the Technology Acceptance Model (TAM) as it contextualizes them within a framework of industrial export. The results emphasize the importance of adoption of digital tools in the HVAC industry being dependent on perceived usefulness, ease of use, and relative advantage which is in line with these models. However, the study adds new insight, by demonstrating that digitalization is not sufficient without technological and organizational readiness. This highlights the need for an integrative adoption strategy by simultaneously aligning digital systems (e.g. IoT, BIM, digital twins) with technological maturity and workforce capability.

Fourth, the findings provide support for the Global Value Chain (GVC) Theory and Porter's Diamond Model, in the sense that they empirically show how the technological and digital advancements can help firms to move up the value chain and compete globally. The study demonstrates that Indian HVAC firms that invest in advanced production technologies and related to international standards, gain better credibility and access to better export segments of higher value. These outcomes confirm the effects of technological sophistication on the improvement of the level of firm's and national economy's competitiveness as envisioned by Porter's framework through increased better factor conditions, intensity of innovation and responsiveness to global demand.

Fifth, the research is a development of the idea known as the Technology Organization Environment (TOE) Framework, which portrays the interdependence of technological philosophies of readiness, organizational ability and help from the outside toddler environment occasionally. Evidence from qualitative findings shows that even when technology is available, if firms have low financial capacity, inadequate infrastructure and lack leadership commitment to the innovation, then firms struggle to effectively adopt innovations. This creates a nuance in the TOE model of promoting a focus on the importance of contextual readiness and policy support, as important as the availability of technology, in determining successful adoption outcomes.

Finally, using Productivity Theory by Solow (1957), the study statistically supports that the upgrading of technology has a great impact on productivity and increasing export. The quantitative analysis showed the possibility of measurable improvements in export performances as a result of technological sophistication, which is a corroboration that productivity increase following technology adoption are directly translated into competitiveness at macroeconomic level.

From a practical point of view, the research brings up real actionable insights for players of the industry who are action oriented, policymakers and academic institutions. For members of the industry, the study points to the fact that the export of competitiveness is a combination of technology, digital tools and workforce development. Firms are incentivized by relating technological investment (automation, energy efficient systems and smart controls), to employee training, process innovation and leadership commitment. Continuous learning and innovation oriented culture should be built into the corporate strategy in order to assure its continued success on export front.

For policymakers, the results point to the need for financial and institutional assistance for the reduction of barriers to adoption of technologies especially for small and medium sized

enterprises (SMEs). Policies, such as tax incentives, grants to modernise technologies and subsidised loans can help to facilitate investment in advanced manufacturing and digital technologies. Stronger digital infrastructures, comprising both stable regulatory environments and activities in exploration, industries and academia will help in the acceleration of the technology diffusion and innovation through the sectors. Skill development programmes under national schemes such as Skill India and Digital India can help in furthering the development of readiness of human capital in the HVAC sector.

For the academic institutions and industry associations, the study is making a role in promoting knowledge creation and dissociation in a supplemental way. Universities and research institutions can offer support to the sector, for example, through the development of applied research, case studies and professional certification through the development of programs related to digital manufacturing as applied to automation and sustainability in the Heating, Ventilation and Air Conditioning (HVAC) systems. Industry bodies such as ASHRAE, ISHRAE, CII and FICCI can encourage benchmarking, sharing of best practice and transfer of technology on part of industry to fill the capability gaps between firms to encourage sector wide competitiveness.

6.3 Limitations of the study

While this study gives important information about the linkage of technological upgradation, digitalization, and export competitiveness in the Indian HVAC industry, the present study is not without limitations. These limitations are mostly concerned with the scope of data, the limits of method and context in which the research was carried out. Acknowledgment of such limitations is important not just for interpreting the results appropriately, but also for the future research to achieve a more comprehensive understanding of the topic.

First is limited scope of the study to Indian HVAC industry which despite being a global connected industry with relevance from that perspective is just one sector of industrial world under a particular national context. The findings are thus indicative of those particular structural, regulatory and technological conditions that are unique to India's manufacturing environment and may not be directly generalisable to other industries and countries. While industry of the HVAC industry is a good proxy for the analysis of the export oriented technological transformation cross industry comparison could allow for more general insights on whether similar patterns of competitiveness could be observed in other advanced manufacturing industries.

Second was the quantitative approach that made use of secondary data from the panel data and primary inputs acquired through structured Interviewers. Although this mixed approach added to the robustness of the findings, there are still some data limitations. The variables used to measure digitalization, such as the count of broadband as a measure of digital infrastructure, may fail to capture the depth of digital transformation that is happening at the firm level. Additionally, because of constraints on data availability, the analysis was carried out at the regional level of aggregation and not on individual firms, which may mask firm specific differences in terms of technological adoption, strategy and performance. Future studies may benefit from the use of firm level longitudinal data sets that can be used to more geographically examine the interaction between digital and technological factors over time.

Third, although in qualitative phase of this study rich contextual depth has been achieved with semi structured interview of industry professionals, it was not without limitations. The sample of participants was based on voluntary participation and this could have induced response bias, as firms who are more involved with technological and digital initiatives may have been more inclined to participate in the study. In addition, the lack of extended

case study observations and/or longitudinal qualitative follow ups reduced the ability to examine managerial decision making and implementation processes in finer detail. Expanding in the future qualitative research through multi case studies or ethnographic approaches could come closer to understanding the internal organizational mechanisms that lead to technology adoption, digital integration, and export competitiveness.

Fourth, the research design of the study was cross sectional, which means that the study recorded data and perceptions at a specific point in time. However, technology transformation and digital integration are dynamic and changing processes. Consequently, the findings represent the state of relationships as they existed when the study was conducted and may not fully account for changes in the policy environments or market conditions and technology innovations that may take place over time. Longitudinal studies that follow individual firms over several years would yield more compelling causal evidence as to the relationship between long term technological investments and export performance and competitive positioning.

6.4 Recommendations for future research

Based on results and limitations in the current research, some research opportunities for future research are suggested in order to deepen the understanding of effects of technological upgradation and digitalization on export competitiveness in industrial areas such as HVAC. These recommendations are aimed at reinforcing the academic and practical pillars of research in this field, by promoting more general methodological approaches, comparative approaches as well as longitudinal research.

First, in the future the scope of analysis could be widened from the HVAC industry to other more advanced manufacturing and export oriented sectors like automotive components, and renewable energy equipment or precision engineering. Comparative cross sectoral

studies would be helpful to understand whether the relationships identified between technological sophistication, digitalization and export competitiveness prove to be the same across industries, or are affected by sector specific elements such as: technology intensity; supply chain structure and market orientation. This would help to develop a more generalize model of technological competitiveness that would suit emerging economies.

Second, there is much scope for firm level and longitudinal analyses to complement the focus on the regional and cross sectional design of the current study. Future research could tap pattern level panel data or capture case studies that are longitudinal in orientation to determine the dynamic nature of technological transformation and its long term impact to export performances. Tracking these firms over several years would allow researchers to see how both sustained investments in technologies, policy changes and global market shifts relate to export growth, the ability to innovate and trajectories of competitiveness.

Third, it could be possible to focus on further research on how measurement approaches could be improved for key constructs such as digitalization, technological upgradation, and competitiveness. The current research was based on the available quantitative indicators like broadband count and share of technological export which may not fully reflect the multidimensionality of the digital transformation. Future researchers could create more comprehensive indices that combine quantitative and qualitative dimensions to embody both digital maturity levels and related innovation culture and automation of processes in deeper detail in order to boost the construct validity and explanatory precision.

Fourth, there remains an opportunity to explore more deeply the role of human capital and organizational culture in shaping technological adoption and export competitiveness. While this study identified workforce skill development and leadership commitment as key enablers of successful technological transformation, it did not empirically examine the mediating or moderating effects of specific human resource strategies such as reskilling

programs, digital literacy initiatives, or innovation oriented leadership practices on the relationship between technological capability and export performance. Future research could extend this line of inquiry by adopting a comprehensive mixed methods design that combines quantitative analyses with in depth semi structured interviews or case based investigations. Such an approach would enable a richer understanding of managerial attitudes, employee readiness for digital transformation, and the organizational behaviours that influence the success of technology driven competitiveness initiatives.

Fifth, there seems to be potential research to be conducted in the future into the policy and ecosystem level determinants of industrial competitiveness. The expansion of the analytical framework to consider additional factors such as government incentives, institutional support, infrastructure availability and public private partnerships would provide a more holistic understanding of how external environment help or hamper technological advances. Comparative studies between regions within India or between the emerging economies, could be useful in identifying the best practices and policy interventions for increasing the pace of such technological diffusion and exports.

APPENDIX A:
INTERVIEW GUIDE

QUESTIONS FOR RQ1 (Will technological upgradation and digitalization effect the export competitiveness of the HVAC industry in India?)

Section 1: Background Information

1. Could you please briefly introduce yourself, your role and your experience in the HVAC industry, especially in exports (If any)?

Section 2: Technological Upgradation

2. How would you assess the current level of technological adoption in the Indian HVAC industry?
3. Which key technologies your company has adopted in past 3-5 years and brief what impact have they had on efficiency and quality of the product?

Section 3: Role of Digitalization

4. To what extent your company has adopted digital tools (e.g., ERP, IoT, CRM)?
5. Can you share how those tools influenced organization's export performance or international customer engagement?

Section 4: Export Competitiveness

6. How do you assess India's position in global HVAC exports in comparison with other countries?

7. In your opinion, how do technological advancements impact on India's competitiveness in the global HVAC market?

Section 5: Recommendations, Future Outlook and Closing (Open ended)

8. What trends do you foresee in the next five years regarding technology and digitalization in the Indian HVAC export market?
9. Would you be open to reviewing the transcript of this interview to ensure the accuracy of your responses?

QUESTIONS FOR RQ2 (What strategies can be developed to promote technological adoption in the Indian HVAC industry by identifying key barriers and challenges?)

Section 1: Background and Contextual Information

1. Please describe your role in the HVAC industry and your organization's core focus.

Section 2: Barriers and Challenges in Technological Adoption

2. What are the primary barriers your company faces in adopting new technologies (e.g., financial, skills gap, infrastructure challenges)?
3. How significant is the lack of skilled personnel adopting advanced technologies?
4. Is there any other barriers and challenges when implementing new technologies?

Section 3: Strategies to Overcome Barriers

5. What strategies does your company use to address financial challenges (e.g., funding, subsidies)?
6. Does your organization collaborate with external platforms or R&D bodies for technology upgrades?

Section 4: Impact of Technology Adoption on Business Performance

7. Do advanced technologies provide your company with a competitive edge in the market? If so, how?

Section 5: Recommendations, Future Outlook and Closing

8. What recommendations would you provide to encourage technology adoption across the HVAC industry?
9. Is there anything else you would like to share regarding technological adoption in the HVAC sector?
10. Would you be open to reviewing the transcript of this interview to ensure the accuracy of your responses?

APPENDIX B:
INFORMED CONSENT

Title of Study:

Transforming Export Competitiveness: Technological Upgradation and Digitalization in The Indian HVAC Industry.

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Institution: Swiss School of Business and Management (SSBM), Geneva

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You are invited you to take part in a research project that will examine how technology upgrades and digitalisation can help improve the competitiveness of the Indian heating, ventilation and air conditioning (HVAC) industry when competing internationally. We will look at how technological advancements affect international competitiveness as well as strategies to address barriers to adoption. Your input will help to provide solutions for industries and government to improve performance within this sector. Participation in this study involves a semi structured interview that will last approximately 30 minutes. During the interview, we will discuss your experiences with challenges, strategies, and outcomes related to technology adoption in your organization.

Participation is entirely voluntary. You may refuse to participate, skip any questions you are not comfortable answering, or withdraw from the interview at any time without any consequences.

Your responses will be kept confidential. All information collected during this study will be kept confidential (including audio recordings and transcriptions) and all identifying information removed from the database. The findings of the study will be reported in an anonymous manner.

There are no foreseeable risks associated with participating in this study. Your insights, however, will help improve understanding of technological adoption and may contribute to practical solutions for industry challenges.

By signing below, you confirm that you have read and understood this information, and you agree to participate in the interview.

Participant's Name: _____

Participant's Signature: _____

Date: _____

Researcher's Name: Akash Machindra Pol.

Researcher's Signature: _____

Date: _____

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