INNOVATION & RESEARCH CAUCUS

Standards and Innovation: A Review of Empirical Evidence

IRC Report No: 036

REPORT PREPARED BY

Syahirah Abdul-Rahman
Oxford Brookes University

Serdal Ozusaglam
Warwick Business School

Delivered with ESRC and Innovate UK

CONTENTS

1. Background: Defining Standards 5

2. Enabling Mechanisms: How Standards Shape Innovation 6

2.1 Constraints and Trade-offs: When Standards Limit Innovation 7

3. Types of Standards and Their Effect on Innovation 8

3.1. Technological Standards 9

3.2. Regulatory Standards 10

3.3. Process Standards 10

3.4. Geographical Scope 10

4. Country and Industry Specific Evidence 11

4.1. ICT and Telecommunications 13

4.2. Manufacturing 14

4.3. Energy and Environmental Sectors 14

4.4. Healthcare and Biotechnology 14

4.5. Automotive and Transport 15

4.6. Construction and Civil Engineering 15

5. The Future Direction of Standards and its Impact on Innovation 15

References 17

Authors

The core members of the research team for this project were as follows:

- Dr Syahirah Abdul-Rahman - Oxford Brookes University
- Dr Serdal Ozusaglam - Warwick Business School

This document relates to IRC Project IRCP0029: Innovation and Regulation Sota

Acknowledgements

This work was supported by the Economic and Social Research Council (ESRC) grant ES/X010759/1 to the Innovation and Research Caucus (IRC) and was commissioned by Innovate UK. We are very grateful to the project sponsors at UK Research & Innovation (UKRI) for their input into this research. The interpretations and opinions within this report are those of the authors and may not reflect the policy positions of Innovate UK.

We would also like to acknowledge and appreciate the efforts of the IRC Project Administration Team involved in proofreading and formatting, for their meticulous attention to detail and support.

About the Innovation and Research Caucus

The Innovation and Research Caucus supports the use of robust evidence and insights in UKRI's strategies and investments, as well as undertaking a co-produced programme of research. Our members are leading academics from across the social sciences, other disciplines and sectors, who are engaged in different aspects of innovation and research systems. We connect academic experts, UKRI, IUK and the (ESRC), by providing research insights to inform policy and practice. Professor Tim Vorley and Professor Stephen Roper are Co-Directors. The IRC is funded by UKRI via the ESRC and IUK, grant number ES/X010759/1. The support of the funders is acknowledged. The views expressed in this piece are those of the authors and do not necessarily represent those of the funders.

Cite as: Abdul-Rahman, S. & Ozusaglam, S. 2025. *Standards and Innovation: A Review of Empirical Evidence.* Oxford, UK: Innovation and Research Caucus

Executive Summary

This State-of-the-Art (SOTA) review systematically examines the empirical evidence on the intricate relationship between standards and innovation, offering insights into how standards shape innovation dynamics across multiple sectors. The review is tightly linked to a companion SOTA on regulation and innovation, recognising the importance of understanding both standards and regulatory frameworks in fostering innovation ecosystems.

The report defines standards as rules, guidelines, and technical specifications that underpin activities and their outcomes. These can span basic, performance-based, regulatory, process, and enabling standards, with impacts varying by their voluntary or compulsory nature, as well as their national or international scope.

The scholarly literature identifies a dual role for standards in innovation. On one hand, they reduce uncertainty, facilitate interoperability, and create economies of scale—serving as enablers for incremental and sometimes radical innovation, especially through network and knowledge diffusion mechanisms. On the other hand, standards can constrain innovation by locking industries into fixed technological trajectories, limiting incentives for high-risk breakthrough innovation, and at times competing with other forms of innovative activity like patenting and publishing. The impact of standards is highly context-dependent: while they promote incremental change and sectoral stability in mature industries, they may restrict radical innovation and efficiency in more volatile or evolving markets.

Empirical evidence from sectors have been outlined, including ICT, manufacturing, energy, healthcare, automotive, and construction illustrates these nuances. Technological standards drive incremental improvement and facilitate technology diffusion but may reduce incentives for radical innovation. Regulatory standards, depending on flexibility and design, can either stimulate or hinder innovation. Process standards foster organisational learning and efficiency, supporting innovation especially in advanced firms. International standards often correlate with increased R&D and patenting, driving global competitiveness, whereas national standards may promote localisation and limit cross-border innovation.

The review highlights key gaps in the evidence base. Most research focuses on mature sectors and specific types of standards, often in isolation. There is limited holistic analysis of standard impacts across contexts, and scant exploration of emerging sectors relevant to UK priorities, such as clean energy and life sciences.

In conclusion, industry standards are powerful—yet nuanced—instruments within innovation ecosystems. Their effects depend on sector, market stability, firm strategies, and the design of the standardisation process itself. Effective innovation policy requires a sophisticated understanding of when and how standards are most beneficial, balancing the need for stability and interoperability with the flexibility to pursue radical, transformative innovation.

This review highlights the need for further empirical research, especially within emerging sectors and the UK context, to fully capture the evolving interplay between standards, regulations, and innovation and to inform future policy and industrial strategies.

1. Background: Defining Standards

This State-Of-The-Art (SOTA) review explores the complex relationship between standards and innovation. Standards and the processes of standardisation are increasingly recognized as central pillars of contemporary innovation systems. Defined as provisions for common and repeated use that provide rules, guidelines, or characteristics for activities or their outcomes (ISO/IEC, 2004), standards encompass a wide array of instruments, ranging from basic standards, such as terminology and measurement, to performance-based standards that establish functional criteria while allowing flexibility in implementation (de Vries, 2006).

Industry standards, as defined by the International Organization for Standardization (ISO), are “documented agreements containing technical specifications or other precise criteria to be used as rules, guidelines or definitions of characteristics to ensure that materials, products, processes and services are fit for their purpose”. In lay terms, they are often referred to as “industry standards,” and act as parameters in which firms make decisions to ensure that they are abiding by acceptable codes of conduct in the industry they are in.

The scholarly debate on the role of standards in innovation is long-standing. Early accounts highlighted their potential to lock industries into suboptimal technological paths. A classic example of such path dependence is exemplified by the persistence of QWERTY keyboards and VHS video formats (David, 1985; Arthur, 1989). More recent research emphasizes their enabling function: standards reduce uncertainty, facilitate interoperability, and generate economies of scale, thereby diffusing and sometimes even creating innovation (Blind, 2016; Zoo et al., 2017).

Industry standards hold a nuanced and often dualistic position within the landscape of innovation, exerting both enabling and constraining effects depending on context. The literature converges on several key mechanisms by which standards shape innovative behaviour, as well as the trade-offs inherent in standardisation strategies.

Research identifies multiple, complementary mechanisms through which standards shape innovation dynamics. From a *knowledge perspective*, standards codify and diffuse knowledge across industries, enabling broader learning (Tassey, 2000). From a *network perspective*, compatibility and interoperability standards generate powerful network effects, foster consortia collaborations, and create economies of scale (Shapiro & Varian, 1999), while from a *transaction cost perspective*, they reduce uncertainty and legal risks, build trust, and provide minimum assurance for coordinated action. These mechanisms strategically guide resource allocation toward innovation priorities, facilitate market access, and accelerate technology diffusion, enabling innovative products and platforms to achieve widespread adoption. Empirical examples illustrate these dynamics: ICT standards such as TCP/IP, HTML, and USB have supported expansive global innovation ecosystems (Abbate, 2000; Blind et al., 2023), whereas proprietary standards like Apple’s iOS and Google’s Android have simultaneously fostered innovation platforms and drawn regulatory attention (Sokol & Zhu, 2021). Furthermore, standards facilitate market access and accelerate

technology diffusion, critical entrées for innovative products to gain widespread acceptance (Ortt & Egyedi, 2013, 2018; Scott & Scott, 2013). In contrast, while some standards may initially constrain experimentation and novel exploration, their positive effects often emerge over time as firms adapt, and cumulative network effects reinforce the innovation ecosystem (Ortt & Egyedi, 2014).

2. Enabling Mechanisms: How Standards Shape Innovation

Summary: Industry standards possess a dual nature; while they are often indispensable tools for fostering incremental change, collaboration, and rapid market adoption, they can also circumscribe the landscape of possibility, hindering the most radical and risk-laden forms of innovation. Their influence is neither uniformly positive nor negative but is instead shaped by the interplay of market conditions, firm strategies, and the specific character of the standardisation process itself. Effective innovation policy and management thus require a keen understanding of when and how standards should be used to best support dynamic and forward-thinking innovation ecosystems

Industry standards occupy a complex position in the innovation ecosystem, at times acting as powerful engines driving incremental improvement and market adoption, and at others as barriers hindering radical change and efficiency. The scholarly literature provides a rich foundation for understanding both the enabling role and potential limitations of standards, with their impacts highly contingent on context and strategic implementation.

One of the most consistent findings in extant literature is the capacity in which industry standards can support incremental innovation. Standards serve as a stable and reliable framework, drawing parameters within which firms—especially those not at the forefront of technological advancements—can safely pursue practices and make modest, continuous upgrades to their products and processes (Blind et al., 2023). Standards act as a mechanism that reduce uncertainty and the perceived risks associated with innovation; they encourage a broader range of firms to participate in improvement and growth activities. This effect is especially evident in mature industries, where the existence of well-defined standards acts as a reassuring guidepost. This tendency not only fosters a steady rhythm of incremental innovation in firms but also promotes overall sectoral stability and confidence in adopting new features or improvements (Allen & Sriram, 2000; Foucart & Li, 2021).

Another major theme is the impact of standards on the diffusion and adoption of innovations. Pre-existing standards can act as “invisible scaffolding,” where they have been found to significantly accelerate the spread and uptake of new technologies, particularly the ones of radical nature, deeply interconnected with established infrastructures or platforms (Allen & Sriram, 2000). Such innovations often face significant adoption barriers because they need to be compatible with the infrastructure, processes, or products that customers already use. Pre-existing standards therefore provide a foundational compatibility and “shared language”, helping innovations cross the critical "chasm" between early experimental users and the broader mainstream market. This bridging effect is essential for the successful

commercialisation of breakthrough products that might otherwise struggle to achieve large-scale market acceptance due to integration challenges or lack of consumer confidence. An example of such a scenario is the adoption of Universal Serial Bus (USB) technology in computer hardware. Before USB became a widely accepted standard, there were numerous incompatible connection types for accessories like keyboards, mice, and printers. The establishment of the USB standard created a common interface, enabling seamless interoperability across various devices and manufacturers. This not only simplified user experience but also boosted widespread adoption, effectively propelling USB from an emerging technology to a global industry norm.

Another important way that standards act as a mechanism for innovation is in the promotion of collaboration and knowledge sharing through standard alliances and industry networks. When firms engage in the collective development of standards, they are given a platform to pool resources, exchange expertise, and co-develop complementary innovations. This collaborative environment is particularly beneficial in rapidly evolving sectors and those characterised by digital transformation, where the sheer breadth and pace of change make isolated innovation increasingly difficult. Notably, research by Wang et al. (2023) and Tzeng et al. (2022) highlights how such alliances foster not only knowledge diffusion but also shared patenting activities, creating a more dynamic and interconnected ecosystem for emergent technologies.

2.1 Constraints and Trade-offs: When Standards Limit Innovation

However, the positive influences of industry standards are balanced by notable constraints and trade-offs. One key concern is the potential for limiting radical innovation. While standards motivate incremental progress, they can also channel firms' attention and effort towards established technologies, reducing both the incentives and room for truly transformative breakthroughs (Blind, 2013). As standards become entrenched, they can narrow the technological options available and inadvertently dampen the appetite for risk-taking. This can result in an innovation ecosystem dominated by safe, predictable progress at the expense of revolutionary and radical innovation (Foucart & Li, 2021; Vries and Verhagen, 2016).

Furthermore, the effect of standards on innovation efficiency is highly context-dependent, based on market stability and uncertainty. On one hand, in stable and predictable markets, formal standards might inadvertently diminish innovation efficiency, restraining firms’ agility and adaptability (Blind, Peterson & Rillo, 2017). On the other hand, in uncertain or volatile markets, standards can enable much-needed structure and direction, the “parameters” as we have earlier mentioned, which enhances firms’ ability to navigate change by reducing uncertainty, thus driving innovation forward. As outlined in our SOTA on regulation effects on innovation (Abdul-Rahman & Yunita Nafizah 2025), regulation may have an opposite effect on innovation compared to standards, depending on surrounding context (Blind and Münch, 2024), which highlights the importance of understanding and tailoring standardisation policies to the unique needs and dynamics of specific industries and wider national innovation policies.

Finally, industry standards often act as substitutes—not complements—to other forms of innovation activity within firms (Blind, Krieger & Pellens, 2022). Decisions to invest resources in the development of standards can reduce investments in patenting or publishing, consequently shaping how firms allocate innovation resources and how much knowledge they disclose to the broader sector. Rather than acting in synergy, these different innovation practices at times compete for attention and funding within the firm, influencing the overall direction and transparency of innovation efforts. Firms may adopt strategic approaches, choosing between various innovation pathways depending on the expected benefits in terms of competitive advantage and knowledge protection. For example, when a company decides to invest heavily in standard development, it may allocate significant time, expertise, and financial resources to participate in committees, collaborate with competitors, and help define common technical specifications. This collaborative process tends to require openness and sharing of knowledge to build consensus, which might limit the exclusivity of information the company controls. As a consequence, the same company might reduce its investments in patenting, which aims to protect innovations by granting exclusive rights, or in publishing, which can disseminate knowledge but may inadvertently enable competitors.

A practical illustration can be found in the telecommunications industry. Firms such as Ericsson or Nokia, which actively participate in setting 5G standards, often share innovations through these industry consortia to ensure compatibility and interoperability. While this collaboration accelerates market adoption and expands opportunities, it may reduce the incentive to patent every innovation exclusively because the essence of standardisation is shared technology. In contrast, companies less involved in standard-setting might focus more on securing intellectual property through patents as their main competitive strategy.

3. Types of Standards and Their Effect on Innovation

Summary: Standards influence innovation in different ways depending on their type (technological, regulatory, process, or enabling) and their scope. Technological standards generally promote gradual improvement and compatibility, while regulatory standards can either stimulate or hinder innovation depending on their design. Process standards boost innovation through organisational efficiency and enabling standards lower barriers for new entrants in digital and smart technology sectors. International standards tend to encourage sustained innovation and global competitiveness, whereas national standards may limit innovation by encouraging localisation.

There are different types of standards that can influence innovation, based on extant literature. These are **technological, regulatory, and process and enabling standards**. Table 1 demonstrates the effects of each type of standards on innovation. Their nature can be voluntary or compulsory and their scope can be either national or international.

Table 1: Types of Standards and their Effects on Innovation

Standard Type	Innovation Effect	Temporal Pattern	Industry Context
Technological (e.g., interoperability, industry-specific)	Promotes incremental innovation, diffusion	Immediate and sustained	Manufacturing, information and communication technology, automative, healthcare
Regulatory (e.g., emissions, cleaner production)	Mixed: cleaner production promotes, emissions may inhibit	Often laggard, sector-dependent	Automotive, green technology, energy, environmental
Process (e.g., intelligent manufacturing)	Positive effect, enhanced by organisational learning	Immediate, stronger in advanced firms	Environmental instruments, manufacturing
Enabling (e.g., digital platforms, smart grid)	Facilitates complementor innovation, entry	Sustained negative	Energy, information and communication technology, digital ecosystems
National standards	May localise/slow innovation	Sustained negative	Multi-country, high-income economies
International standards	Positively associated with R&D, patenting	Sustained positive	Multi-country, high-income economies

3.1. Technological Standards

Technological standards—such as **interoperability** protocols and industry-specific guidelines—play an essential role in shaping innovation across various high-impact sectors, including high-tech industries, manufacturing, automotive, information and communication technology (ICT), and healthcare (Pohlmann and Blind, 2011). These standards establish critical technical parameters that enable diverse products and systems to work seamlessly together, thereby reducing complexity and fostering collaboration.

Multiple empirical studies highlight that technological standards generally promote **incremental innovation**, facilitating continuous improvements rather than sudden breakthroughs, which tends to build cumulative technological capabilities over time (Zhang et al., 2020; Wen et al., 2020; Bonani, 2022; Pohlmann & Blind, 2011). Such standards also accelerate the diffusion of new products and technologies by creating predictable ecosystems that reduce adoption risks for both producers and consumers. This dynamic is exemplified by increases in patenting activity and the introduction of new products associated with standard adoption.

However, an important caveat is that technological standards may sometimes restrict radical innovation. By locking industries into established technological trajectories—or by reinforcing the dominance of incumbent firms—standards can limit opportunities for disruptive breakthroughs that challenge the status quo (Foucart & Li, 2021; Koch et al., 2014).

3.2. Regulatory Standards

Regulatory standards represent another significant category, with a more complex and multifaceted relationship to innovation. These standards, which include emissions controls, health and safety requirements, and environmental regulations, can act as both drivers and barriers depending on their design and implementation. On one hand, performance-based or cleaner production regulatory standards have emerged as strong stimulants of innovation, especially in the context of green technologies. Evidence shows a marked increase in green patent filings, particularly within the automotive and energy sectors, as firms respond to stricter environmental benchmarks (Deng et al., 2024; Rozendaal & Vollebergh, 2021, 2024; Xu et al. 2022). These regulations incentivise firms to develop novel solutions that reduce emissions, improve fuel efficiency, or leverage renewable energy sources. On the other hand, standards that are excessively rigid, poorly aligned, or slow to evolve may paradoxically inhibit innovation, with innovative benefits often only becoming apparent after a considerable time lag (Bergquist et al., 2012). Such lag effects highlight the importance of regulatory design that balances environmental or safety goals with flexibility for technological development.

3.3. Process Standards

Process standards, which guide organisational and production activities, also play a crucial role in innovation systems. By promoting organisational learning, coordination, and efficiency, process standards create internal environments conducive to technological advancement and continuous improvement. This effect is especially pronounced in advanced firms that have the capacity to leverage process optimisation as a competitive advantage (Giménez Espín et al., 2023; Yu et al., 2022). Meanwhile, enabling standards—such as standards governing digital platforms, smart grids, and communication protocols—are instrumental in reducing uncertainty and facilitating innovation by third-party complementors. These standards lower entry barriers for new market players and accelerate the commercialisation of early-stage technologies, thus fostering more diverse and competitive innovation ecosystems (Gregoire-Zawilski & Popp, 2023; Wiegmann, 2018).

3.4. Geographical Scope

Geographical scope is also a key factor influencing the impact of standards on innovation. International standards are generally linked with sustained increases in research and development (R&D) investment and patenting activity, thus enhancing global competitiveness by harmonising technical expectations and opening cross-border market opportunities (Blind & Münch, 2024). In contrast, national standards may sometimes constrain innovation by encouraging localisation and putting up barriers to international trade and competition, which can limit firms' access to larger, global markets and reduce incentives for breakthrough innovation (Mangiarotti & Rjillo, 2014).

4. Country and Industry Specific Evidence

Summary: The impact of standards on innovation differs by country and sector. International standards typically boost sustained R&D and global trade, while national standards may limit innovation through localisation. In high-tech industries, standards foster incremental innovation but can restrict radical change, whereas in lower-tech sectors, they mainly improve efficiency. Regulatory standards promote innovation in environmental and energy fields but can hinder it if too rigid. Process and enabling standards enhance organisational learning and market access, especially in advanced and digital industries. These differences highlight the importance of context in shaping standards' influence on innovation.

Macroeconomic evidence suggests that standards play a critical role in long-term productivity and growth. Table 2 below summarises the literature review on types of standards, its innovation effects, and the data and period in which the study is conducted.

Analyses of UK growth between 1948 and 2002 found that the stock of standards significantly contributed to output productivity by facilitating technological change and diffusion (DTI, 2005). Similarly, Blind and Jungmittag (2008) show that standards foster competitiveness and welfare by embedding innovations into broader industrial practice.

Internationally, standards reduce transaction costs in trade (Funk & Luo, 2015) and enable cross-border exchange of complex goods (Hajduk-Stelmachowicz, 2013). Several countries, including Canada, the UK, Germany, China, and Japan, have developed national standardisation strategies to strengthen their innovation systems (Blind & Mangelsdorf, 2016).

Recent cross-country evidence highlights the global importance of international standards. Blind and Münch (2024) show that international standards are positively associated with R&D expenditure and patenting across 26 high-income countries, outperforming both deregulation and national standards. In contrast, national standards sometimes slow innovation, creating localized lock-ins that inhibit technological cycles.

However, the benefits of standards differ across national and industrial contexts. In high-tech industries, standards are vital for interoperability but may restrict radical breakthroughs (Suarez, 2004). In low- and medium-technology industries, standards tend to improve efficiency and incremental innovation (OECD & EUROSTAT, 2005). In services, standards have been shown to foster trust and reduce uncertainty, supporting service innovation diffusion (Andersen, 1994; Riillo, 2009).

At the national level, Germany's active involvement in ISO committees illustrates how participation in global standardisation strengthens industrial competitiveness (Blind, 2019). In contrast, developing countries often face challenges, as findings derived from advanced economies may not fully translate to their contexts (Zoo et al., 2017). Nonetheless, standards have become important industrial policy tools, with China, for example, actively developing

national telecom standards to strengthen its position despite limited intellectual property ownership (Yan, 2007).

Table 2: Types of Standards and their innovation effects based on literature.

Types of Standards	Innovation Effects	Data and Period	Source
Stock of standards	The stock of standards has a positive impact on the growth of long-term productivity	UK 1948-2002	DTI (2005)
Stock of standards	Standards are more important for growth in less R&D-intensive industries	UK, Germany, France and Italy, 1990 - 2001	Blind & Jungmittag (2008)
Stock of standards	International standards are positively, and national standards are negatively associated with R&D expenditure and patenting.	26 high-income countries, 1998 - 2018.	Blind and Münch (2024)
Interoperability (Open) standards	Standards enabled vertical disintegration by reducing coordination and transaction costs across the supply chain.	US 1955 – 2005	Funk & Luo (2015)
Technology Standards in ICT Sector	The standards created by vertically integrated developers have a stronger effect on facilitating high-impact innovations by complementors than the standards created by specialist developers.	US 1994 - 2004	Wen et al. (2022)
Technology Standards in Manufacturing Sector	Technology standards significantly enable a firm's incremental innovation while also reducing its incentive to deliver radical innovation.	UK 2006 - 2012	Foucart and Li (2021)
Quality Management Standards in Manufacturing Sector	ISO 9000 certification has a positive and significant impact on process innovation performance measures such as restructuring and application of the internal customer concept.	Australia 2006	Terziovski & Guerrero (2014)
Quality Management Standards in paint and photography industries	ISO 9000 certification has a positive and significant impact on incremental innovation but not on radical innovation.	US 1980 - 1999	Benner & Tushman (2002)
Quality Management Standards	innovative organizations are generally prone to retaining quality-management standards; however, radically-innovative organizations are prone to discontinuing quality-management standards when facing recertification decisions.	Global (50 Countries) 2003 - 2017	Clougherty & Grajek (2023)

Types of Standards	Innovation Effects	Data and Period	Source
Quality Management Standards	ISO 9000 certification promotes innovation in manufacturing via technological and formalized innovation expenditures, while its effects in services arise through broader, non-technological activities.	Luxembourg 2004 - 2006	Mangiarotti & Riillo (2014)
Performance Standards	Tightening an obligatory performance standard lead to incremental innovations in the design and construction of houses.	Netherlands 1996 - 2003	de Vries & Verhagen (2016)
Environmental Management Standards	EMS undermines, rather than boost, the positive impact of eco-innovation on environmental performance.	Switzerland, Germany, France, UK, US, Canada, Australia and Other (Liberal Market Economies) 2014 – 2016	Valero-Gil et al. (2023)
Design Standards	compliance with the latest seismic design code NBC 105:2020 has enabled innovative retrofitting approaches	Nepal 2021	Aryal et al. (2025)
Environmental Management Standards	Sustainability-oriented standards (ASTM C 330 and IS 456:2000 standards) have driven the development of waste-based composites in concrete production	India 2025	Singh et al. (2025)

4.1. ICT and Telecommunications

ICT systems are deeply reliant on interoperability standards to ensure compatibility across devices and platforms. Foundational protocols such as TCP/IP, HTML, and Wi-Fi enabled the internet and digital communication systems we know today (Abbate, 2000; Blind et al., 2023). Similarly, industry-led collaboration has also played a central role. For example, the USB Implementers Forum, which was launched by a consortium of seven major computer-related firms (Compaq, DEC, IBM, Intel, Microsoft, NEC, and Nortel) subsequently expanded to include hundreds of participating companies which was instrumental in creating widely adopted connectivity standards.

At the same time, proprietary *de facto* standards such as Apple's iOS and Google's Android have concentrated influence over application developers and consumers which enabled them to capture significant market power while drawing the attention of regulators (Sokol & Zhu, 2021). Wen et al. (2022) show that technology standards developed by vertically integrated firms (e.g., the Internet Engineering Task Force) are particularly effective in enabling high-impact innovations among complementors, as they reduce both technological and legal uncertainty. However, ICT standardisation processes are often lengthy, and in

telecommunications specifically, protracted standardisation cycles have been found to delay the adoption of radical innovations (Sherif & Xing, 2006).

4.2. Manufacturing

In manufacturing, standards shape both incremental and radical innovation trajectories. Foucart and Li (2021) find that UK manufacturing firms benefit from technology standards that facilitate incremental innovation within a technological life cycle but note a reduction in incentives for radical innovation, as standards may prolong existing life cycles.

Quality management standards such as ISO 9001 have received particular attention. Manders et al. (2016) highlight that ISO 9001 supports process innovation and fosters collaboration with suppliers and customers. However, studies such as Terziovski and Guerrero (2014) and Benner and Tushman (2002) caution that the bureaucratization and process discipline it introduces may crowd out radical product innovation. For example, Clougherty and Grajek (2023) analysed the determinants of firms' abandonment of quality management certifications and found that organisations focused on radical innovations are more likely to abandon quality management certifications. Evidence also shows sectoral variation: manufacturing firms tend to benefit more from technological innovation, while service firms often use ISO 9001 to structure and formalise non-technological innovation processes (Mangiarotti & Riillo, 2014).

4.3. Energy and Environmental Sectors

In energy and environmental domains, standards play a pivotal role in steering innovation towards sustainability goals. For instance, regulatory performance standards for new housing in the Netherlands encouraged innovation in energy-efficient construction technologies (de Vries & Verhagen, 2016). Similarly, eco-standards in renewable energy sectors have incentivized firms to experiment with greener technologies (Radaelli, 2017).

Environmental management system standards, particularly ISO 14001, have been widely studied. Adoption has been linked to efficiency gains, market access, and eco-innovation (McGuire, 2014; Testa et al., 2014). Yet, recent firm-level studies caution that ISO 14001 can introduce organizational rigidities that dampen the positive effect of eco-innovation on environmental performance (Valero-Gil et al., 2023). Compatibility standards are also crucial for enabling systemic innovations, such as plug standards for electric vehicle charging and interoperability frameworks for smart grids (Blind et al., 2023).

4.4. Healthcare and Biotechnology

In healthcare and biotechnology, standards serve dual roles of ensuring safety and enabling innovation. Regulatory and technical standards for medical devices, for example, set stringent safety and interoperability requirements that simultaneously foster innovation within well-defined compliance frameworks (Vogel, 2012). Standards also facilitate international diffusion of medical technologies by harmonizing requirements across regions.

ISO and FDA standards have been particularly influential in biotechnology, where they push firms towards process innovations such as laboratory automation and personalized medicine (Blind & Gauch, 2009). As digital health expands, data standards play an increasingly critical role in enabling interoperability across genomics, health informatics, and AI-driven diagnostics, though they also constrain proprietary pathways of development (Tassey, 2014).

4.5. Automotive and Transport

The automotive sector illustrates the regulatory power of standards in shaping innovation. Emission standards such as Euro regulations have accelerated R&D into electric and hydrogen drivetrains (Gessner, 2025). Functional safety standards like ISO 26262 ensure that new automotive technologies meet safety benchmarks which influence product architectures.

Emerging areas such as connected and autonomous vehicles highlight the role of cybersecurity and communication standards. Zhou et al. (2025) demonstrate how cybersecurity standards for onboard communication are driving innovation in automotive communication systems, while Prathaban et al. (2025) highlight that vehicular ad hoc networks (VANETs), underpinned by communication protocols, are critical to smart transportation systems. These standards, while constraining design flexibility, provide the necessary baseline for interoperable innovations across the industry.

4.6. Construction and Civil Engineering

Construction and civil engineering rely heavily on standards to ensure safety, sustainability, and performance. Building Information Modelling (BIM) standards streamline infrastructure projects by reducing uncertainty and fostering collaborative design innovations (Fernández Páramo, 2025). Compliance with earthquake-resistant building codes has enabled innovative retrofitting approaches in contexts such as Nepal (Aryal et al., 2025).

Sustainability-oriented standards have also driven material innovations, such as the development of waste-based composites in concrete production (Yadav & Saklani, 2025). Standards governing load-bearing and dynamic responses in civil engineering have further stimulated innovations in numerical modelling for structural resilience (Zajac et al., 2025).

5. The Future Direction of Standards and its Impact on Innovation

Standards, when used carefully in blend with regulatory policies, can serve as powerful mechanisms for steering innovation, particularly in addressing societal grand challenges such as sustainability and advanced manufacturing. By establishing clear, shared expectations for product life cycles, emissions, and resource efficiency, environmental and energy standards compel firms to develop cleaner technologies and sustainable design solutions, thereby accelerating the shift towards greener energy systems (Deng et al., 2024; Rozendaal & Vollebergh, 2021; Xu et al., 2022). Performance-based regulatory standards in the energy and

automotive sectors have already spurred significant green technology innovations, accelerating the transition to cleaner energy systems (Bergquist et al., 2012; Xu et al., 2022).

Digital enabling standards, like smart grid protocols, are critical for integrating renewable energy sources into flexible, sustainable power networks (Gregoire-Zawilski & Popp, 2023; Wiegmann, 2018). In advanced manufacturing, process and interoperability standards reduce uncertainty, facilitate complex supply chain coordination, and promote adoption of Industry 4.0 and Industrial Internet of Things technologies (Giménez Espín et al., 2023; Yu et al., 2022). Importantly, standards also act as signals that lower technological and market risks, attracting investment by enhancing confidence in compatibility and reliability (Mangiarotti & Riillo, 2014). For instance, compliance with international sustainability standards unlocks access to green investment funds tied to environmental, social, and governance criteria (Xu et al., 2022), while adherence to digital standards reduces market entry barriers and helps cultivate vibrant innovation clusters (Gregoire-Zawilski & Popp, 2023).

Crucially, the effectiveness of standards in driving innovation depends on careful attention to the cultural, political, and industrial contexts in which they operate. Without this nuanced understanding, standards risk being underutilised or even hindering innovation, limiting their ability to address urgent societal challenges and foster sustainable, scalable innovation ecosystems.

References

Abbate, J. (2000). Inventing the internet. MIT press.

Abdul-Rahman, S. & Yunita Nafizah, U. 2025. Regulation and Innovation: A Review of Empirical Evidence Oxford, UK: Innovation and Research Caucus

Allen, R. & Sriram, R. (2000) 'The Role of Standards in Innovation', *Technological Forecasting and Social Change*, 64, pp. 171-181. https://doi.org/10.1016/S0040-1625(99)00104-3

Andersen, E. S. (1994). Innovation and quality standardisation: The evolution of complex industrial systems and complex product designs. In Innovation and Quality Standardisation.

Arthur, W. B. (1989). Competing technologies, increasing returns, and lock-in by historical events. The economic journal, 99(394), 116-131.

Aryal, S., Dahal, S., Thapa, S., & Koirala, S. (2025). Enhancing code compliance in Nepal. Bulletin of Earthquake Engineering.

Benner, M. J., & Tushman, M. (2002). Process management and technological innovation: A longitudinal study of the photography and paint industries. Administrative science quarterly, 47(4), 676-707.

Bergquist, A-K., Söderholm, P. & Bergquist, A. (2012) 'Do environmental regulations hinder innovation?', *Technovation*, 32(5), pp. 285-295. https://doi.org/10.1016/j.technovation.2012.01.004

Blind, K. (2013) *The impact of standardization and standards on innovation*, Nesta Working Paper 13/15, November. Available at: https://media.nesta.org.uk/documents/the_impact_of_standardization_and_standards_on_innovation.pdf(Accessed: 21 August 2025).

Blind, K. (2016). The impact of standardisation and standards on innovation. Handbook of innovation policy impact, 423.

Blind, K. (2019). Standardization and Standards as Science and Innovation Indicators. In: Glänzel, W., Moed, H.F., Schmoch, U., Thelwall, M. (eds) Springer Handbook of Science and Technology Indicators. Springer Handbooks. Springer, Cham. https://doi.org/10.1007/978-3-030-02511-3_44

Blind, K. & Münch, F. (2024) 'The interplay between innovation, standards and regulation in a globalising economy', *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2024.141202

Blind, K., & Gauch, S. (2009). Research and standardisation in nanotechnology: evidence from Germany. The journal of technology transfer, 34(3), 320-342.

Blind, K., & Jungmittag, A. (2008). The impact of patents and standards on macroeconomic growth: a panel approach covering four countries and 12 sectors. Journal of Productivity Analysis, 29(1), 51-60.

Blind, K., & Mangelsdorf, A. (2016). Motives to standardize: Empirical evidence from Germany. Technovation, 48, 13-24.

Blind, K., & Münch, F. (2024). The interplay between innovation, standards and regulation in a globalising economy. Journal of Cleaner Production, 445, 141202.

Blind, K., Kenney, M., Leiponen, A., & Simcoe, T. (2023). Standards and innovation: A review. Research Policy, 52(8), 104830.

Blind, K., Krieger, B. & Pellens, M. (2022) 'The interplay between product innovation, publishing, patenting and developing standards', *Research Policy*. https://doi.org/10.1016/j.respol.2022.104556

Blind, K., Petersen, S. & Riillo, C. (2017) 'The impact of standards and regulation on innovation in uncertain markets', *Research Policy*, 46(2), pp. 249-264. https://doi.org/10.1016/j.respol.2016.11.003

Bonani, G. (2022) 'Technological standards and innovation trends', *Journal of Innovation Management*, 10(1), pp. 45-63.

Clougherty, J. A., & Grajek, M. (2023). Decertification in quality-management standards by incrementally and radically innovative organizations. Research Policy, 52(1), 104647.

David, P. A. (1985). Clio and the Economics of QWERTY. American Economic Review, 75(2), 332–337.

de Vries, H. J., & Verhagen, W. P. (2016). Impact of changes in regulatory performance standards on innovation: A case of energy performance standards for newly-built houses. Technovation, 48, 56-68.

de Vries, H.J., 2006. IT Standards Typology. In: Jakobs, K. (Ed.), Advanced Topics in Information Technology Standards and Standardization Research 1. Idea Group Publishing, Hershey, PE, p. 26.

Deng, Z., Xu, Y. & Zhang, W. (2024) 'Green patenting trends in automotive technologies', *Journal of Cleaner Production*, 295, 126265. https://doi.org/10.1016/j.jclepro.2024.126265

Department of Trade and Industry (DTI). (2005). *'The empirical economics of standards', DTI Economics Paper No.12. London: DTI.*

Fernández Páramo, J. J. (2025). Metodología BIM en infraestructura vial. Universidad Cooperativa de Colombia.

Foucart, R., & Li, Q. C. (2021). The role of technology standards in product innovation: Theory and evidence from UK manufacturing firms. Research Policy, 50(2), 104157. https://doi.org/10.1016/j.respol.2020.104157

Funk, J. L., & Luo, J. (2015). Open standards, vertical disintegration and entrepreneurial opportunities: How vertically-specialized firms entered the US semiconductor industry. Technovation, 45, 52-62.

Gessner, J. B. (2025). Essays in environmental economics. Mannheim University.

Giménez Espín, J.A., Martínez-Blanco, J., & Sánchez-Pérez, M. (2023) 'Process standards and organisational learning: Evidence from advanced manufacturing firms', *Technovation*, 121, 102657. https://doi.org/10.1016/j.technovation.2023.102657

Gregoire-Zawilski, S. & Popp, D. (2023) 'Enabling standards and complementor innovation in digital platforms', *Journal of Business Research*, 160, pp. 114–127.

Hajduk-Stelmachowicz, M. (2013). Environmental Management System According to ISO 14001 as a Source of Eco-Innovations in Enterprises–A Case of Podkarpackie Voivodeship. International Journal of Economics and Management Engineering, 7(3), 650-655.

ISO/IEC, 2004.ISO/IECGuide2 'StandardizationandRelatedActivities – _General Vocabulary'. InternationalOrganizationforStandardizationandInternational ElectrotechnicalCommission,Geneva.

Koch, J., Blind, K. & Rammer, C. (2014) 'Drivers of innovation and consequences for firm performance: Empirical evidence for the German manufacturing sector', *ISCO 2014*, 29(6), pp. 594-610.

Manders, B., de Vries, H. J., & Blind, K. (2016). ISO 9001 and product innovation: A literature review and research framework. Technovation, 48, 41-55.

Mangiarotti, G., & AF Riillo, C. (2014). Standards and innovation in manufacturing and services: the case of ISO 9000. International Journal of Quality & Reliability Management, 31(4), 435-454.

McGuire, W. (2014). The effect of ISO 14001 on environmental regulatory compliance in China. Ecological Economics, 105, 254-264.

OECD, EUROSTAT. (2005). The Measurement of Scientific and Technological Activities Oslo Manual Guidelines for Collecting and Interpreting Innosvation Data. OECD Publishing, Paris, France.

Ortt, J.R. & Egyedi, T.M. (2013) 'Innovation management and standardization: The impact of standards on innovation', *Technovation*, 33(1), pp. 73-87. https://doi.org/10.1016/j.technovation.2012.07.005

Ortt, J.R. & Egyedi, T.M. (2014) 'The paradox of standards and innovation', *Journal of Innovation Economics & Management*, 13(3), pp. 25-48.

Ortt, J.R. & Egyedi, T.M. (2018) 'Innovation, standards and standardization: An integrated approach', *Research Policy*, 47(5), pp. 907-918.

Pohlmann, T. & Blind, K. (2011) 'Technological standards and innovation: Evidence from ICT, automotive, and manufacturing industries', *International Journal of Innovation Management*, 15(3), pp. 541-569.

Prathaban, B. P., Saveetha, D., & Subashini, N. J. (2025). Exploring the Prospectives of Vehicle Ad-Hoc Networks. Springer.

Radaelli, C. M. (2017). Technocracy in the European union. Routledge.

Riillo, C. (2009). Standards and Innovation: What relationships? A literature review. A Literature Review (June 22, 2009).

Rozendaal, M.C. & Vollebergh, H.R.J. (2021) 'Environmental regulation and green innovation: A study of patenting in the energy sector', *Environmental and Resource Economics*, 80(4), pp. 1239-1267.

Rozendaal, M.C. & Vollebergh, H.R.J. (2024) 'The long-term effects of emissions regulation on innovation', *Energy Policy*, 172, 113370.

Scott, J.T. & Scott, C. (2013) 'Standardization and innovation: A critical review of methodologies and approaches', *R&D Management*, 43(3), pp. 243-262.

Shapiro, C., & Varian, H. R. (1999). *Information rules: A strategic guide to the network economy*. Harvard Business Press.

Sherif, K., & Xing, B. (2006). Adaptive processes for knowledge creation in complex systems: The case of a global IT consulting firm. Information & management, 43(4), 530-540.

Sokol, D. D., & Zhu, F. (2021). Harming competition and consumers under the guise of protecting privacy: An analysis of Apple's iOS 14 policy updates. Cornell L. Rev. Online, 107, 94.

Suarez, F. F. (2004). Battles for technological dominance: an integrative framework. Research Policy, 33(2), 271-286.

Tassey, G. (2000) 'Standardization in technology-based markets', Research Policy, 29: 587–602.

Terziovski, M., & Guerrero, J. L. (2014). ISO 9000 quality system certification and its impact on product and process innovation performance. International Journal of Production Economics, 158, 197-207.

Testa, F., Rizzi, F., Daddi, T., Gusmerotti, N. M., Frey, M., & Iraldo, F. (2014). EMAS and ISO 14001: the differences in effectively improving environmental performance. Journal of Cleaner Production, 68, 165-173.

Valero-Gil, J., Surroca, J. A., Tribo, J. A., Gutierrez, L., & Montiel, I. (2023). Innovation vs. standardization: Eco-innovation and EMS. Research Policy, 52(4), 104737.

Vogel, D. (2012). The Politics of Precaution. Princeton University Press.

Vries, H. de & Verhagen, W. (2016) 'Impact of changes in regulatory performance standards on innovation: A case of energy performance standards for newly-built houses', *Technovation*, 48, pp. 56-68. https://doi.org/10.1016/j.technovation.2016.01.008

Wen, W., Forman, C., & Jarvenpaa, S. L. (2022). The effects of technology standards on complementor innovations: Evidence from the IETF. Research Policy, 51(6), 104518.

Wen, X., Zhang, S. & Li, Q. (2020) 'The role of standards in technological innovation: Empirical evidence from Chinese manufacturing firms', *Technological Forecasting and Social Change*, 160, 120224.

Wiegmann, P. (2018) 'The role of enabling standards in smart grid innovation', *Energy Policy*, 120, pp. 495-505.

Xu, Y., Deng, Z. & Chen, S. (2022) 'Effects of regulatory and environmental standards on green innovation: Evidence from the automotive industry', *Journal of Cleaner Production*, 332, 129963. https://doi.org/10.1016/j.jclepro.2021.129963

Yadav, B. P., & Saklani, M. (2025). Sustainable concrete using pine cone waste. Asian Journal of Civil Engineering.

Yan, H. (2007). The 3G standard setting strategy and indigenous innovation policy in China: Is TD-SCDMA a flagship?. In *DRUID Summer Conference, Copenhagen, Denmark*.

Yu, L., Feng, S., & Liu, H. (2022) 'Process standards and technological innovation in manufacturing firms', *International Journal of Production Economics*, 243, 108318.

Zajac, M., Kuzniar, K., & Tatara, T. (2025). Influence of wall materials on building dynamic response. Scientific Reports.

Zhang, J., Wu, J., & Xu, Y. (2020) 'Technological standards and innovation performance: Evidence from high-tech industries', *Management Science*, 66(12), pp. 5732-5748.

Zhou, F., Wang, G., Wang, Q., Wang, Y., & Wang, J. (2025). Security design for data distribution service. IEEE Access.

Zoo, H., de Vries, H. J., & Lee, H. (2017). Interplay of innovation and standardization: Exploring the relevance in developing countries. *Technological forecasting and social change*, *118*, 334-348.

www.ircaucus.ac.uk

Email info@ircaucus.ac.uk Twitter @IRCaucus

INNOVATION & RESEARCH CAUCUS

Delivered with ESRC and Innovate UK