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Transforming Export Competitiveness: Technological Upgradation and Digitalization in the Indian Heating, Ventilation, and Air Conditioning Industry

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Abstract

This study investigates the impact of technological upgradation and digitalization on the export competitiveness of India's Heating, Ventilation, and Air Conditioning (HVAC) industry. Drawing on a 23-year panel dataset from 51 low-and-lower-middle-income countries, the research employs econometric analysis using high-tech exports and broadband subscriptions as proxies. The findings reveal that technological upgradation—measured through medium and high-tech exports—has a statistically significant positive impact on export competitiveness. In contrast, digitalization, proxied by broadband subscriptions, shows no significant effect, suggesting that mere infrastructure is insufficient without deeper operational integration. The Indian HVAC sector, though poised for growth amid global demand and sustainability mandates, faces challenges such as limited R&D investment, inadequate digital adoption, and scale inefficiencies. The study proposes a theoretical framework linking technological advancement and digital readiness with competitive export performance, offering insights for policymakers and industry stakeholders. It underscores the need for strategic investments in innovation, sector-specific digital tools, and workforce development. By aligning macroeconomic data with sectoral realities, the research contributes to a nuanced understanding of how emerging economies like India can leverage technological transformation to boost global trade competitiveness.

Keywords: technology upgradation; digitalization; export competitiveness; India

1. Introduction

In today's fast-paced global economy, export competitiveness is a crucial driver of economic growth and industrial success. Trade based on comparative advantage has been recognized as a catalyst for development, particularly for emerging economies like India. Exports play a pivotal role in India's growth strategy, with policies increasingly focused on enhancing outward trade. The Economic Survey (2022) reported that India achieved over 75% of its ambitious US$ 400 billion export target for 2021-22, reinforcing the nation's commitment to strengthening its global trade footprint. Exports are also central to India's aspiration of becoming a USD 5 trillion economy by 2024-25 (Kumar, 2022).

The Heating, Ventilation, and Air Conditioning (HVAC) industry is an integral component of India's economic and industrial landscape. The HVAC Market Assessment and Transformation Report (2014) projected a significant expansion in India's built environment, with the constructed area expected to increase from 2,100 million square meters in 2005 to 10,400 million square meters by 2030. This rapid growth intensifies the need for energy-efficient HVAC solutions, underscoring the sector's relevance in India's broader sustainability and

industrial policy framework. As noted by Chechi (2023), the Indian HVAC industry is evolving in response to changing consumer preferences, regulatory mandates, and environmental concerns. While the sector offers substantial growth opportunities, it also faces intense international competition and rapidly shifting market demands.

The Indian HVAC industry is expected to grow at a Compounded Annual Growth Rate (CAGR) of 16.0% between 2021 and 2030 (Chandrashekhar, 2022). According to the EEPC India Report on HVAC-R (2022), the United States, UAE, and China were the top three destinations for Indian HVAC exports in 2020, accounting for 16.7%, 7.0%, and 5.92% of global exports, respectively. To enhance global competitiveness and expand its export capabilities, the Indian HVAC industry must adopt technological advancements and embrace digital transformation. However, the sector faces various challenges, including high investment costs, technical complexities, data security concerns, and evolving environmental regulations.

Technological upgradation is instrumental in improving product quality, energy efficiency, and operational effectiveness. Innovations such as intelligent control systems, sustainable refrigerants, and advanced heat exchange solutions enhance performance while promoting environmental sustainability. Digitalization further transforms operations by enabling predictive maintenance, remote diagnostics, and optimized inventory management. The integration of digital technologies presents new opportunities for market expansion and enhanced efficiency.

This study examines the impact of technological upgradation and digitalization on the export competitiveness of India's HVAC industry. By integrating perspectives from technology, business management, and international trade, this research provides insights for businesses, policymakers, and industry associations. Understanding these advancements is crucial for strengthening India's position in the global HVAC market and ensuring sustainable industrial growth.

2. Literature Review

2.1. India's HVAC landscape and global positioning

India has made significant strides as a major sourcing market for HVAC machinery and components, benefiting from a skilled workforce and government initiatives promoting manufacturing and exports. Indian manufacturers are increasingly aligning with international quality standards, enhancing their credibility in global markets. This has led to growing export opportunities, positioning India as a key supplier in the global HVAC supply chain (ET2C, 2023).

Globally, China and Turkey have emerged as dominant manufacturing hubs, leveraging economies of scale and strategic locations to facilitate HVAC production and trade. However, India's improving business environment has made it an attractive alternative manufacturing destination. According to EIU's Asia Outlook (2023), India now competes with China and Southeast Asia in attracting foreign investment. India has improved its macroeconomic environment score from 6.1 to 6.9 and market opportunities score from 7.1 to 7.9 in Q2 2022-23. Ranking 52nd in EIU's global business environment index, ahead of China, India presents lower political risks compared to Southeast Asia, further enhancing its investment appeal (TOI, 2022). Investment in India's electronics sector has surged, supported by government-backed production-linked incentives (PLI). Exports of electronics rose by 50% to $14 billion in 2021 and sustained this momentum in 2022. Companies like Foxconn, a key Apple supplier, are expanding in India, diversifying beyond China. Additionally, India's G-20 presidency and trade agreements with Australia and the UK are expected to further boost investments (S&P Global, 2022; Morgan Stanley, 2022).

Economic projections suggest India will surpass Japan and Germany to become the world's third-largest economy, with an average GDP growth rate of 6.3% through 2030. Rising real income per capita, averaging 5.3%, is expected to drive consumer spending, making India a key market among G20 economies. Policies like PLI and "Make in India" aim to boost manufacturing output, create jobs, and increase the sector's GDP contribution to 25%. Foreign investors are increasingly viewing India as a viable manufacturing hub, driven

by structural reforms and a strong policy framework (GOI, 2021). The global shift away from China, coupled with India's improving competitiveness, is accelerating its role in global supply chains.

2.2. Competitiveness and Economic Growth

In a globalized world, competitiveness plays a critical role in economic growth. As highlighted by Ruzekova (2020), national competitiveness significantly influences economic, political, and social development. Competitive nations attract foreign investment, leading to increased productivity, technological advancements, and export growth (Cekmeova, 2016; D'Aleo & Sergi, 2017). A country's ability to sell goods internationally, maintain economic stability, and innovate determines its competitive advantage (Rodriguez & Rodrik, 2001; Carvalho et al., 2012). Virjan et al. (2023) argue that competitiveness and economic growth reinforce each other, with higher competitiveness driving innovation, efficiency, and job creation. The World Economic Forum (WEF, 2017) defines national competitiveness through 12 pillars, grouped into three categories: basic requirements (institutions, infrastructure, health, education), efficiency enhancers (higher education, labour markets, financial development, technological readiness), and innovation factors. Gama et al. (2020) emphasize that competitiveness evolves through stages, transitioning from resource reliance to efficiency-driven and ultimately innovation-led economies.

Technological advancement is a fundamental driver of sustained economic growth. Maric et al. (2021) identifies three key mechanisms: efficient resource allocation, capital accumulation, and technological progress. Innovation fosters long-term economic expansion by generating new industries and higher-value jobs (Thierer, 2014; Broughel & Thierer, 2019). Studies show that firms investing in digitalization experience higher sales growth, operational efficiency, and market valuation (Babina et al., 2022; Mikalef & Gupta, 2021; Mishra & Pani, 2021). AI adoption has further accelerated this trend, driving product innovation and market leadership.

Digital transformation enhances competitiveness by facilitating international trade and enabling businesses to integrate into global supply chains. Cassetta et al. (2020) found that Italian SMEs leveraging e-business technologies experienced higher internationalization success, provided these digital tools were combined with process and organizational innovations. Similarly, Liu et al. (2023) highlight that the diffusion and adoption of digital technologies are crucial for economic expansion, requiring skilled labour and strategic decision-making to optimize their impact. The role of competitiveness and innovation in economic growth has been extensively studied across countries. Terzic (2021) examined leading and emerging European economies, concluding that nations with strong innovation capabilities, infrastructure, and macroeconomic stability achieved higher growth rates. These insights underscore the significance of national competitiveness as a key determinant of economic resilience and recovery. As global economies shift towards digitalization and technological advancement, competitiveness will continue to shape economic trajectories, positioning nations like India as emerging leaders in the global marketplace.

2.3. Growth Trends in HVAC Industry: Global Insights

The HVAC industry exhibits diverse regional trends and strong growth projections. A report on the global HVAC industry (2024) indicates that the industry is largely influenced by regional regulations and differences. Asia has one of the largest HVAC market sizes, with China leading in air conditioner demand. The demand for air conditioners in North America and other Asian countries, excluding China and Japan, exceeded 20 million units in 2022. Europe reached a new high of 9.5 million units, marking an increase from the previous year.

Projections suggest that total HVAC demand will increase approximately eightfold in terms of tonnage of refrigeration (ToR) by 2037-38. Among various HVAC segments, space cooling in buildings is expected to witness the most significant growth, projected to rise elevenfold from the 2017-18 baseline. This growth is driven by economic development, rising incomes, urbanization, and expansion of the aspirational class.

In the space cooling segment, key HVAC products include room air conditioners, chiller systems, variable refrigerant flow (VRF) systems, and packaged DX systems. Room air conditioners, dominating in tonnage, 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, while VRF systems, requiring advanced controllers, are anticipated to expand at approximately 15% CAGR due to their energy efficiency. The packaged DX market is expected to experience modest 5% growth. Studies suggest that Indian consumers will purchase over 150 million room ACs over the next decade, representing a conservative retail value of approximately 5,10,000 crore INR. The Indian HVAC market has grown significantly due to rapid urbanization, rising incomes, and increased awareness of indoor air quality. This growth has attracted substantial investments from domestic and international players, pushing India's HVAC market to USD 9.1 billion in 2023.

Despite India's market size, a major challenge remains the lack of scale in manufacturing. The Indian HVAC sector consists of numerous small and medium-sized enterprises (SMEs), and even larger firms do not match the scale of Chinese manufacturers. This structural issue limits India's ability to counter import dominance, contributing to technology-related challenges. The challenges are not about access to cutting-edge technologies but rather the capacity to scale and modernize production.

To address this, the Indian government has taken proactive measures to enhance local manufacturing and exports. In 2020, a ban was imposed on importing air conditioners with refrigerants, eliminating a major source of Chinese imports. Additionally, India introduced policies such as the Production Linked Incentive (PLI) scheme to boost local manufacturing and enhance the competitiveness of domestic MSMEs. State governments are also being encouraged to align their industrial policies with export growth strategies, as Maharashtra, Gujarat, Karnataka, Tamil Nadu, and Telangana contribute 75% of India's total exports. However, there is still a need to assess how market dynamics, domestic manufacturer competitiveness, and technological innovation affect the HVAC sector's long-term growth trajectory.

2.4. HVAC Innovation through Technological Upgradation and Digitalization

Digitalization is reshaping the modern industry by transforming information collection, sharing, and utilization. The integration of technologies such as big data, cloud computing, IoT, and AI has fundamentally altered business operations, driving efficiency and innovation. Digitalization enables organizations to move away from traditional processes, fostering collaborative value creation and enhanced business models. The shift towards digital business models is critical for global competitiveness.

Embracing digitalization is no longer optional but essential for businesses seeking resilience and sustainability. Governments worldwide are investing in digital infrastructure, including IoT and AI, to accelerate technological transformation. Two critical elements of this shift are Digital Public Infrastructure (DPI) and the Digital Adoption Index (DAI). DPI enhances service efficiency and innovation, reducing business costs, while DAI measures a country’s readiness to adopt digital technologies. Reports highlight India’s progress in digital adoption, with its DAI rising significantly in recent years.

The HVAC industry, vital for indoor climate control, is experiencing rapid digital transformation. Innovations such as variable refrigerant flow (VRF) systems, smart thermostats, and heat pumps are improving energy efficiency and sustainability. Digitalization in energy management allows for optimized heating and cooling, reducing energy consumption while maintaining comfort and air quality.

The integration of AI and IoT in HVAC systems is a major advancement, enabling real-time data analysis, performance optimization, and predictive maintenance. AI-driven systems can analyze usage patterns, adjust cooling or heating requirements dynamically, and enhance overall efficiency. IoT-enabled HVAC systems allow for remote control via smart devices, offering increased convenience and cost savings.

Smart buildings, incorporating HVAC digitalization, improve safety, reliability, and energy efficiency. Seamless integration of building management systems with HVAC systems reduces overall energy expenditure and enhances operational efficiency. As the industry advances, digitalization will play an

increasingly significant role in shaping future HVAC developments. Despite the evident benefits, literature remains limited on how technological advancements in HVAC impact international market penetration and competitiveness. Questions remain on how digitalization and technological upgradation can enhance global competitiveness and the strategies needed to promote these advancements. Addressing these gaps is crucial for developing a robust and competitive Indian HVAC industry capable of expanding its global footprint.

Technological change impacts production and labour dynamics, creating both opportunities and challenges. While innovation can boost efficiency and competitiveness, it also alters job structures and economic distribution. The HVAC sector must navigate these changes by investing in R&D, fostering innovation, and leveraging digital transformation to remain competitive in the global market. Addressing the technological gaps in India's HVAC industry is essential. SMEs face challenges in industrial design, compliance, and upgrading machinery. Efforts must be made to modernize production, enhance quality standards, and develop technological capabilities. Strengthening domestic manufacturing through policy support and investment in digital technologies will be key to improving India's HVAC export competitiveness and achieving long-term growth.

2.5. Research Gaps

The literature review highlights several unexplored areas regarding the relationship between technology, digitalization, and export competitiveness in the HVAC industry. Initially, much less research regarding the precise impact of technology and digitalization on export competitiveness in the context of global competition. Indeed, Vishnuraj (2023) and Mahurkar (2023) emphasize the transformative potential of digitalization in the HVAC industry, particularly through the integration of AI and IoT devices. Chandra (2023) discussed on smart building integration but does not link such advances with export competitiveness. Many other studies including Matt & Raunch (2020), Ferrantino & Koten (2019) and Cassetta et al (2020) recognized the digitalization broader role in enabling export competitiveness, however, still sector specific focus specifically in the Indian context are scarce and there is a lack of in-depth investigation into how technology and digitalization can be strategically leveraged to enhance export competitiveness. Therefore, there is a clear need for quantitative research to precisely assess the impact of technology and digitalization on export competitiveness. Thus, this study gap should be addressed.

Second, much less research on understanding the strategies needed to promote technological adoption in the Indian HVAC industry by identifying key barriers and challenges. Dixit and Bhasin (2022) and institutions like BEE (2023), highlighted challenges such as limited R&D access, infrastructural limitations, skill shortages, and financial barriers, but there is insufficiency in theorised testing. Aqmala (2024) highlighted how digital transformation helped MSME's from Southeast Asia to improve their competitiveness. However similar approach has not yet explored in case of Indian HVAC sector. This research gap leaves room for understanding financial constraints faced by SMEs, a significant skills gap within the workforce, organizational resistance to change, and infrastructural challenges such as integrating new technologies with existing systems. These identified gaps in the existing literature present valuable opportunities for further research and exploration in the field.

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

This study proposes conceptual framework, as shown in Figure 1, suggesting that technological upgradation and digitalization improve cost efficiency, product quality, innovation capability, and workforce skills. These improvements positively impact export competitiveness, leading to economic growth, industry growth, sustainability, and job creation. This evaluation is based on the author's own analysis using competitive intelligence, a market research blog (2023), and data from the World Bank (2016 and 2021).

As discussed below, most definitions of digitalization highlight its role in transforming business processes, leading to improved product quality and efficiency, shifting customer expectations, and fostering new collaborations. Additionally, the studies examined below highlight the impact of digital technologies on

internationalization, economic growth, productivity growth, job creation, and the substantial changes occurring across business, societal, and technological domains.

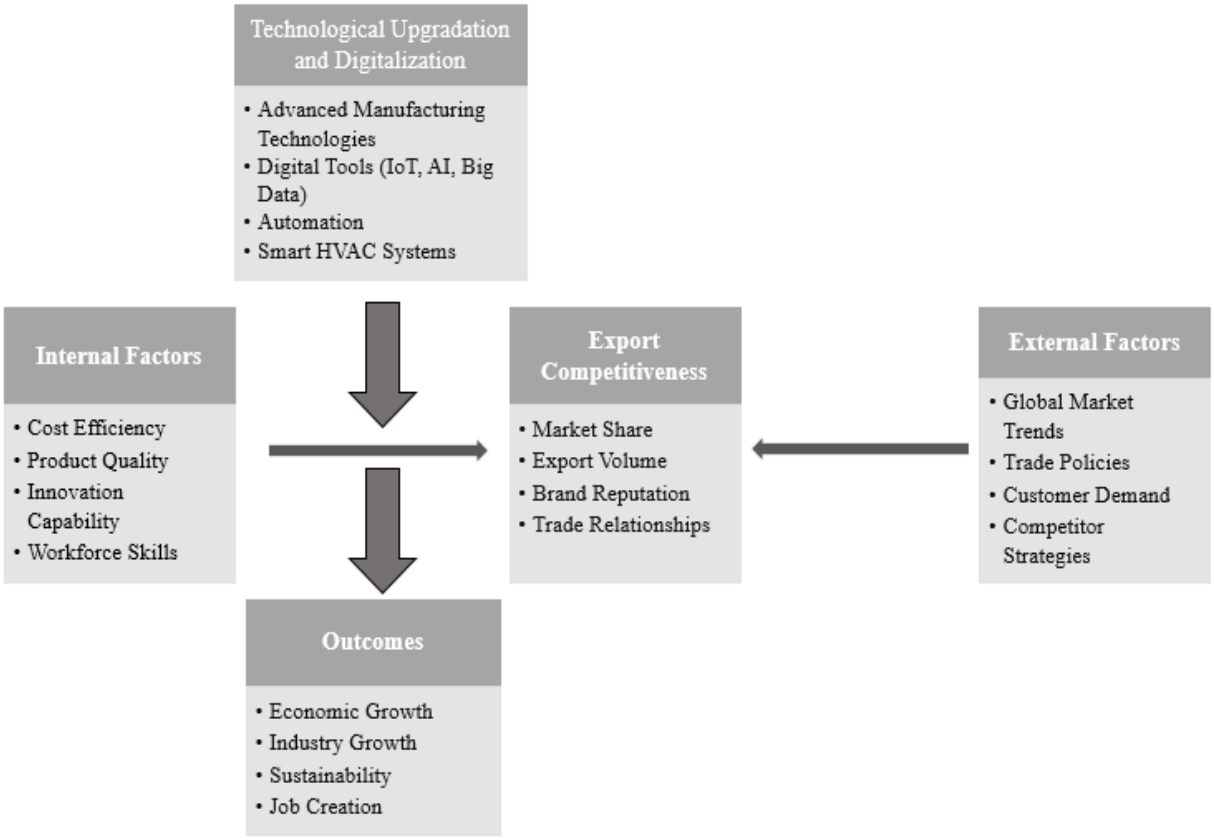

Figure 1. Conceptual framework of Technological upgradation and digitalization effect on the export competitiveness of the HVAC industry in India.
Source: Author's own illustration.

Digitalization, defined as the "use of digital information and technologies to transform business processes, affects all industries". At its deepest, digitalization and the broader digital transformation that it produces even change the nature of business. "Digital technologies" often refer to electronic tools, systems, devices, and resources that generate, store, or process data. "Digitalization" is the use of digital technologies and data as well as the interconnection that results in new activities or changes to existing activities (OECD, 2019). "Digitalization is a multidimensional and rapidly evolving concept that incorporates a multitude of digital technologies, such as the internet, electronic data exchange using e-mail or other online systems, dedicated online platforms and marketplaces, and advanced manufacturing or Industry 4.0". (Ferrantino and Koten, 2019; Matt and Rauch, 2020). The Society 5.0 revolution is known as the concept of industry in the digital era. It has a social focus, which is developing more rapidly and broadly impacts all activity processes within the organization. There are four main impacts of the Society 5.0 revolution for firms in all sectors: shifting customer expectations, improving product quality using data, changing operational models to digital models, and forming new collaborations (Aqmala, 2024).

The International Energy Agency (2017) explained the concept of digitalization as "the increasing interaction and convergence between the digital and physical worlds." This interaction involves three fundamental elements. The first element is Data, which refers to digital information. The second is Analytics, which involves the use of this data to produce useful information and insights. The third is Connectivity, which is the exchange of data between humans, devices, and machines (including machine-to-machine communication) through digital communications networks. Since the 1980s, rapid technological progress has significantly lowered the costs associated with transportation and communication. This shift made it feasible for companies to separate and relocate various stages of production across different countries. Alongside liberalized trade policies and the reunification of the global economy following the integration of the East and West, these

changes laid the foundation for today's intricate international value chains—where each country contributes based on its comparative strengths (World Bank, 2020).

Digital progress and reports (2023) presented that digitalization has opened new avenues for innovation, efficiency, and inclusion, bringing tangible benefits and new possibilities to individuals, organizations, and nations. After analysing the multiple definitions of digitalization and its necessity, the researcher analysed a few more studies. These studies examine the relationship between digital technologies and internationalization (Cassetta, Monarca, Dileo, Di Berardino, and Pini, 2020), the relationship between digital technologies and economic growth (Liu et al., 2023), technological innovation and productivity growth (Babina et al., 2022; Mikalef and Gupta, 2021; Mishra and Pani, 2021; Mishra et al., 2022), and potential job opportunities (Autor et al., 2022).

Most studies (Cassetta et al., 2020; Liu et al., 2023; Babina et al., 2022; Micallef & Gupta, 2021; Mishra & Pani, 2021) were found to specifically focus on the relationship between digital technologies and factors such as economic growth, competitiveness, innovation, and certain business changes or the implementation of specific technologies in organizations. While many components are linked to digital transformation, no comprehensive framework integrates them all. Many studies are abstract and iterative, lacking precise specification of the impact of digital technologies on export competitiveness. A more detailed formalization of digital technologies and their effects would be beneficial for better understanding. To address this, the author carefully analysed a competitive intelligence and market research report on the HVAC industry, which reported a ₹5000-crore investment in new technology (Markets and Markets, 2023).

The report addressed key questions, including: How can this impact the overall demand for HVAC? What are the top three areas where this can have a significant impact in the future? Which of the other five industries that depend on HVAC will be impacted by this, and how? What will be the impact of this deal over the next five years at a global level? After analysing the report, the author highlighted three major impact categories. The primary impacts were increased efficiency and energy savings, technological advancements, and environmental sustainability. The secondary impacts involved effects on industries such as construction, energy, technology, and manufacturing. Lastly, the next five-year impacts included increased efficiency and energy savings, creation of new products and services, adoption of more advanced technology, opening up new markets for HVAC systems, increased demand and growth opportunities, increased market concentration and market power, impacts on pricing, innovation, and consumer choice in the industry, as well as increased growth and profitability. This analysis provides a detailed formalization of the investments in new technologies and their impact on efficiency, technological advancements, the top five industries related to the HVAC industry, and the global impact over the next five years.

2.7. Research Purpose and Research Question

The purpose of this research is to understand how technology upgradation and digitalization impacting the export competitiveness of Indian HVAC Industry. While the global HVAC market is moving quickly towards innovation embracing automation, smart technologies, and efficient digital systems, many Indian firms are still catching up. They often rely on older technologies and face challenges in adopting digital practices, which can hold them back in the international market. With global players using technology to lower costs, improve quality, and respond faster to market needs, it is important to examine whether similar shifts in the Indian HVAC sector could help boost their export competitiveness. This study looks closely at that connection and what it could mean for the industry's future in global trade.

Will technological upgradation and digitalization effect the export competitiveness of the HVAC industry in India?

H1: There is statistically significant impact of technological upgradation and digitalization on the export competitiveness of the HVAC industry in India.

3. Methodology

3.1. Research Design

This study adopts a quantitative method to identify the impact of technological upgradation and digitalization on export competitiveness in the Indian HVAC sector. The study uses national-level data analysing to identify impact, patterns, and relationships in between the dependent and independent variables. As the national level HVAC specific trade data is not available, this study uses macroeconomic indicators as proxies for technological upgradation, digitalization and export competitiveness, particularly in economies with industrial structures similar to India.

Three indicators are selected first, Exports of Goods and Services (% of GDP) as a proxy for dependent variable (export competitiveness), second, Medium and High-Tech Exports (% of Manufactured Exports) used as a proxy for first independent variable (technological upgradation) and lastly Fixed-Broadband Subscriptions (Count) which represents second independent variable (digitalization). These indicators are obtained from globally recognized datasets which includes the World Bank's World Development Indicators (WDI) and UNESCO's ITU Data Hub. Due to data unavailability, more relevant indicators like digital adoption in businesses or e-commerce could not be included. The study focuses on trend analysis of 23-year period from 2000 to 2022 and includes 51 low- and middle-income countries, enabling a panel data analysis that combines temporal and cross-sectional dimensions. This macro level strategy offers empirical insights into how national-level technological upgradation and digitalization effect on export competitiveness performance, particularly in relation to Indian HVAC industries.

3.2. Data Collection

In this study data is drawn entirely from secondary sources by using a structured and consistent framework to ensure reliability and comparability. The indicators were carefully selected based on their relevance to the study's core variables technological upgradation, digitalization, and export competitiveness and obtained from two globally recognized databases which includes the World Development Indicators (2024) and the ITU Data Hub from the UNESCO (2024). The study uses the three indicators first, Exports of Goods and Services (% of GDP) as a proxy for export competitiveness, second, Medium and High-Tech Exports (% of Manufactured Exports) to reflect the extent of technological upgradation and lastly, Fixed-Broadband Subscriptions (Count) as an indicator of digital infrastructure and by extension to the digitalization. The dataset includes 51 low- and middle-income countries with a time frame of 23-years period, thereby supporting a longitudinal analysis. This approach ensures uniformity and cross-country comparability in data representation and enhances the robustness of the statistical modelling.

3.3. Methods

This study applies a standardized instrumentation framework, allowing a rigorous evaluation of the relationship between technological upgradation, digitalization, and export competitiveness. The first indicator, exports of Goods and Services (% of GDP), obtained from the World Bank's World Development Indicators which measures the total value of goods and services exported as a percentage of GDP. A higher percentage reflects strong export competitiveness, indicating the presence of favourable trade policies, industrial infrastructure, and integration into global value chains (World Bank, 2023). Then second indicator, technological upgradation, a critical driver of export competitiveness which improves the quality and performance of products will be measured as medium and high-tech exports (% of Manufactured Exports) indicator will be obtained from the World Bank's World Development Indicators. A greater share of technologically advanced exports indicates higher industrial capabilities and innovation-driven competitiveness, allowing firms to produce goods that command greater market value and face lower price competition (World Bank, 2023; OECD, 2023).

Lastly, digitalization strengthens export competitiveness by improving efficiency, reducing trade barriers, and enabling access to global markets. The Fixed-Broadband Subscriptions (Count) indicator will be obtained from

UNESCO's ITU Data Hub, measures broadband penetration, which is essential for e-commerce, digital supply chains, and global connectivity. Countries with higher broadband adoption experience faster economic growth and ease of doing business, as digital technologies enhance the ability of firms to access new markets, integrate into international production networks, and adopt Industry 4.0 innovations such as automation and artificial intelligence (UNCTAD, 2021).

3.4. Data Analysis

This study adopts a panel data analysis technique to identify the impact of technological upgradation and digitalization on export. Panel data analysis is particularly well-suited to this type of longitudinal and cross-sectional investigation because this method allows analysing data from the same set of units such as countries, firms or individuals over multiple time periods, as it combines cross-sectional and time-series data. The econometric model employed in this study is derived from the basic principles of linear regression analysis, extended into a panel structure to capture variations across both entities (countries) and time periods.

The foundational model is expressed as:

$$Y(Exp\_Comp) = X0 + X1(Tech\_Upgrad) + X2\ (Digital) + \epsilon$$

Where:

- **Y(Exp_Comp)** represents export competitiveness, measured by the Exports of Goods and Services (% of GDP) indicator.
- $\mathbf{X_0}$ is the constant term (intercept).
- $\mathbf{X_1}$ represents the coefficient for technological upgradation, measured by Medium and High-Tech Exports (% of Manufactured Exports).
- $\mathbf{X_2}$ represents the coefficient for digitalization, measured by Fixed-Broadband Subscriptions (Count).
- $\boldsymbol{\epsilon}$ is the error term, accounting for variability not explained by the model.

This model assesses the statistical significance and strength of relationships between technological upgradation, digitalization, and export competitiveness, providing empirical evidence for how these factors influence national-level trade performance. The integration of quantitative methods ensures that statistical findings are supported by empirical data, strengthening the overall validity of the research conclusions. The results will provide policy-relevant recommendations for enhancing India's HVAC export performance in alignment with global best practices.

The statistical analysis for this study was carried out using EViews, a widely used econometric software well-suited for handling panel data and conducting regression models. This model evaluates both the statistical strength and the significance of each variable's impact on export competitiveness. Prior to analysis, the dataset was standardized to bring all variables onto a common scale, ensuring comparability across countries. This step was particularly important given the diversity in economic size, digital infrastructure, and trade performance among the 51 selected countries. Standardization also helped improve the consistency and reliability of the results by minimizing distortions caused by differences in units or data ranges (UNCTAD, 2021).

To ensure the robustness of the findings, several measures were taken to uphold validity and reliability. External validity is supported by the use of globally recognized trade and technology indicators, which allow the results to be applied more broadly, even beyond the HVAC sector (World Bank, 2023). Internal validity is enhanced by the inclusion of a diverse group of 51 low- and middle-income countries, helping to reduce selection bias and reflect a balanced mix of economies at different stages of technological advancement. Construct validity is ensured by relying on clear, widely accepted indicators to represent technological upgradation, digitalization, and export competitiveness (OECD, 2023).

Through this quantitative and econometric approach, the study offers a rigorous and comprehensive analysis of how technological transformation contributes to improving India's export competitiveness in the HVAC industry, framed within a global context.

This study employs panel data analysis which integrates both cross-sectional and time-series dimensions by observing the same set of countries over multiple years. This structure allows for a deeper understanding of variations not just across nations but also over time, it also offers insights into how macroeconomic factors evolve and interact. Panel regression models such as pooled ordinary least squares (POLS), fixed effects model, and random effect model are commonly used within this framework, with the choice of model depending on the characteristics of the data and underlying assumptions about country-specific differences.

In this study, the panel dataset covers 23-year period from 2000 to 2022 across 51 low-and-lower-middle-income countries (LLMICs) and includes three key variables: Exports of Goods and Services (% of GDP) as the dependent variable, and Fixed Broadband Subscriptions and Medium and High-Tech Exports (% of Manufactured Exports) as independent variables. Given the nature of the dataset, a panel regression approach was applied to account for both country-specific and time-specific effects, ensuring a more accurate analysis of the relationships among technological upgradation, digitalization, and export competitiveness.

Panel data offers several advantages over purely cross-sectional or time-series methods. By increasing the number of observations, it enhances the degrees of freedom, reduces multicollinearity among explanatory variables, and allows for the control of unobserved heterogeneity, thereby producing more efficient and reliable estimates (Baltagi, 2005; Faster Capital, 2024). In the context of this research, panel analysis enables an evaluation of how technological factors impact the export performance of economies similar to India, providing policy-relevant insights for the HVAC sector.

According to Baltagi (2005) and Wooldridge (2010), panel data methods improve estimation efficiency and reduce omitted variable bias when unobservable heterogeneity exists across units. To identify the most appropriate panel regression model in between Pooled OLS, Random Effects Model (REM), or Fixed Effects Model (FEM), a structured step by step approach was carried out using EViews software. The process starts with estimating a pooled OLS regression, which does not account for individual heterogeneity across countries and serves as a baseline model. Next, the Breusch-Pagan Lagrange Multiplier (BP-LM) test was conducted to assess whether a panel data structure with random or fixed effects would be more suitable than the pooled model. This test involved three key checks. First, the null hypothesis (H_0) assumes there is no panel effect, meaning the pooled model is adequate. Second, if the p-value is greater than 0.05, the null hypothesis cannot be rejected, suggesting that the pooled OLS model remains appropriate. Third, if the p-value is less than 0.05, the null hypothesis is rejected, indicating the presence of panel effects and the need to proceed with either REM or FEM.

Once panel effects were confirmed, the random effects model was estimated to account for both within country and between country variations. To determine whether the fixed or random effects model was more suitable, the Hausman test was applied. This test examines whether the unobserved individual effects are correlated with the explanatory variables. Here too, three steps were involved: the null hypothesis assumes that random effects are appropriate, meaning there is no such correlation. If the p-value is greater than or equal to 0.05, the null hypothesis cannot be rejected, and the REM is considered appropriate. However, if the p-value is less than 0.05, the null hypothesis is rejected and the fixed effects model is preferred as it yields consistent and unbiased estimates.

3.5. Sampling Strategy

This study adopts a purposive sampling approach by focusing on a sample of 51 low- and middle-income countries (LMICs). These countries were selected based on their economic similarities to India, particularly in terms of income levels and industrial development stages. The selection of countries is appropriate for this analysis, as it allows for meaningful comparisons across nations facing similar developmental challenges. By examining countries within this income bracket, the study aims to identify patterns and insights that are

relevant to India's context, especially concerning the adoption of technology and digital infrastructure in export-oriented industries. Data for these countries were sourced from the World Bank's World Development Indicators (WDI), ensuring consistency and reliability in the variables used for analysis. This sampling approach enhances the study's relevance and applicability, providing a robust framework for understanding how technological and digital advancements influence export competitiveness in economies comparable to India.

4. Results

To explore how technological upgradation and digitalization influence export competitiveness, a panel data regression was carried out. The dependent variable in the analysis was the Exports of goods and services (% of GDP) and the two main independent variables were Fixed broadband subscriptions (Count) (a proxy for digitalization) and high-tech exports (% manufactured exports) (representing technological upgradation).
The first step involved estimating a baseline model using pooled ordinary least squares (POLS). The results showed that high-tech exports had a positive and statistically significant effect on exports (p-value = 0.000), suggesting that countries investing more in advanced technological exports tend to perform better in terms of export competitiveness. However, the fixed broadband variable was statistically insignificant (p-value = 0.9766), indicating no clear impact on exports in this model. The low R-squared value (0.088) also indicated that the model explained only a small portion of the variation in export performance. Since POLS assumes that all observations are homogeneous and ignores any individual-specific effects, it was necessary to test whether this model was appropriate for the panel dataset.

To address this Breusch-Pagan LM test was conducted to check for cross-sectional dependence. The p-values from all three tests Breusch-Pagan LM, Pesaran scaled LM and Pesaran CD were 0.0000, which are all well below the 0.05 threshold. Thus, the null hypothesis of no cross-sectional variation is rejected. In simple terms, this confirms that the data exhibit significant panel effects, and the use of POLS would likely lead to biased results. Therefore, a more suitable panel model was required. Next, the Random Effects Model (REM) was estimated. The results were broadly consistent with the POLS output, with the high-tech exports variable remaining significant at the 1% level ($p = 0.000$) and the broadband subscriptions variable still showing no significant impact ($p = 0.9279$). The explanatory power of the model improved slightly, with an adjusted R2 of 0.144. This suggests that accounting for country-level heterogeneity improved the model's fit.

To determine whether the Random Effects or Fixed Effects model was more appropriate, a Hausman test was performed. The test shown a p-value of 0.9555, which is greater than the conventional 0.05 level ($p > 0.05$). Since the ($p > 0.05$), the null hypothesis cannot be rejected, suggesting that the random effects are uncorrelated with the regressors. This indicates that the Random Effects Model is statistically appropriate for this dataset, and it is also more efficient than the Fixed Effects alternative.

As shown in Table 1, based on the results of the Breusch-Pagan and Hausman tests, the Random Effects Model (REM) is statistically appropriate for the given panel data. The choice is validated by the insignificance of the Hausman test ($p > 0.05$), indicating that the unobserved individual effects are uncorrelated with the regressors.

The findings clearly suggest that only technological upgradation, which was captured through indicator, high tech exports show a statistically significant impact on export competitiveness and on other hand the proxy indicator of digitalization measured by fixed broadband subscriptions does not. Since the effect of digitalization is not statistically significant and the overall evidence does not support a consistent and strong influence from both variables, there are no sufficient grounds to reject the null hypothesis. Therefore, the null hypothesis (H_0) is retained, indicating that, based on the current model and dataset, there is no statistically significant impact of technological upgradation and digitalization on the export competitiveness of the HVAC industry in India.

Table 1. Results of the panel data analysis (randomized effect model).

Variable	Coefficient	Std. Error	T-Statistic	Prob.
Y (Exp_Comp)	22.96164	3.031665	7.573936	0.0000
X1(Tech_Upgrad)	1.03E-08	1.13E-07	0.090585	0.9279
X2 (Digital)	0.318576	0.037815	8.424558	0.0000
Effects Specification				
			S.D	Rho
	Cross-section random		14.41765	0.8319
	Idiosyncratic random		6.480289	0.1681
Weighted Statistics				
R-squared	0.147995	Mean dependent var		3.234458
Adjusted R-squared	0.144216	S.D. dependent var		6.970906
S.E. of regression	6.456999	Sum squared resid		18803.47
F- statistic	39.16973	Durbin-Watson stat		0.500612
Prob (F- statistic)	0.000000			
Unweighted Statistics				
R-squared	0.079716	Mean dependent var		31.47960
Sum squared resid	102016.5	Durbin-Watson stat		0.092272

5. Discussion

The findings of this study provide evidence that technological upgradation proxied through the indicator-Medium and High-Tech Exports (% of Manufactured Exports) has a statistically significant and positive effect on export competitiveness among low and middle-income countries. This reveals the validity of the proposed framework which suggests that innovation-oriented manufacturing can enhance a country's position in global trade by promoting higher value-added production, improving quality, and reducing reliance on price competition (Babina et al.,2022; Liu et al.,2023). To reach these conclusions, the study utilized a panel data regression model which captures both temporal and cross-sectional variations across countries (Baltagi, 2005; Wooldridge, 2010). Selecting 51 LMICs over a 23-year span this model facilitated a longitudinal evaluation of the factors driving export competitiveness. The initial estimation employed the Pooled Ordinary Least Squares (OLS) model, followed by the Breusch-Pagan Lagrange Multiplier (LM) test, which confirmed significant individual effects. Subsequently, the Hausman test indicated that the Random Effects Model (REM) was statistically appropriate, given the absence of correlation between the regressors and unobserved effects ($p > 0.05$). The REM demonstrated stronger explanatory power than the pooled model and upheld the statistical significance of technological advancement.

On other hand, digitalization which is measured by fixed broadband subscriptions in count, did not exhibit a statistically significant impact on export competitiveness. This outcome does not suggest that digitalization is irrelevant; rather, it implies that broadband access, while fundamental, may be too broad or basic a metric to capture the operational impacts of digital transformation fully. Digitalization encompasses a multifaceted array of technologies, including cloud computing, the Internet of Things (IoT), artificial intelligence (AI), e-commerce integration, and big data analytics (Matt & Raunch, 2020; Veldhoven & Vanthienen, 2021). The indicator used fixed broadband subscriptions per 100 people, captures general access to digital infrastructure but does not reflect how deeply digital tools are embedded into industrial operations. In actual, digitalization in India is playing an increasingly vital role in helping HVAC manufacturers move beyond traditional cost-based competition. Features like energy efficient automation, remote diagnostics, predictive maintenance and smart control systems are becoming essential for firms aiming to compete in global markets (Vishnuraj, 2023; Mahurkar, 2023).

India has taken important steps through initiatives such as the Digital India programme which was launched in 2015 and significantly expanded the country's digital backbone. Still, actual digital adoption across industrial sectors remains uneven. For example, the Smart Cities Mission is promoting the integration of intelligent HVAC systems into sustainable urban infrastructure, (Ministry of Electronics and IT, 2022). Similarly, the National IoT Policy (MeitY, 2021) highlights the use of connected devices many of which are directly relevant to HVAC systems. Moreover, programs under the Bureau of Energy Efficiency (BEE) and Energy Efficiency Services Limited (EESL) are incentivizing energy efficient appliances, encouraging HVAC manufacturers to incorporate AI based monitoring, smart sensors and digital energy management systems

into their product lines, (BEE, 2023; EESL, 2022). However, challenges persist. Many Indian HVAC firms, especially small and medium enterprises (SMEs) struggle to adopt digital technologies due to high costs, skill shortages, and limited ecosystem support (Mukherjee, 2018; Dixit & Bhasin, 2022). Bridging this gap calls for targeted policies that go beyond infrastructure.

Government schemes could play a more active role by offering financial incentives for adopting ERP systems, IoT technologies and cloud-based production tools. At the same time, Programs like Pradhan Mantri Kaushal Vikas Yojana (PMKVY) should continue expanding digital upskilling for workers in manufacturing sectors like HVAC (Ministry of Skill Development and Entrepreneurship, 2023). Furthermore, fiscal incentives for adopting ERP systems, AI tools, and digital twin technologies could accelerate transformation at the firm level. Finally, the absence of statistical significance in the broader panel analysis may simply reflect the limitations of using general macro indicators to capture sector level transformation. When viewed in the context of India's policy landscape and industrial priorities, digitalization is not just relevant but it is indispensable. Its real impact will be realized not just through access to broadband, but through how deeply digital tools are integrated day in day out workings of HVAC businesses.

5.1. Study Contributions and Limitations

Study employs a robust panel data approach over 23 years across 51 countries, identifying high-tech exports as a statistically significant driver of export competitiveness. It refines the understanding of how digitalization should be measured in the context of international trade performance. It challenges simplistic interpretations of digital access and advocates for a more nuanced appreciation of digital readiness, operational integration and sector specific digital practices. Moreover, by focusing on the HVAC industry, a sector often underexplored in export competitiveness literature, this study adds valuable insights that can inform industrial policy, trade strategy and technology promotion in emerging economies like India. Academically, this study contributes to the refinement of the measurement and conceptualization of export competitiveness drivers. It challenges the assumption that basic digital access directly enhances trade performance and it highlights the need of understanding of digital readiness and operational integration. It also demonstrates that while macro-level proxy indicators are useful, they can be complemented with sector-specific or firm-level data to yield more precise insights.

Practically, the findings have significant implications for policymakers and industry stakeholders. Government initiatives aimed at improving export competitiveness should extend beyond infrastructure development to promote technology intensive manufacturing, particularly in the HVAC sector. This includes increasing funding for research and development, incentivizing firms to adopt high efficiency and smart HVAC technologies and supporting certifications that align with global standards. Simultaneously, digital policies should focus on enterprise level support, offering incentives for the adoption of AI, IoT, and cloud-based systems among HVAC manufacturers, especially small and medium sized enterprises (SME's) that may lack the resources to undertake this transformation independently.

While the panel data approach enhances generalizability, it inevitably sacrifices granularity. The use of macro level proxy indicators, such as fixed broadband subscriptions and high-tech exports, is a limitation when exploring industry specific impacts. These indicators do not fully capture the practical integration of digital and technological tools at the firm level, particularly within the HVAC sector. Additionally, this study focuses on cross country data, which means country specific policy environments, institutional structures and digital readiness levels are not directly accounted for. India, for example, may possess unique strengths or barriers in digital transformation that are masked by regional averages. Future studies should incorporate micro level data including firm level adoption of digital technologies (IoT, Big data, etc.), research and development expenditure, patent activity and export diversification to provide a more precise understanding of the dynamics at play. Additionally, a mixed methods approach, combining econometric analysis with case studies or interviews, could also uncover context specific enablers and barriers to export competitiveness in HVAC industry.

6. Conclusions

This study reveals, how improvements in technology and the use of digital tools affect how well countries perform in exports, with a special focus on India's HVAC industry. The panel data analysis with Random Effect Model (REM) used for data from 51 low-and-lower-middle-income countries over 23-year period. The results clearly show that countries investing more in advanced technology, measured through high-tech exports as % of GDP tend to do better in international trade. On the other hand, simply having access to the internet through broadband does not seem to directly impact on export competitiveness. This suggests that digital infrastructure alone isn't enough, and it needs to be used actively within industries to make a difference. Beyond contributing to the ongoing policy debates around export-oriented growth, the study also builds on the conceptual understanding of how technology upgradation and digital transformation interact. It supports the idea that while digital infrastructure is a foundational enabler, it is technological capability reflected in product innovation, research and development intensity, and industry specific upgrades that directly strengthens a country's position in global markets. For researchers, this means future studies should adopt more refined indicators and possibly explore mixed methods approaches that combine national trends with firm-level insights. From a business strategy and policy planning perspective, the study provides two approaches. First, Indian HVAC firms should be encouraged and supported to adopt advanced technologies not only to improve product quality but also to meet increasingly stringent global market standards for energy efficiency and sustainability. Second, digital transformation efforts need to go beyond infrastructure development and instead focus on incentivizing digital tool adoption at the firm level through skill development, financial support for digital systems and sector specific digital readiness frameworks.

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