

How Technological Capability Accumulation Reshapes Industrial Competitiveness

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Abstract

This paper examines the relationship between innovation, research and development (R&D), technological transformation, and industrial competitiveness in an environment characterized by rapid technological and organizational change. The literature reviewed shows that competitiveness increasingly depends on firms' capacity to accumulate technological knowledge, absorb external information, protect and commercialize intellectual property, and transform research expenditure into sustained productivity improvements. The paper also considers the effects of Industry 4.0, artificial intelligence, robotics, digital platforms, FinTech, and blockchain on industrial performance, emphasizing that technological adoption generates stronger results when supported by adequate organizational capabilities, skills, data resources, and managerial practices. A further dimension concerns the increasing integration of environmental sustainability with industrial strategy through green innovation, digital supply chains, servitization, and resilience-oriented production systems. The literature indicates that these transformations are influenced by institutional conditions, industrial policies, competitive pressures, and innovation ecosystems. Overall, the paper argues that contemporary industrial competitiveness cannot be explained by technological investment alone. It results from interactions among R&D, organizational capabilities, external knowledge, human capital, digital transformation, sustainability strategies, institutional quality, and the capacity of firms to commercialize and operationalize technological advances.

Keywords: R&D; Innovation; Industrial competitiveness; Digital transformation; Technological capabilities

JEL classification: O31; O32; O33; L60; O25

Introduction

Industrial competitiveness has traditionally been associated with productivity, production costs, investment, and firms' capacity to maintain or expand their positions in domestic and international markets. Technological change has progressively modified this interpretation by placing innovation, knowledge accumulation, and research and development at the center of industrial performance. Firms increasingly compete through their ability to generate new products, improve production processes, incorporate external knowledge, and transform technological resources into commercially valuable outcomes. R&D expenditure consequently represents more than a current input into innovation. It contributes to the cumulative development of tech-



nological capabilities that influence future productivity, organizational learning, and firms' capacity to respond to changing market conditions. The literature reviewed in this paper indicates that these effects are neither immediate nor homogeneous. Their magnitude depends on firm size, industrial characteristics, strategic positioning, absorptive capacity, knowledge spillovers, and access to complementary organizational resources. International market exposure can further modify incentives for technological investment by increasing the expected returns associated with innovation. Industrial competitiveness should therefore be considered as a dynamic process in which internal research efforts interact with external knowledge environments, organizational capabilities, and market opportunities to determine the productive and commercial consequences of technological investment.

The technological environment in which these processes occur has itself undergone substantial transformation. Industry 4.0, artificial intelligence, robotics, digital platforms, blockchain, and digitally integrated supply chains have expanded the range of technologies available to industrial firms while simultaneously increasing organizational requirements for successful implementation. Digital transformation is consequently not reducible to equipment acquisition or software adoption. It requires firms to develop competencies, reorganize routines, involve employees, integrate data across organizational boundaries, and adapt technological choices to specific production and market objectives. At the same time, environmental sustainability has become increasingly connected with industrial strategy. Green innovation, resource efficiency, sustainable supply-chain practices, resilience, and digital servitization now influence cost structures, differentiation possibilities, stakeholder relationships, and long-term competitiveness. These developments also increase the importance of public policies, institutional quality, intellectual-property protection, skills, and innovation ecosystems. The purpose of this paper is therefore to examine how R&D, technological capabilities, digital transformation, sustainability, and institutional conditions jointly reshape industrial competitiveness. Rather than considering these dimensions independently, the paper treats contemporary competitiveness as the result of complementarities among technological resources, organizational capacities, knowledge networks, human capital, market conditions, and supportive institutional arrangements.

1. R&D, Knowledge and Technological Capabilities as Foundations of Industrial Competitiveness

1.1. R&D Investment, Innovation and Productivity

Audretsch and Belitski (2020) imply that industrial competitiveness depends on firms' ability to combine internal R&D with external knowledge spillovers, since productivity and innovation reflect both proprietary research and access to broader knowledge environments. Raymond et al. (2015) reinforce this dynamic interpretation by showing that R&D affects productivity through persistent innovation processes rather than through an immediate one-period effect. Bond and Guceri (2017) add firm-level evidence that sustained research expenditure is positively associated with productivity among UK establishments where R&D represents an economically significant activity. Lee et al. (2019) further demonstrate that technological investment and operational efficiency are complementary sources of performance, indicating that knowledge creation alone is insufficient unless firms can translate research outputs into efficient production and organizational routines. Taken together, these contributions imply that R&D should be understood as an accumulated capability embedded within wider organizational and knowledge systems. Its contribution to competitiveness emerges progressively through innovation, learning, productivity improvement, and operational exploitation. Firms therefore ob-



tain stronger benefits when internal research capacity is accompanied by mechanisms that absorb external knowledge and convert technological advances into more efficient commercial and productive processes.

Baumann and Kritikos (2016) imply that firm size influences the probability of undertaking R&D but does not eliminate the productivity benefits available to smaller firms that successfully invest in innovation. Wadho and Chaudhry (2018) extend this perspective to Pakistani manufacturing by showing that innovation can improve productivity in traditional industries, although organizational capabilities and access to knowledge condition firms' capacity to generate those gains. Ugur et al. (2016) provide an important qualification by showing that private and social returns to R&D are positive on average but heterogeneous across industries, datasets, complementarities, and time horizons. Guo et al. (2018) add a strategic dimension by demonstrating that the performance consequences of R&D depend partly on firms' competitive positioning and resource-allocation choices. Together, these contributions imply that technological investment does not produce uniform returns across firms. Smaller enterprises and firms in developing economies can achieve substantial productivity improvements from R&D, but outcomes depend on organizational capability, strategic coherence, knowledge access, and industry conditions. The competitive value of research expenditure therefore lies not simply in its magnitude but in the capacity of firms to align technological investment with complementary resources and an appropriate market strategy.

Peters et al. (2022) imply that exposure to larger export markets can increase incentives for R&D by raising the expected commercial returns to innovative activity. This perspective connects with Audretsch and Belitski (2020), who show that firms benefit when internally generated knowledge is combined with external spillovers, suggesting that international exposure can widen both market opportunities and access to knowledge. Guo et al. (2018) further indicate that R&D performance depends on strategic positioning, meaning that firms must align technological investment with differentiation and market objectives if innovation is to generate commercial value. Raymond et al. (2015) add that the effects of R&D are inherently dynamic, with research contributing to later innovation and productivity rather than producing immediate gains. Considered together, these contributions imply that industrial competitiveness emerges from interactions among market scale, knowledge accumulation, strategic positioning, and firms' ability to sustain innovation over time. Internationalization can strengthen incentives to innovate, but the resulting benefits depend on whether firms possess sufficient research capabilities and organizational mechanisms to convert larger market opportunities into productive technological investment and persistent productivity improvements.

1.2. Absorptive Capacity, Open Innovation and External Knowledge

Tzokas et al. (2015) imply that external knowledge contributes to industrial competitiveness only when firms possess sufficient absorptive capacity to recognize, assimilate, and exploit it through technological capabilities and customer relationships. Liu et al. (2021) reinforce this mechanism by showing that absorptive capacity converts external knowledge into competitive advantage partly through improvements in labor productivity, making knowledge integration economically meaningful only when it modifies productive routines. Ali et al. (2016) add that high performance can emerge from different configurations of absorptive capacity and organizational innovation rather than through one universal sequence of capabilities. Gómez et al. (2017) further demonstrate that information technology can facilitate the coordination and exploitation of external knowledge in open-innovation processes, although its benefits depend on organizational arrangements. Taken together, these contributions imply that access to external technological information is not sufficient for performance improvement. Firms require complementary capabilities for selecting, processing, integrating, and operationalizing knowledge.



Digital infrastructure can facilitate these processes, but organizational alignment determines whether external information becomes innovation and productivity. Absorptive capacity therefore acts as a central mechanism linking increasingly open and technologically complex knowledge environments to sustainable competitive performance.

Asimakopoulou et al. (2020) imply that external knowledge sourcing can improve innovation efficiency when firms are capable of selecting and absorbing heterogeneous information without allowing search and coordination costs to become excessive. Baum et al. (2019) reinforce this conditional interpretation by showing that the productivity effects of external knowledge vary according to firms' innovation strategies, indicating that greater openness is not automatically superior. Si et al. (2020) add that different knowledge sources contribute differently to product and process innovation, making the alignment between sourcing strategy and innovation objective particularly important. Goyal et al. (2020) further distinguish customer co-creation from partner-based knowledge sourcing and show that the origin of information shapes subsequent knowledge creation and innovation outcomes. Together, these contributions imply that industrial firms need selective rather than indiscriminate openness. Expanding the number and diversity of external knowledge sources can increase technological opportunities, but it also raises integration complexity. Competitive benefits are more likely when firms identify sources that complement existing capabilities and correspond to the specific product or process innovations being pursued. External knowledge therefore becomes strategically valuable through its fit with internal resources, innovation objectives, and organizational capacity for coordination. Zhang et al. (2018) imply that open innovation can strengthen manufacturing performance when firms effectively manage inbound and outbound knowledge flows and integrate external technological resources into internal innovation processes. Gómez et al. (2017) provide a complementary digital mechanism by showing that information technology supports the coordination of external knowledge, thereby increasing the effectiveness of open-innovation activities when organizational structures are appropriately designed. Tzokas et al. (2015) add that technological capabilities and customer relationships determine whether acquired knowledge can be transformed into useful competitive resources. Asimakopoulou et al. (2020) further demonstrate that the efficiency gains from external sourcing depend on firms' ability to absorb heterogeneous knowledge without incurring disproportionate coordination costs. Considered together, these contributions imply that industrial competitiveness increasingly depends on firms' capacity to orchestrate knowledge networks rather than rely exclusively on internally generated technologies. Open innovation expands the technological resource base available to manufacturers, but it also creates managerial demands related to partner selection, information integration, digital coordination, and absorptive capacity. Firms that develop these complementary capabilities are better positioned to transform technological openness into innovation efficiency, productivity, and durable competitive advantage.

1.3. Patents, Intellectual Property and Technological Capabilities

Maresch et al. (2016) imply that patents contribute to firm performance only under particular competitive and technological conditions, since their economic value varies with both market rivalry and the stage of the patent life cycle. Ambrammal and Sharma (2016) reinforce this appropriability perspective by showing that patenting is associated with stronger performance among Indian manufacturing firms, although the relationship depends on organizational and technological characteristics. Barbu and Militaru (2019) add that intellectual property rights strengthen the relationship between innovation and manufacturing performance by helping firms protect and exploit the knowledge generated through innovative activity. Hungund (2020) extends this mechanism to Indian software-product firms, where systematic intellectual-property management, formal protection, and commercialization practices are associated



with stronger performance. Taken together, these contributions imply that innovation alone does not guarantee competitive advantage. Firms must also possess mechanisms that allow them to retain and commercialize part of the value created by technological investment. Intellectual property therefore functions as a complementary strategic capability whose contribution depends on competitive conditions, organizational routines, and the ability to convert protected knowledge into marketable outputs. The value of patents should consequently be evaluated through their strategic use rather than their mere presence.

Dindaroğlu (2018) implies that patent counts provide an incomplete representation of technological competitiveness because patents differ substantially in quality, technological importance, and appropriability. Danish et al. (2020) reinforce this interpretation in the Indian pharmaceutical industry by showing that economically valuable patents contribute more meaningfully to firm outcomes than simple accumulation of patent numbers. Christodoulou et al. (2018) add evidence from China that patent productivity varies considerably across business areas and ownership structures, indicating that expanding inventive activity does not automatically produce equivalent productive benefits. Wang et al. (2020) further demonstrate that patent outcomes increasingly emerge from interorganizational cooperation networks, with different network structures producing different innovation results among technology-based SMEs. Together, these contributions imply that industrial competitiveness depends on the quality, productivity, and organizational context of firms' patent portfolios rather than on patent volume alone. Firms capable of generating commercially relevant inventions and embedding them within effective internal or collaborative structures are better positioned to obtain lasting benefits from intellectual property. Patent-based indicators should therefore distinguish between simple inventive output and the technological assets that genuinely contribute to innovation performance, productivity, and market differentiation.

Plank and Doblinger (2018) imply that public R&D support can strengthen firm-level innovation when technological uncertainty and externalities discourage sufficient private investment, particularly in emerging technological sectors such as renewable energy. Wang et al. (2020) provide a complementary organizational mechanism by showing that SMEs can compensate for limited internal R&D resources through appropriately structured patent-cooperation networks. Christodoulou et al. (2018) further demonstrate that the productive value of patents depends on firms' capacity to commercialize and exploit technological outputs rather than simply generate registered inventions. Danish et al. (2020) add that patent quality is especially important for performance in technology-intensive industries, since differentiated and commercially relevant inventions produce stronger outcomes than numerical patent accumulation. Considered together, these contributions imply that technological competitiveness emerges from interactions among public support, collaborative networks, patent quality, and commercialization capacity. Public intervention can stimulate research where private incentives are insufficient, while cooperation can broaden the technological resources available to smaller firms. However, neither funding nor collaboration guarantees performance unless resulting inventions possess sufficient quality and firms can convert them into economically valuable products, processes, or protected technological positions.

2. Technological Transformation and the Reconfiguration of Industrial Performance

2.1. Industry 4.0 and Digital Transformation

Dalenogare et al. (2018) imply that Industry 4.0 should not be treated as a homogeneous technological package because individual technologies contribute differently to operational and



competitive performance. Synnes and Welo (2016) reinforce this selective perspective by showing that manufacturing competitiveness depends on integrative capabilities that reconcile high-volume efficiency with low-volume flexibility and customization. Buer et al. (2021) add that digitalization patterns differ according to company size and production environment, making technological fit an important condition for performance. Szász et al. (2021) further demonstrate that the benefits of Industry 4.0 vary with organizational and environmental conditions, supporting a contingent rather than universal interpretation of digital transformation. Taken together, these contributions imply that successful manufacturing digitalization depends less on maximizing the number of technologies adopted than on selecting configurations consistent with firms' production systems and strategic objectives. Connectivity, automation, analytics, and integrated manufacturing technologies can strengthen competitiveness, but their contribution varies with scale, operational architecture, and market requirements. Industry 4.0 therefore generates stronger performance when technological choices are deliberately matched to the forms of flexibility, efficiency, customization, and responsiveness that firms seek to develop. Vogelsang et al. (2019) imply that digital transformation in manufacturing is fundamentally an organizational capability-building process because technological implementation requires management commitment, appropriate competencies, and coherent processes of change. Agostini and Filippini (2019) reinforce this interpretation by showing that Industry 4.0 creates substantial coordination demands when advanced technologies must be integrated with established routines, structures, and workforce practices. Tortorella et al. (2021) add a human-capital mechanism by demonstrating that employee involvement mediates the relationship between Industry 4.0 implementation and operational performance, indicating that technological systems create value partly through workforce participation. Lin et al. (2023) further show that the performance effects of Industry 4.0 depend on internal capabilities as well as external competitive conditions. Together, these contributions imply that manufacturers cannot obtain durable competitive benefits from digital technologies through equipment acquisition alone. Digital transformation requires complementary investments in skills, managerial practices, organizational structures, and employee participation. The ability to integrate technological information into routines and continuous improvement processes therefore becomes as important as the technology itself. Firms with stronger organizational foundations are better positioned to translate connected production systems into measurable improvements in productivity, flexibility, and competitive performance.

Somohano-Rodríguez and Madrid-Guijarro (2022) imply that competitive intensity influences both the incentives for Industry 4.0 adoption and the returns firms obtain from digital technologies, making digitalization a strategic response to rivalry as well as an efficiency-enhancing investment. Szász et al. (2021) provide a complementary contingency perspective by showing that organizational and environmental conditions determine whether technological investments generate superior outcomes. Lin et al. (2023) similarly demonstrate that external competitive conditions interact with internal implementation capabilities in shaping manufacturing performance. Dalenogare et al. (2018) add that technologies should be selected according to the specific performance dimensions firms seek to improve rather than adopted as an undifferentiated bundle. Considered together, these contributions imply that Industry 4.0 influences industrial competitiveness through interactions between market pressure, technological choice, and organizational readiness. Intense rivalry can encourage manufacturers to digitalize, but adoption will not necessarily create equivalent advantages when firms differ in skills, scale, production systems, or strategic priorities. Digital transformation therefore becomes competitively valuable when organizations identify technologies suited to their market challenges and possess the complementary capabilities required to convert those technologies into operational and strategic improvements.



2.2. Artificial Intelligence, Robotics and Automation

Acemoglu et al. (2020) imply that robot adoption can strengthen the competitive position of individual firms even when the aggregate employment consequences of automation are more complex, since adopting firms improve productivity and expand relative to competitors. Koch et al. (2021) reinforce this interpretation by showing that Spanish manufacturers adopting robots experience higher output and productivity and can also increase employment within the firm, although adoption is concentrated among businesses that already possess favorable characteristics. Graetz and Michaels (2018) provide a broader cross-country perspective by linking greater robot use to productivity growth and demonstrating that automation contributes materially to industrial performance. Cheng et al. (2019) add that robotics adoption in China responds to rising labor costs, industrial policy, and technological catch-up, making automation part of a broader strategy for sustaining manufacturing competitiveness. Taken together, these contributions imply that robotics can generate a self-reinforcing competitive process. Firms and countries with stronger technological, financial, and organizational capabilities are better positioned to adopt automation, after which productivity improvements can further strengthen their market positions. Robotics therefore affects competitiveness through both technological upgrading and competitive redistribution rather than through labor substitution alone.

Babina et al. (2024) imply that artificial intelligence can strengthen firm competitiveness through growth and product innovation rather than solely through reductions in operating costs, particularly when firms develop complementary AI-related human capital. Rammer et al. (2022) reinforce this capability-based interpretation by showing that AI use is associated with stronger innovation activity when organizations possess the knowledge, data, and complementary resources required to exploit the technology. Gao and Feng (2023) add a productivity mechanism by linking AI adoption to improvements in decision-making, resource allocation, and operational efficiency. Balsmeier and Woerter (2019) broaden the discussion by showing that digitalization restructures employment and changes the skill composition required by firms rather than producing a uniform decline in labor demand. Together, these contributions imply that AI and digital technologies create competitive advantages through complementarities between technology and human capital. Algorithms alone do not guarantee productivity or innovation gains; firms must develop skills, data resources, and organizational routines that allow these tools to be integrated into production and innovation processes. The uneven distribution of these complementary capabilities can therefore generate widening performance differences between technologically advanced firms and organizations that remain unable to exploit digital transformation effectively.

Duan et al. (2023) imply that industrial robots can generate substantial productivity improvements when automation is integrated effectively into firm-level production processes. This perspective connects with Graetz and Michaels (2018), who show across countries that robot adoption contributes positively to productivity growth, indicating that automation represents a significant source of industrial upgrading. Babina et al. (2024) extend the technological argument toward artificial intelligence by demonstrating that investments in AI-related capabilities support firm growth and new-product development, while Cheng et al. (2019) show that automation strategies are themselves shaped by changing labor costs, policy support, and technological catch-up. Considered together, these contributions imply that contemporary industrial competitiveness increasingly depends on firms' capacity to combine multiple forms of advanced technology with complementary organizational capabilities. Automation and AI can improve productivity, support innovation, and strengthen market position, but adoption incentives and



returns vary according to firm characteristics and national industrial conditions. Technological transformation may therefore widen competitive differences when capable firms adopt earlier and accumulate further productivity advantages. Sustained competitiveness requires not merely access to robotics or AI but the organizational, human, and policy capabilities needed to convert these technologies into productive and innovative outcomes.

2.3. Digital Platforms, FinTech and Blockchain as Competitive Technologies

Cenamor et al. (2019) imply that digital platforms can reduce some of the competitive disadvantages associated with limited SME scale, but only when firms possess platform capabilities, network capabilities, and sufficient organizational ambidexterity to coordinate relationships across digital ecosystems. Jiang et al. (2023) reinforce this capability-based interpretation by showing that SME innovation benefits arise when firms can effectively use platforms to access information, partners, and market resources rather than through platform adoption alone. Xie et al. (2022) extend the mechanism toward business-model innovation, demonstrating that digital-platform participation can reshape value creation, customer relationships, and revenue structures through organizational capability reconfiguration. Jun et al. (2022) further show that digital infrastructure generates stronger innovation performance when combined with organizational readiness and improvisational capabilities that allow firms to respond rapidly to emerging opportunities. Taken together, these contributions imply that platformization strengthens competitiveness through connectivity and resource orchestration rather than simple technological access. SMEs can enlarge their effective market reach and compensate partly for resource limitations, but competitive benefits depend on their ability to reorganize internal resources, manage ecosystem relationships, and adapt business models. Digital platforms therefore become productive strategic assets when technological connectivity is combined with dynamic organizational capabilities.

Gaglio et al. (2022) imply that digital transformation can improve innovation and productivity among small manufacturing firms in emerging economies, although the magnitude of these benefits depends on firms' underlying capabilities. El Hamidi et al. (2020) provide a complementary Moroccan perspective by showing that lower information costs, automated processes, blockchain functionality, simplified exchanges, and competitive pressure encourage SMEs to adopt digital loyalty programs. Ait Hbib et al. (2024) extend this mechanism to B2B FinTech platforms, where cost reduction, financing access, market expansion, innovation culture, firm size, and government support influence adoption. Makhrouf et al. (2024) add an important qualification by demonstrating that blockchain adoption remains constrained by complexity, perceived costs, and risk, while compatibility and opportunities for experimentation facilitate technological uptake. Together, these contributions imply that SME digitalization simultaneously reflects competitive incentives and organizational constraints. Digital technologies can reduce transaction costs, expand customer and market access, and improve operational coordination, but adoption requires firms to absorb implementation costs and technological uncertainty. Competitiveness therefore depends not simply on whether new technologies exist but on whether SMEs possess supportive innovation cultures, compatible processes, institutional support, and sufficient capacity to experiment with and integrate them.

Errassaa et al. (2023) imply that technological competitiveness and financial flexibility are increasingly interconnected because Moroccan SMEs' willingness to adopt crowdfunding depends positively on digitalization alongside knowledge, perceptions, and social networks. Ait Hbib et al. (2024) reinforce this relationship by showing that B2B FinTech adoption can widen access to finance while simultaneously reducing costs and expanding markets, suggesting that digital platforms can affect several dimensions of SME competitiveness at once. El Hamidi et al. (2020) add that digital loyalty systems improve customer–firm interactions through lower information



and exchange costs, indicating that FinTech-related technologies can influence competitive positioning beyond financing itself. Gaglio et al. (2022) provide the broader emerging-economy perspective by demonstrating that digital transformation can support both innovation and productivity among small manufacturers. Considered together, these contributions imply that digital competitiveness increasingly emerges from complementarities between technological, financial, and organizational capabilities. SMEs capable of integrating digital customer systems, financing platforms, and broader digital technologies can reduce transaction frictions and access additional resources for expansion and innovation. However, these benefits remain dependent on internal digital readiness and the ability to convert technological adoption into productive organizational change.

3. Sustainable, Organizational and Institutional Sources of Industrial Competitiveness

3.1. Green Innovation and Sustainable Industrial Competitiveness

Wang (2019) implies that green innovation becomes more competitively valuable when environmental objectives are embedded in organizational culture rather than pursued through isolated projects, since green culture supports continuous innovation and stronger environmental performance. Weng et al. (2015) reinforce this interpretation by showing that stakeholder expectations can stimulate environmental innovation in ways that improve both ecological and corporate performance. Tang et al. (2018) add a managerial dimension by demonstrating that environmental concern and organizational conditions shape the financial consequences of green innovation, indicating that management must recognize environmental change as a strategic opportunity. Cai and Li (2018) further show that eco-innovation results from interactions between internal capabilities and external pressures such as environmental regulation and market demand. Taken together, these contributions imply that green innovation contributes to industrial competitiveness when firms integrate environmental objectives into managerial priorities, organizational routines, and technological investment. External pressure can encourage adoption, but firms obtain stronger performance benefits when internal culture and managerial commitment allow environmental requirements to be converted into resource efficiency, product improvement, and strategic differentiation rather than treated solely as compliance obligations.

Hojnik and Ruzzier (2017) imply that eco-innovation can generate competitive advantages through several channels, including cost reduction, differentiation, reputation, and improved market positioning. Chen and Liu (2019) reinforce this strategic interpretation by showing that the capacity to profit from green innovation depends on its alignment with firms' broader competitive strategies, distinguishing technological achievement from effective value capture. Tariq et al. (2019) add that green product innovation can be associated with higher profitability and lower financial risk, while market-resource intensity and environmental conditions influence the strength of these relationships. Brasil et al. (2016) extend this perspective to the Brazilian textile industry, demonstrating that eco-innovation can improve business performance even in traditional manufacturing sectors exposed to regulatory, resource, and market pressures. Together, these contributions imply that environmental innovation is not confined to technologically advanced industries and does not automatically create financial value. Its contribution depends on whether firms can use green technologies to strengthen differentiation, improve efficiency, manage risk, or respond to changing customer expectations. Sustainable competitiveness therefore requires firms to connect environmental innovation explicitly with market positioning and operational strategy.



Touil et al. (2023) imply that green transformation among Moroccan SMEs depends on economic and energy-efficiency considerations as well as stakeholder pressure and profitability, indicating that sustainability adoption is closely connected with competitive and resource-management objectives. Cai and Li (2018) provide a complementary perspective by showing that environmental regulation, market demand, and organizational capabilities jointly shape eco-innovation decisions. Weng et al. (2015) further demonstrate that stakeholder expectations can encourage green innovation capable of simultaneously improving environmental and corporate outcomes. Hojnik and Ruzzier (2017) add that these innovations can generate competitive advantages when they translate into lower costs, differentiation, reputation, or improved market positioning. Considered together, these contributions imply that sustainable industrial competitiveness emerges from interactions between external pressure and internal economic incentives. Firms are more likely to adopt environmental technologies and green supply-chain practices when sustainability contributes to efficiency, profitability, and stakeholder legitimacy. Environmental adaptation therefore becomes more durable when it is supported by business benefits rather than dependent exclusively on regulatory pressure, allowing firms to integrate ecological objectives into broader strategies of competitiveness and operational improvement.

3.2. Digital and Sustainable Supply Chains, Servitization and Resilience

Ivanov and Dolgui (2020) imply that industrial competitiveness increasingly depends on the ability of supply networks to remain viable under severe disruption rather than merely achieve efficiency under normal operating conditions. Belhadi et al. (2021) reinforce this resilience perspective by showing that localization, Industry 4.0 technologies, real-time information, big-data capabilities, and interorganizational cooperation help automotive supply chains respond to COVID-19 disruptions. Büyüközkan and Göçer (2018) provide the technological foundation for this argument by demonstrating that digital supply chains improve connectivity, visibility, analytics, and integration across suppliers and customers. Oubrahim et al. (2023) extend the evidence to Moroccan manufacturing by showing that digital transformation improves sustainable supply-chain performance partly through stronger supply-chain integration. Taken together, these contributions imply that digitalization creates competitive value when it strengthens coordination beyond the boundaries of the individual firm. Data visibility, connected technologies, and information sharing improve firms' capacity to adapt production, reorganize sourcing, and preserve operational continuity when external conditions change. Supply-chain digitalization therefore contributes to competitiveness through both efficiency and resilience, but its benefits depend on whether firms use technology to develop integrated and adaptable interorganizational networks rather than isolated internal digital systems.

Martín-Peña et al. (2018) imply that digitalization facilitates servitization by enabling continuous connectivity, data collection, and customer interaction, allowing manufacturers to move beyond one-off product sales toward service-oriented business models. Crozet and Milet (2017) reinforce the economic relevance of this transformation by showing that adding services can affect manufacturing performance and alter firms' revenue structures and differentiation strategies. Martín-Peña et al. (2020) further demonstrate that digital technologies support the development and delivery of service offerings, although firms must undertake complementary organizational transformation to obtain performance benefits. Opazo-Basáez et al. (2018) add an environmental dimension by showing that digital and green servitization can jointly generate productivity benefits within the automotive industry. Together, these contributions imply that manufacturing competitiveness increasingly depends on the integration of products, services, and digital capabilities. Digital technologies allow firms to maintain longer-term customer relationships, generate data-intensive solutions, and create new sources of value beyond the phys-



ical product itself. Servitization therefore becomes more competitively effective when manufacturers possess sufficient organizational capabilities to redesign business models and when digital services simultaneously support efficiency, customer value, and environmental objectives. Touil et al. (2024) imply that sustainable supply-chain practices can contribute directly to corporate financial performance when green technologies, supplier-cost management, sustainability-oriented contracting, production optimization, transparency, and traceability reduce transaction frictions. Opazo-Basáez et al. (2018) provide a complementary mechanism by showing that digital and environmental servitization can reinforce one another and generate productivity advantages through more efficient resource use and differentiated customer offerings. Oubrahim et al. (2023) further demonstrate that digital transformation improves sustainable supply-chain performance when it strengthens integration across organizational boundaries. Büyükköçkan and Göçer (2018) add that connectivity, visibility, and analytics are central capabilities of digitally integrated supply chains. Considered together, these contributions imply that digital and sustainable transformation should not be treated as separate industrial strategies. Technologies that improve information flows and coordination can also support traceability, resource efficiency, sustainable contracting, and environmental management. Their competitive value is therefore strongest when firms combine digital infrastructure with supply-chain integration and sustainability-oriented organizational practices. Industrial competitiveness increasingly reflects the ability to coordinate technological, environmental, and interorganizational capabilities in ways that improve both operational and financial performance.

3.3. Industrial Policy, Regulation, Skills and Innovation Ecosystems

Aghion et al. (2015) imply that industrial policy can strengthen technological competitiveness when public support is designed to preserve rivalry among firms rather than shield selected incumbents from competitive pressure. Amable et al. (2016) reinforce this conditional interpretation by showing that the effects of product-market regulation on innovation and productivity depend on industries' distance from the technological frontier, meaning that liberalization cannot be expected to produce identical outcomes in every technological context. Melo et al. (2015) add that industrial policy must address capability accumulation and technological gaps rather than simply provide financial or human resources, since firms may lack the incentives or organizational foundations required for sustained innovation. Atkeson and Burstein (2019) further demonstrate that innovation subsidies can generate important welfare effects while producing only modest medium-term output gains, emphasizing the importance of spillovers, firm heterogeneity, and dynamic responses. Taken together, these contributions imply that effective innovation policy requires more than broad financial support or deregulation. Public intervention becomes more productive when it strengthens capabilities, preserves competition, and accounts for firms' technological positions. Industrial policy should therefore be calibrated to sectoral conditions and designed to encourage cumulative learning and innovative investment without creating persistent protection from market discipline.

Brown et al. (2017) imply that institutional conditions governing intellectual-property protection, accounting standards, and contract enforcement can be more important for private R&D investment than isolated tax incentives. Spring et al. (2017) reinforce this institutional perspective by showing that high-value manufacturing depends on organizational and institutional mechanisms capable of bridging research and commercial production, including intermediate research organizations that reduce commercialization failures. Melo et al. (2015) similarly emphasize cumulative capability formation as a prerequisite for reducing technological gaps, while Aghion et al. (2015) show that state support produces stronger outcomes when firms remain exposed to competitive pressure. Together, these contributions imply that technological competitiveness depends on an innovation system rather than on single policy instruments. Firms



require credible appropriability rules, financing institutions, research-commercialization linkages, and incentives to invest in innovation under competitive conditions. Subsidies may support technological activity, but their effect is likely to remain limited when contract enforcement, knowledge transfer, or commercialization institutions are weak. Industrial upgrading therefore requires coherent institutional arrangements capable of connecting research resources, firm capabilities, market incentives, and competitive selection.

Maisiri and van Dyk (2021) imply that Industry 4.0 competitiveness depends fundamentally on workforce capabilities because digital and interconnected production systems require systematic reskilling rather than equipment acquisition alone. Adebajo et al. (2023) reinforce this conclusion by identifying human capital as the most important readiness dimension for Industry 4.0, followed by interoperability and data-handling capabilities. Spring et al. (2017) add that broader institutional architectures are required to connect technological research with commercial manufacturing, indicating that firm-level skills must be supported by effective innovation institutions. Brown et al. (2017) further show that institutional quality affects firms' willingness to undertake R&D, linking technological readiness with appropriability and contracting conditions. Considered together, these contributions imply that digital industrial transformation depends on complementarities between technology, skills, institutions, and organizational readiness. Advanced manufacturing technologies can generate productivity gains only when firms possess employees capable of operating, interpreting, and adapting digital systems and when information can move effectively across organizational boundaries. Sustainable technological competitiveness therefore requires parallel investment in human capital, interoperability, data capabilities, and supportive innovation institutions rather than a technology-centered modernization strategy.

4. Discussion

The literature first indicates that the relationship between R&D and industrial competitiveness is cumulative and strongly dependent on complementary capabilities. Audretsch and Belitski (2020) emphasize that firms benefit from combining internal R&D with external knowledge spillovers, while Raymond et al. (2015) show that research affects productivity through persistent innovation processes rather than immediate effects. Bond and Guceri (2017) similarly associate sustained R&D expenditure with stronger productivity among firms for which research constitutes an economically meaningful activity. These findings suggest that expenditure alone provides an incomplete explanation of technological performance. Baumann and Kritikos (2016) show that smaller firms can obtain productivity benefits from innovation despite being less likely to undertake formal R&D, while Wadho and Chaudhry (2018) demonstrate that organizational capabilities condition the productivity consequences of innovation in developing-country manufacturing. Ugur et al. (2016) further identify substantial heterogeneity in R&D returns across industries and time horizons. This interpretation is reinforced by Tzokas et al. (2015) and Liu et al. (2021), for whom absorptive capacity determines whether externally acquired knowledge can be transformed into productive capabilities. Industrial competitiveness consequently depends on the interaction between research expenditure, knowledge absorption, organizational learning, and firms' ability to operationalize technological resources rather than on R&D intensity considered in isolation.

A second result concerns the increasingly organizational character of digital competitiveness. Dalenogare et al. (2018) show that Industry 4.0 technologies do not generate identical performance effects and should therefore be selected according to the operational objectives pursued by firms. Szász et al. (2021) similarly emphasize the importance of organizational and environmental contingencies, while Vogelsang et al. (2019) identify managerial commitment, competencies, and organizational change as central elements of digital transformation. Tortorella et



al. (2021) further demonstrate that employee involvement contributes to the translation of Industry 4.0 adoption into operational performance. Comparable complementarities appear in automation and artificial intelligence. Graetz and Michaels (2018) associate industrial robot adoption with productivity growth, and Koch et al. (2021) find positive output and productivity effects among robot-adopting manufacturers. Babina et al. (2024), however, extend the interpretation beyond automation by showing that AI can contribute to growth and product innovation when firms develop complementary human capital. Rammer et al. (2022) likewise connect AI use with innovation where appropriate data, knowledge, and organizational resources exist. These studies therefore suggest that technological diffusion can widen performance differences between firms because access to technology is not equivalent to the capacity to use it effectively. A third dimension concerns the increasing convergence between technological competitiveness, sustainability, resilience, and institutional conditions. Wang (2019) and Weng et al. (2015) show that green innovation produces stronger organizational and environmental outcomes when sustainability is incorporated into internal culture and stakeholder relationships. Hojnik and Ruzzier (2017) further identify cost reductions, differentiation, reputation, and market positioning as mechanisms through which eco-innovation can support competitive advantage. The same logic extends to industrial networks. Ivanov and Dolgui (2020) emphasize supply-chain viability under disruption, while Büyüközkan and Göçer (2018) associate digital supply chains with greater connectivity, visibility, and integration. Oubrahim et al. (2023) show that digital transformation can improve sustainable supply-chain performance through stronger integration, and Touil et al. (2024) connect sustainable supply-chain practices with corporate financial performance. These firm-level transformations remain dependent on wider institutional arrangements. Aghion et al. (2015) argue that industrial policy is more effective when public support preserves competition, whereas Melo et al. (2015) emphasize technological capability accumulation. Brown et al. (2017) additionally highlight intellectual-property protection and contract enforcement. The evidence therefore supports an integrated interpretation in which sustainable technological competitiveness requires coordinated development of firm capabilities, supply networks, skills, institutions, and innovation policies.

Conclusion

This paper shows that industrial competitiveness in a changing technological environment is increasingly determined by the capacity of firms to combine research, innovation, organizational adaptation, and technological exploitation. R&D remains an important foundation of productivity and technological development, but its effects depend on the ability of firms to accumulate knowledge over time, absorb external information, protect valuable inventions, and convert research outputs into commercially productive applications. The literature therefore challenges interpretations that associate competitiveness mechanically with higher R&D expenditure or greater numbers of patents. Technological resources generate differentiated outcomes according to organizational capabilities, knowledge networks, market conditions, intellectual-property strategies, and the quality of technological outputs. Similar conclusions emerge from the literature on Industry 4.0, robotics, and artificial intelligence. Digital technologies can increase productivity, flexibility, innovation, and market responsiveness, but their contribution depends on complementary investments in skills, data capabilities, managerial practices, employee involvement, and organizational redesign. Contemporary industrial competitiveness consequently reflects a cumulative process in which technologies interact with firm-specific resources and learning mechanisms. Firms capable of coordinating internal research, external knowledge, human capital, and technological adoption are better positioned to transform technological change into sustained improvements in productivity, innovation, and market performance.



The analysis also indicates that technological competitiveness can no longer be separated from environmental, organizational, and institutional transformations. Green innovation can support cost efficiency, differentiation, reputation, and market positioning when environmental objectives are integrated into corporate strategy rather than treated solely as regulatory obligations. Digital supply chains, servitization, and resilience-oriented practices similarly enlarge the sources of industrial performance by improving information flows, coordination, resource efficiency, and firms' capacity to respond to disruption. These developments place additional importance on public policy and institutional quality. Effective industrial policy should support technological capability formation while maintaining competitive incentives, facilitating commercialization, strengthening knowledge-transfer mechanisms, and providing credible institutional conditions for innovation. Workforce skills and interoperability are equally important because advanced production systems require employees and organizations capable of operating and adapting increasingly interconnected technologies. Industrial competitiveness should therefore be approached as a systemic outcome rather than as the consequence of a single technological investment. Its sustainability depends on the alignment of R&D, digital transformation, environmental innovation, human capital, organizational capabilities, supply-chain integration, and institutional support. Such alignment determines whether technological change produces temporary efficiency improvements or contributes to durable industrial upgrading and competitive performance.

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