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SYSTEMIC APPROACH TO TECHNOLOGY INNOVATION MANAGEMENT: A PATENT-BASED ASSESSMENT

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A B S T R A C T

To become more competitive in the digital economy, over 170 nations and regions have implemented digital development policies worldwide. Integrated technology systems that change business models, organisational structures, production processes, and product development trajectories are especially important for revitalising businesses and areas with structural issues because technological innovation has a direct impact on economic growth. This research adds to a larger systemic analysis of technological innovation in various geographical areas. In addition to evaluating innovation success from a patent-based perspective in important global regions—China, Japan, the United States, and the European Union—its main goal is to evaluate the function and importance of innovation management methodically. The study was carried out from 2023 to 2025, and the data was analysed from 2000 to 2023. The study supports the idea that Asian economies, especially China and Japan, are becoming leaders in technology innovation management based on trends in development dynamics and crisis resilience.

1. INTRODUCTION

Innovative technologies play a pivotal role in advancing multiple dimensions of business operations, including product development, order processing, logistics, production automation, quality assurance, and marketing innovation. In addition, they substantially enhance analytical, forecasting, and strategic planning processes. Labour-intensive and ergonomically hazardous tasks are increasingly being replaced by automated and digitally supported solutions, thereby improving both productivity and workplace safety. Advances in production system programming, capability expansion, cost optimisation, precise process monitoring, and real-time information flow are made feasible by technological innovation (Venkataraman & Pinto, 2019). The integration of industrial automation, collaborative robotics, and expert systems—often referred to collectively as smart manufacturing—facilitates the substitution of machine intelligence for human labour and expertise. While this transition generates considerable gains in efficiency and productivity, it also poses significant challenges for smaller firms and regions that are structurally disadvantaged. Such actors frequently lack sufficient financial resources and technological expertise to adopt state-of-the-art solutions.

A persistent obstacle is the fragmented and isolated application of digital technologies. Many firms continue to equate digitalisation with mere informatisation, leading to the proliferation of "digital islands." This phenomenon disregards the fundamental capabilities of digital technologies—namely, connectivity, computation, and information exchange. As a result, corporate digital investments often underperform, undermining incentives for sustained innovation (Tao et al., 2023). The role of AI in improving the business performance of distressed companies (i.e., firms facing structural inefficiencies, low competitiveness, or limited resources) is also significant. Still, it differs from its role in high-performing firms. AI can support demand

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forecasting, scenario planning, and risk assessment, which are often lacking in distressed firms. By analysing patent databases and technology trends, AI can help distressed firms identify viable innovation paths without excessive R&D spending. While AI offers great opportunities, distressed firms and regions often lack the capital, digital infrastructure, and skilled workforce to fully implement it. From a human capital perspective, advanced technologies enable more efficient recruitment, accelerated training, and higher labour productivity, thereby contributing to employment growth. Nevertheless, financially constrained firms frequently approach innovation through cost-reduction strategies such as workforce downsizing rather than capability-building. In this context, Industry 4.0 technologies represent both a challenge and an opportunity: they serve as key drivers of innovation, competitiveness, and organisational transformation (Zhuo & Chen, 2023).

The disruptive effects of global crises—including the COVID-19 pandemic, geopolitical conflicts, and macroeconomic volatility—have underscored the strategic importance of technological innovation for economic resilience and competitiveness. Although globalisation and foreign direct investment have accelerated the diffusion of advanced technologies, structurally disadvantaged firms frequently remain excluded due to limited resources, weak performance, and insufficient adaptive capacity. To maintain competitiveness under such conditions, firms must systematically align their strategies with technological and socio-economic trends. This alignment requires not only strengthening internal R&D and relocating innovation processes to research and business parks, but also fostering deeper collaboration with universities, science parks, and research institutes (Venkataraman & Pinto, 2019). Foresight instruments such as innovation radar and systemic regional foresight are valuable in enabling vulnerable firms to anticipate emerging risks and opportunities, thereby enhancing their preparedness in both production and non-production domains. According to the World Economic Forum, technology-driven innovation contributes to economies by creating jobs, improving productivity, increasing sales and GDP, enabling flexible ICT-based services, and fostering comprehensive organisational transformation. Global digital connectivity has expanded at an unprecedented pace. Cross-border bandwidth consumption has increased approximately 45-fold since 2005 and is projected to grow nearly ninefold within the next five years, driven by rising flows of information, search activity, communication, video streaming, digital transactions, and intra-firm data exchange. This surge in digital flows has transformed global trade patterns. Millions of small and medium-sized enterprises (SMEs) have become exporters through their participation in e-commerce platforms such as Alibaba, Amazon, eBay, Flipkart, and Rakuten. Currently, an estimated 12% of international trade in goods occurs via cross-border e-commerce. Comparable dynamics are evident in online payment systems, digital collaboration platforms, and data management services, which expand business opportunities and support start-up growth, particularly in less-developed regions (Kokkodis, 2020). Evidence also shows that digitalisation enables even the smallest firms to internationalise. Surveys conducted by the McKinsey Global Institute (2023) indicate that 86% of technology start-ups report engaging in some form of cross-border activity. In parallel, approximately 360 million consumers participate directly in cross-border e-commerce, while nearly 900 million individuals maintain international connections on social media platforms, illustrating the expanding role of digital networks in both commercial and social domains.

The uneven adoption of digital technologies across countries has created significant disparities in global economic performance. Nations that lag in integrating digital tools and participating in global flows face measurable opportunity costs. According to MGI estimates, world GDP could have been $10 trillion (equivalent to 13% higher) had lower-performing economies contributed to cross-border flows at the same intensity as the top quartile over the past decade. (McKinsey Global Institute, 2023) This gap highlights not only the economic benefits of digital integration but also the risks associated with delayed digital adoption, particularly for emerging and developing economies striving to close competitiveness gaps.

Technological preparedness has become increasingly crucial for industrial enterprises amid pandemic-related risks and global socioeconomic shifts. The outcomes of innovation processes—including technology mapping, foresight, roadmapping, R&D, implementation, commercialisation, and intellectual property (IP) protection—profoundly influence productivity, product obsolescence rates, and economic outcomes (Venkataraman & Pinto, 2019). Firms that fail to build internal technological and commercial capabilities risk long-term dependency on technology transfer and imitation, leaving them vulnerable to crises and market volatility. In such cases, even minor shocks may result in bankruptcy due to heightened debt exposure and weak adaptability. Systemic technological innovation thus emerges as a critical mechanism for enhancing production efficiency, resource utilisation, product quality, market share, and profitability, with broader contributions to public finance through increased tax revenues.

At the international level, technology has become a decisive tool of economic and geopolitical competition. Recent analysis by the Australian Strategic Policy Institute (2024) shows that China leads global research output in 37 of 44 critical technology domains, ranging from AI and robotics to advanced defence technologies. By contrast, the United States maintains global leadership in specialised fields such as natural language processing, vaccines, space technologies, quantum computing, and high-performance semiconductors. The European Union, through its Horizon Europe programme (2021–2027), invests approximately €100 billion in research and innovation, supporting leading enterprises in sectors including health, transport, renewable energy, and environmental technology. Japan maintains a unique innovation system rooted in institutional structures and process excellence; however, declines in patenting activity, R&D expenditure, and global innovation rankings indicate stagnation in recent years (Chebbouba, 2025). China's strong research capacity, robust IP protection, and state-driven innovation policy have positioned it as the global frontrunner not only in existing technologies but also in emerging areas of strategic importance (Zhong et al., 2020). With lower production costs—estimated at 30% below Western levels—Chinese technologies are particularly attractive to developing economies, further consolidating its influence. Comparative patent analysis across China, Japan, the United States, and the European Union over the past two decades reveals significant shifts in innovation management practices and highlights the growing dominance of Asian economies in global technological development.

This study examines the innovation activity of selected countries, with a primary focus on patent activity as a proxy for innovation performance. Patent data are widely recognised as a key indicator of innovative output at both the firm and national levels, reflecting not only the technological capacity of companies but also the effectiveness of broader innovation policies and strategies. Accordingly, the following section analyses supporting factors of patent activity to assess cross-country differences in innovation performance and to explore the policy and strategic implications arising from these patterns.

2. LITERATURE REVIEW

To begin our study, we focus on some of the most significant global trends related to business and technological innovation. Businesses today face substantial economic, technological, and personal challenges, including global competition, sustainability pressures, resource constraints, market volatility, cybersecurity risks, and workforce skill shortages. These pressures require companies to adopt more flexible, efficient, and resilient manufacturing strategies while addressing social and environmental responsibilities. Industry 4.0 provides a conceptual framework for this transformation, integrating cyber-physical systems, robotics, big data, the Internet of Things, and artificial intelligence to create intelligent and connected manufacturing networks. ICT serves as the backbone of these systems, enabling real-time monitoring, data-driven decision-making, and integration among suppliers, customers, and global operations. Smart manufacturing operationalises these technologies, increasing productivity, energy efficiency, and adaptability while addressing both economic and societal challenges. Mass customisation is a key strategic outcome of this transformation. By combining ICT-based smart manufacturing with flexible production systems, companies can deliver personalised products at costs close to mass production while meeting individual consumer preferences and remaining competitive. Global challenges, Industry 4.0 trends, ICT advances, smart manufacturing, and mass customisation form an interconnected system that illustrates how technological innovations are reshaping production, business strategies, and societal expectations, while also introducing risks that must be carefully managed. Patents play an indispensable role in these trends but can also create new societal risks.

In recent years, significant investments in computerisation, automation, and robotisation of production—particularly in more developed countries such as the US, China, Japan, Germany, and India—have driven new trends and paradigms in industrial production and commercial operations. The two main developments in mass customisation or large-volume production are automation and robotisation (Wahrmann et al., 2019). Industrial companies increasingly utilise complex information systems, expert systems, collaborative robots, flexible organisational structures, and integrated networks. These firms are already engaged in marketing analysis, forecasting, research, production preparation, logistics, maintenance, and intellectual property (IP) protection. To generate synergistic benefits from innovation collaboration under current conditions, organisational structures are emerging that connect collaborating enterprises with banks, suppliers, research institutes, and customers. Fourth-generation technologies are incorporated into manufacturing processes and various aspects of society through Industry 4.0. Industry 4.0—the integration of digital technologies, automation, and cyber-physical systems into production and business processes—plays a significant role in stimulating new technological patents. On one hand, new technologies require numerous technological inventions and create an environment that supports rapid innovation, cross-industry collaboration, and the commercialisation of novel technologies. Patents serve as strategic tools for IP management, collaboration, and commercialisation (Chesbrough, 2006). They also function as empirical indicators of technological capabilities and policy effectiveness (Armstrong et al., 2024) or as systemic measures of innovation output and policy success (Freeman et al., 2018). Hall et al. (2005) emphasised that the number of patents and citations can serve as a reliable indicator of long-term innovative output at both the firm and national levels. Industry 4.0 patents and their implementation influence both socioeconomic shifts and the practical application of Industry 4.0 technologies. The realisation of industrial transformation and modernisation, as well as the growth of contemporary industry, has become a necessity in the new era, particularly for emerging nations, due to the ongoing advancement of industrialisation and improvements in production efficiency. The practice of industrial production is shaped by the accumulation of technologies and corresponding changes in both the technologies themselves and related systems, resulting from the continuous rise in technological inputs. In particular, the technology accumulation effect arises when earlier technological inputs lead to subsequent innovation through accumulation, with prior patents remaining relevant in later developments (Chen, 2022). Consequently, technological development has a long-term impact on societal shifts and economic advancement. Today, these synergies are especially crucial for problematic businesses and regions.

In times of crisis, individuals from different organisations and enterprises can contribute to invention processes through open innovation, generating important synergistic effects. Many Industry 4.0 innovations have emerged thanks to such cooperation. According to Vermicelli et al. (2020), open collaboration, crowdsourcing, and QRCI/QRM (Quick Response Manufacturing) are key approaches that foster technological breakthroughs in firms and regions. Patents provide companies with legal protection for their inventions. This protection increases their willingness to share knowledge, license technologies, or collaborate with external partners, since it reduces the risk of losing competitive advantage. Within open innovation, companies often exchange technologies, and patents act as a “currency” that can be traded, licensed, or cross-licensed. A patent can also serve as a reward for collaboration in the innovation process. Open innovation is therefore an effective collaborative strategy for firms to overcome technological and informational barriers and achieve shared objectives (Yin et al., 2025).

During crises, company development and cooperation differ significantly from normal conditions, requiring adjustments in business strategies and tactics (Orlando & Rodano, 2020). The three main objectives of effective crisis management are to mitigate negative impacts, ensure survival, and lay the foundations for future growth (Bundy et al., 2016). However, finding cooperation partners is more difficult in such periods. Firms and industries face numerous external threats, including a sharp decline in demand, fluctuations in input prices and transportation costs, and reduced access to bank loans or foreign investment (Flögel & Gärtner, 2020). Innovation processes are shaped not only by a company’s own operations and capabilities but also by the technological infrastructure, resources, and support available in the surrounding region. Many changes in technological innovation and production are not short-lived trends, but rather generational shifts closely linked to the overall technological advancement of society (Graham, 2020). Historically, industrial transformation has been characterised by mechanisation, automation, informatisation, and new production systems; longer cycles of radical innovation; gradual integration of new technologies into production; specialisation of economic activities; participation in global business ecosystems; demographic shifts toward industrialised regions; and social change in the form of new occupations and intellectual property (Schwab, 2017). For radical technological developments, open cooperation should be long-term in nature, and patents are often indispensable. New technologies frequently reshape local business operations, trigger social and economic transformations, and create new demands for environmental protection. They often eliminate inefficient market mechanisms and establish new sectors by improving product and service specifications (e.g., transistor radio, calculator, personal computer, digital camera, LCD TV, mobile phone, human–robot systems, digital marketing). Empirical evidence suggests that open innovation strongly supports continuous learning practices and shapes them through mechanisms such as trade credit provision, the accumulation of green patents, and improved information exchange (Yin et al., 2025). Although open innovation also entails risks, in times of crisis it can be indispensable — particularly given the limited resources and capacities of organisations under pressure.

According to Fernández-Portillo et al. (2020), information and communication technologies (ICT) are arguably the most important innovations of the past several decades. Since the 1980s, ICT advancements and their widespread use have improved the quality of life across the globe. With the help of technological developments such as cloud computing, data mining, and mobile telecommunications, the Internet has connected people worldwide. The diffusion of ICT has significantly transformed government, business, education, and healthcare (Le, 2019). ICT has also driven a new kind of globalisation and the development of advanced technologies. ICT creates the foundations not only for Industry 4.0 but also for other technological breakthroughs such as quantum computing, artificial intelligence (AI), machine learning (ML), and blockchain. Myovella et al. (2020) note that ICT investment has increased dramatically in developing countries as well. For instance, in 1997, China had fewer than 1 million internet users and fewer than 10 million personal computer users. By 2011, however, China led the world in the manufacture, use, and internet penetration of personal computers, with comparable advances in India, South Asia, and Eastern Europe (Myovella et al., 2020). Zhou et al. (2024) conducted empirical analyses using detailed patent disclosure data from listed companies and found that digital technologies significantly improve not only organisational performance but also eco-efficiency.

According to Pradhan et al. (2014), ICT can foster growth in four ways: first, by improving quality of life; second, by enhancing business competitiveness; third, by diversifying the economy; and fourth, by supporting the retention of businesses. ICT also substantially reduces transaction costs in financial services (Hasbi & Dubus, 2020). Its rapid expansion has strengthened human capital development, facilitated e-commerce, created new employment opportunities, and improved network externalities and information dissemination (Adeleye & Eboagu, 2019). Even in SMEs, production processes have steadily become more digital and automated. Computers have become the primary tools for planners, designers, builders, and technicians, supplemented by printing and three-dimensional imaging. According to

Waschull et al. (2017), ICT is now used to execute a large share of production, service, and control processes. Meanwhile, ICT costs continue to decline annually. It is estimated that approximately 10% of all corporate investment is directed toward ICT, and around 55% of all ICT investment is devoted to digital transformation. By 2026, more than half of CIOs are expected to lead business transformation, enabling digitally mature organisations through strategic technology planning and replatforming to support an agile, data-driven, and collaborative workforce (Infotechlead, 2021). Computers are the principal instruments used by more than half of the global population (ITU, 2020). At the same time, current industrial patterns of consumption and production have significant environmental impacts, including global warming, biodiversity loss, and pollution of air, land, and water. Intelligent manufacturing, fuelled by the rapid growth of ICT (particularly AI), is at the centre of a new wave of industrial transformation and upgrading. The next generation of ICT, characterised by greater sensitivity, flexibility, and connectivity, is key to advancing business innovation and ensuring that manufacturing technologies keep pace with global standards. Unlike general technological progress, ICT developments extend beyond improving products. They enhance external information acquisition, optimise manufacturing and sales processes, strengthen organisational structures, increase managerial and communication efficiency, and expand the capacity for technological absorption (Chege et al., 2020). Consequently, it is more important than ever for industrial firms to invest in ICT. According to the OECD (2020a), the Netherlands, Sweden, the Czech Republic, the United States, and France have made the largest recent ICT investments relative to gross fixed capital formation, and compared to developing economies, these countries also achieve stronger economic outcomes. Most industrial firms' technological advances now depend on ICT innovation to boost productivity (Venkataraman & Pinto, 2019; Kumar & Suresh, 2009). Even when considering the so-called "productivity paradox," it is difficult to precisely measure ICT's contribution to economic productivity, yet most industrial and commercial activities today would be impossible without it. ICT is also a crucial tool for transmitting organisational culture and expertise (Kolerová & Otčenášková, 2015). Programmers and IT specialists hold some of the highest-paying yet most demanding jobs. Effective planning, preparation, implementation, management, and control of production all rely on information management. Innovation and structural investment are essential to building successful information systems, though these processes have often been undervalued by struggling firms. As Li et al. (2025) observe, firms developing ICTs often apply for patents to protect against imitation and safeguard economic benefits. However, ICTs evolve at such a rapid pace that patents, which typically take months or years to be granted, may already be outdated by the time they are approved. Moreover, many ICT innovations are based on software or algorithms, which remain difficult to patent under current legal frameworks (e.g., in the EU and the US).

Project principles often underpin innovation cycles; the conclusion of a project typically marks the end of a corresponding cycle of product innovation. New initiatives in technology, organisation, production, funding, or marketing can each trigger innovation cycles. Mass customisation (MC), sometimes referred to as individual mass production, uses ICT to adapt large-scale manufacturing to individual consumer needs (Paoletti, 2018). As Yetis et al. (2022) note, MC begins when customers place orders online, which are then manufactured in factories. Effective MC requires continuous communication with suppliers, carriers, and customers, while also supporting market research. ICT allows firms to map entire production cycles and address potential issues in real time. Enabling technologies such as digital design, 3D printing, blockchain, modular systems, AI-driven recommendation tools, and advanced robotics make it possible to deliver personalised products at costs close to mass production. Patents often protect these enabling technologies, safeguarding proprietary methods and modular architectures. Industry 4.0 has amplified these dynamics by introducing IoT, flexible business models, new financing mechanisms, and heightened risks of technological and IP-related challenges (Rose, 2016). Consequently, ICT advancements, global logistics, digital marketing, and co-financing have become central to industrial production. Finally, standardisation enables economies of scale and scope, while innovation enhances responsiveness and flexibility. Both are complementary in strengthening MC capabilities, with innovation significantly accelerating delivery (Wang et al., 2016).

In addition to higher maintenance, depreciation, and investment costs, the growing sophistication and digitisation of manufacturing also increase demands on human resources, education, and training. Human capital has therefore become a crucial asset for businesses in the context of automation and robotisation (McCoy et al., 2019). Automation and robotisation trends generate many patentable technologies. Any advancement in robotics or automated systems (e.g., new robotic welding methods or AI-powered logistics platforms) can be protected by patents. Patents encourage investment in automation and robotics by granting innovators exclusive rights and a return on costly research and development. For example, large companies such as ABB, KUKA, and Fanuc hold extensive robotics patent portfolios, which influence who can commercialise specific technologies. However, as Wang and Hsu (2020) noted, excessive patent concentration can limit smaller firms' access to automation technologies and create barriers to entry. Smart manufacturing, as a result, can bring disruptive changes to production technologies and business models in the manufacturing industry. These technologies must also be adapted to the needs of problematic businesses and regions. Many workers in manufacturing and maintenance now hold college degrees and regularly use

ICT and foreign languages in their work. While some employees can be redeployed into maintenance, logistics, or administrative roles, automation and robotisation do not necessarily imply widespread layoffs of manual workers. Even in times of crisis, company management should avoid dismissing employees outright (Ymous et al., 2020). Alternatives include remote work, reduced hours, job rotation, government subsidies, launching new production programmes, or entering new markets.

Driven by cross-border innovation and rapid development, international digitalisation and informatisation are now entering a phase of deeper penetration, making the digital economy a genuine new engine of global growth (Brynjolfsson & Collis, 2019). In recent years, the digital economy has advanced not only in the West but also significantly in Asia (China, Japan), where it has fostered the integration of digital technologies with traditional economic activities (Taglioni & Winkler, 2016). Emerging information technologies and applications—such as the sharing economy, blockchain, 3D printing, and machine learning (ML)—have further contributed to the rise of manufacturing innovation (Sutherland & Jarrahi, 2018). According to most observers, the digital economy will permeate nearly all aspects of society, including political decision-making, economic environments, and interpersonal relations (Hindman, 2018). It is also expected to improve the quality of life, stimulate scientific discoveries, encourage economic growth, and create new employment opportunities. At the same time, global crises and conflicts not only disrupt production and business processes but also reshape business paradigms, including employment stability, innovation strategies, and collaboration practices aimed at greater efficiency and sustainability (Andrade & Badaró, 2020). Building on these technological advancements, Industry 4.0 envisions an environment in which physical and virtual spaces are closely integrated. This integration enables even smaller firms to operate globally and to self-organise their operations in real time with the support of artificial intelligence.

The economic, technological, and personal challenges that emerging economies and struggling businesses face under global competition must also be considered. Companies are investing unprecedented amounts in digital technologies such as machine learning, big data analytics (BDA), blockchain, and augmented reality, integrating them into increasingly broad areas of their operations. On the positive side, digital technologies can enhance the social performance of businesses, for example, by enabling remote work (Asokan et al., 2022). Advanced technologies also improve workplace safety, efficiency, and accident prevention (Matos & Jacinto, 2019). They can support waste treatment, automate processes, raise corporate productivity, and improve both the quality of products and services and the living standards of society. However, if firms invest heavily in technology but neglect human capital, crises may be aggravated. Technology can generate excessive costs, manufacturing inefficiencies, duplication of operations, health risks, and environmental damage. As Zhang & Wang (2025) note, digitalisation improves efficiency but also increases emissions due to rising energy consumption. At the same time, digital monitoring systems, when combined with smart grids and renewable energy, can enhance efficiency and reduce the carbon footprint of transport and production. Nonetheless, sustainability challenges remain, including resource depletion, e-waste, social inequality, and market instability. New technology patents may amplify these downsides. Instead of diffusing innovation widely, patents can consolidate market power, restrict access, and deepen inequalities. Concentration of patents in the hands of large corporations can block smaller firms or startups from innovating; while overlapping patents in fields such as software, telecommunications, or biotechnology create legal uncertainty and slow down progress. Before patenting, manufacturing, and distributing new technologies, public institutions should support rigorous technology assessments to evaluate long-term compatibility with environmental, social, and industrial goals (Grunwald, 2019).

In response to growing demand for ethically and environmentally sustainable practices, international frameworks such as the United Nations Sustainable Development Goals (SDGs) are pushing companies toward more comprehensive approaches. Still, new technologies bring additional social risks. For instance, tracking applications may violate employee privacy, while cryptocurrencies and blockchain can enable unregulated or illegal transactions that fuel human trafficking and modern slavery (Dierksmeier & Seele, 2020). Hohn & Durach (2021) argue that, contrary to common claims, technological progress may not increase social welfare but instead amplify existing sustainability problems in production systems. The rapid expansion of e-commerce illustrates these issues. By 2025, the number of global online buyers is expected to exceed 2.5 billion, representing 25–30% of all retail sales (IIFL, 2024). This growth is driven largely by mobile device adoption and rising internet penetration. Yet such rapid development also entails risks. Digital transactions can expose businesses and consumers to financial losses, reputational harm, and emotional stress. Security and safety measures have therefore become priorities in e-business. A comparative study of 175 Chinese and 262 U.S. firms revealed that government regulation plays a larger role in China, while U.S. companies make more extensive use of the Internet; however, Chinese enterprises lag in adopting inter-organisational e-business technologies (Xu et al., 2004). Further risks include data breaches, hacking, unintended outputs from artificial intelligence (AI), and the high costs associated with protecting intellectual property rights (IPRs). Underestimating these negative effects can result in uncontrollable climate change, severe public health threats, and persistent economic and social crises.

In 2021, the European Union launched the Global Gateway, a connectivity initiative designed to mobilise up to €300 billion by 2027. A central pillar of the project is digital collaboration, which may reinforce the bilateral framework of a future EU–Japan Digital Partnership (Armani & Esteban, 2021). Beyond financing, the initiative creates an "enabling environment" to attract foreign investment in partner countries. The Global Gateway has been compared—often metaphorically—to China's Belt and Road Initiative (BRI) and is intended to complement the Build Back Better World (B3W) initiative led by the United States. While G7 connectivity strategies rely heavily on private capital, the BRI continues to depend primarily on public funding. The Global Gateway also overlaps with the EU's broader digital agenda and Indo-Pacific policy, underlining the importance of digital transformation. Digital innovation requires not only technological adoption but also conceptual phases of innovation, effective implementation, and sustainable integration into markets and organisations (Cheng et al., 2023). Its benefits include higher efficiency, improved customer experience, and reduced costs (Pesch et al., 2021). However, realising these benefits requires significant investment and organisational alignment. Firms must strategically align innovation activities with their goals and values, and in industrial contexts, technology analysis provides critical data for supporting these processes (Kutin et al., 2019).

Competitive industrial production entails the development and application of contemporary technologies for the production and assembly of machine components, as well as the use of sophisticated, high-performance machinery for part manufacturing. Given their significance in the global political and economic landscape, it is crucial to understand how the economic conditions in the United States and China influence G20 industrial production to ensure global stability. This implies that increases in industrial output in these major economies tend to have a ripple effect on the industrial output of other G20 countries. Although economic research has long examined the worldwide influence of US GDP (Kose et al., 2017), recent studies have increasingly emphasised China's potential spillover effects on other nations due to its rising status as a global economic power. A shock to China's GDP can substantially impact other economies, with developing economies being more affected over time (Cashin et al., 2017). Moreover, a shock to China's manufacturing sector can negatively affect its trade partners' export growth, with the effect being more pronounced for countries that maintain strong economic links with China (Blagrave & Vesperoni, 2018).

According to Kumar and Ahmad (2024), in the US and China Industrial Production Index, Japan responds most effectively to shocks compared to other member countries. This underscores Japan's close economic ties to these two industrial giants and its sensitivity to changes in industrial production. In general, the interconnected nature of developed economies makes their industrial output more responsive to fluctuations in US industrial production. In 2025, China maintains its position as the world's leading manufacturing country, driven by strategic investments and technological advancements. Under the "Made in China 2025" initiative, China has made notable progress in sectors such as electric vehicles, robotics, and high-speed rail (WEF, 2025). The United States continues to excel in high-tech sectors while facing increasing global competition, accounting for approximately 9.5% of global manufacturing output, valued at nearly $2.5 trillion (NAM, 2025). Japan has demonstrated significant innovative capabilities but faces demographic and competitive challenges. It remains a global leader in precision engineering, robotics, and automotive manufacturing, with companies such as Toyota and Sony at the forefront of innovation. The European Union, although home to advanced manufacturing, requires substantial investment to modernise its industrial base and remain globally competitive. Estimates suggest that the EU needs approximately €800 billion annually to address challenges such as high energy costs and labour shortages (Reuters, 2025).

The organisation of industrial production and the type of production cycle are largely determined by the characteristics, operational features, and intended purpose of the manufacturing technology. Increasing structural complexity and the pressure to reduce production lead times result in rising costs associated with mastering new product types. Patents frequently embody technological innovations that necessitate radical changes in production organisation, such as workplace automation, robotic handling, or AI in production planning. Patented technologies may introduce new workflows, assembly methods, or supply chain integrations. For instance, patents in additive manufacturing (3D printing) enable a shift from mass to flexible, customised production. When patents become industry standards, firms adapt their production systems to these protected technologies (Comino & Manenti, 2022). A product's manufacturability depends on the effectiveness of production organisation, which requires alignment between technological, financial, and organisational processes, manufacturing methods, services, and business units. Before producing new or improved goods—such as spatially modified gear rims—the production process must be designed and technologically prepared. The development of technological equipment, processes, documentation, and design manufacturability all rely on Technological preparation of production (TPP) (Grubka et al., 2019).

A key challenge for many firms is the effective design and implementation of intellectual property (IP) protection. Alongside TPP, companies must prepare patent documentation and determine suitable mechanisms to safeguard production-technological know-how, particularly when multiple actors are involved. Equally important is the promotion of new products and services without disclosing core corporate knowledge. These processes should be managed in accordance with the firm's broader innovation and production strategy. Well-organised production systems support systematic investment in R&D, yielding higher patent outputs. Large-scale industrial systems further enhance the efficiency of patent commercialisation (Blind et al., 2021). Moreover, organised networks of suppliers, research institutions, and firms (industrial clusters) facilitate joint patenting and technology sharing. However, strong patent portfolios can also consolidate industrial structures by restricting entry or expansion, potentially limiting the innovative capacity of smaller firms.

The type of production is the primary factor shaping differences in TPP. In engineering, aerospace, and automotive industries, TPP is closely linked to the design and optimisation of technological processes (Stasiuk-Piekarska et al., 2017). By contrast, in the food, pharmaceutical, and chemical sectors, the emphasis often lies in balancing natural and technological methods of production. The development of new products in engineering firms typically requires the creation or adaptation of technological processes, with costs rising substantially as product complexity increases. For instance, spatially modified gear rims demand significantly greater technological preparation. As Grubka et al. (2019) note, TPP encompasses the design of equipment, processes, and documentation to ensure manufacturability—tasks that are essential yet costly and labour-intensive. Technological advancement does not always necessitate entirely new inventions; existing technologies can often be adapted to better address customer needs. Dan et al. (2016) highlight that suppliers, partners, and service providers frequently act as key carriers of technological innovation. At the macro level, FORBES (2020) reports that technology's role in driving the global economy continues to expand, despite pressures from slowing Chinese manufacturing, the COVID-19 pandemic, and rising tariffs.

Modern technologies, largely the product of R&D, are essential for introducing novel products or services to the market. Corporate R&D spending is closely linked to sustainable innovation and enhances environmental performance, as measured by eco-efficiency and the intensity of energy use and carbon emissions (Alam et al., 2019). R&D may be conducted internally, leveraging existing resources, or externally, by acquiring expertise or technology from other organisations. In both cases, firms must invest strategically to access knowledge critical to innovation. Standards adoption is frequently regarded as a catalyst for innovation (Swann & Lambert, 2017). By reducing the time required to develop and commercialise new technologies, standards accelerate innovation. They also establish a level playing field, fostering competition and creativity, while promoting the diffusion of new products and enhancing consumer confidence. Standards play a central role in the patent process. They are agreed-upon technical specifications, guidelines, or rules that ensure products, services, or processes are compatible, safe, and efficient (Bekkers & West, 2009). Standards may be formal (e.g., ISO, IEC, IEEE) or de facto (widely adopted industry practices). Some patents, known as Standard-essential patents (SEPs), cover technologies that must be used to comply with a standard—for instance, certain telecommunications or Wi-Fi protocols. During standard development, companies often patent inventions likely to become part of the standard. Such patents must be disclosed and licensed fairly to prevent patent hold-ups or monopolisation.

According to Garcia & Calantone (2002), radical technological breakthroughs are technological advancements so significant that they drastically alter feasible price/performance ratios or open up entirely new types of applications. For businesses launching radically new technological advancements, the lengthy period between the initial introduction and the start of widespread diffusion—known as the adaptation phase—can have detrimental effects. In the face of significant risks, introducing such innovations requires a high degree of commitment from firms over an extended period (Min et al., 2006). Generally, adjustments to the innovation process are needed if the client wants the new product or technology completed sooner, or if new rules and guidelines for innovation processes are implemented. Since production personnel possess the most expertise with the technology, they should be well-trained and encouraged to contribute to the innovation project, especially during a crisis (Dekker & Thakkar, 2018). Determining the allocation of IP rights among project participants is also a crucial step in preparing an innovation project and frequently leads to major challenges. Although there is always risk involved in bringing new technologies or products to market, it is often necessary to preserve and strengthen market positions during a crisis. In the evolution of socio-technological systems, not only a business plan but also a viable company strategy is an essential component of innovation implementation (Planko et al., 2017). According to studies, over 30% of innovation initiatives fail because risks are not adequately recognised and managed, while about 65% of organisations include risk management in their new ventures (Bonnie, 2015).

On the subject of manufacturing and innovation projects, technological advances are inextricably linked to other production preparatory procedures and should not be mistaken for them (Li et al., 2018). Many industrial products are beginning to incorporate an increasing number of technologies, a trend known as "smart manufacturing" or "sophisticated industrial products" (Cizmovic et al., 2020). Artificial intelligence (AI) is an enabling technology that can be integrated into networks of systems and products in industrial settings, driving the transformation of these ecosystems. Smart manufacturing involves a collection of tools to supervise manufacturing processes, control data flow within corporate and business ecosystems, establish ongoing operational monitoring systems, and develop methods for problem identification and prediction (Wamba & Queiroz, 2022). Leading companies demonstrating the use of AI in conjunction with smart manufacturing include Tesla, which is well known for its quality control system capable of quickly detecting defects in vehicles. Bosch employs robotic process automation to handle repetitive tasks and streamline processes, whereas Toyota is notable for its use of AI to optimise the supply chain (Li et al., 2018). Since the development of manufacturing innovations typically requires significant research and development (R&D), prototyping, testing, and investment in equipment, there is a heightened risk of unsuccessful investments. Patents help mitigate some of this risk by offering a period of exclusivity during which the innovator can aim to achieve an adequate return on investment (ROI). This makes it more attractive for firms (and their investors) to allocate resources to the research and development of new manufacturing technologies. Patents can also facilitate collaboration between firms or between firms and research institutions by clearly defining intellectual property rights. This is particularly important when multiple entities are involved in a complex manufacturing innovation project (Triguero et al., 2018).

For example, the globalisation of markets dominated by powerful European, American, and Japanese corporations, together with the growing political emphasis on fostering local technological competition in emerging economies, are the main commercial drivers in the automobile sector. Companies must either enter new business segments, develop suitable products through effective TPP, or innovate their original methods to establish themselves as greenfield automotive firms. The automotive industry continues to expand. The largest markets are currently in China, the United States, and Western Europe, while growth in the coming years will be driven by emerging economies. National policies increasingly support the development of the automotive sector. For instance, the Chinese government provides substantial subsidies for new energy vehicles and actively promotes domestic companies. Independent original equipment manufacturers (OEMs) in both China and Europe are also making progress (Schacher, 2018). Meanwhile, multinational automakers from the United States, Europe, and Japan, with their extensive installed bases and economies of scale, continue to dominate global markets while holding vast portfolios of technology patents.

When dealing with large technological projects and investments, it is often necessary to design technology in several variants, consider flexible technological solutions, and ensure adequate multilayer protection of the related technological intellectual property (IP). Effective IP protection for new technologies can significantly influence the success of innovations. In a competitive environment—where the combination of general and specific knowledge generates economic value and positions technology as a strategic asset—the efficiency of technological innovation increasingly depends on the processes of knowledge sharing and communication (Günsel, 2015). The effectiveness of innovation systems is also shaped by variables such as the geographical and ethnic diversity of members and their roles within the network (Arroyabe et al., 2021). The largest IT companies continue to dominate patent creation. According to an analysis by R&D World, leading tech corporations generated more than 40,000 patents in 2024. Their output was 2.8 times higher than that of automotive companies and 4.2 times higher than that of aerospace companies, widening the gap. Samsung, IBM, Intel, Microsoft, and Apple together received approximately 24,400 patents granted by the USPTO in 2024 (Buntz, 2024).

One well-known example of a highly valuable patent is Amazon's "One-Click" patent, which has been licensed at significant cost by companies such as Apple. Patent analyses can provide a useful summary of what businesses are working on (Szu-chia, 2015). For instance, Apple was awarded a patent that allows audio signals to be divided into multiple pathways, creating the illusion that sound originates from locations other than the speaker itself. Similarly, Amazon was granted a patent for a "non-contact scanning system" that uses hand gestures to identify individuals, requiring customers to scan their palms both when entering a store and when completing a purchase (Bhatia, 2020). Another milestone example is Samsung's patent application for an Image Processing Device and Image Processing Method, which became the five-millionth PCT application published by WIPO (2024b). The successful commercialisation of innovation depends not only on the technical quality of patents but also on effective cross-functional collaboration. Close coordination between production preparation and marketing—supported by robust market research—is critical, as is the involvement of human resources in training and motivating employees throughout the production process. For resource-constrained firms, adopting agile project management practices can further improve outcomes. A comprehensive IP strategy should clearly define organisational responsibilities, establish guidelines for the exploitation of corporate IP, and regulate the treatment of employee inventions, regardless of whether they are developed during or outside working hours and whether company or personal resources are used.

To develop new technologies effectively, collaboration between the intellectual property (IP) management and innovation departments is essential. This cooperation involves transferring and transforming individual knowledge into organisational knowledge, and further converting this knowledge into inventions and innovations. For example, when experts collaborate during the preparation of production processes, knowledge can be formalised and protected through patenting and licensing technological innovations. If a corporation identifies a new technology during the R&D phase, it often needs to safeguard its IP at the "front end of innovation." Patent protection is typically the primary option for securing technological concepts or features related to specific applications. However, patents are also the most expensive form of protection and can become a financial burden for struggling businesses. In such cases, companies may seek more cost-effective alternatives, such as industrial design protection or trademarks. For a technology to qualify for patent protection, it must meet several key criteria: Industrial applicability (practical utility and potential for future patenting), Innovativeness (novelty, effectiveness, and validity), and Clarity and complexity of the description (sufficient detail to protect against imitation and ensure enforceability). (Tidd & Bessant, 2018; WIPO, 2017a; WIPO, 2017b)

In the United States, patents are granted only after filing with and approval by the U.S. Patent and Trademark Office (USPTO). Since the America Invents Act (AIA), the U.S. has adopted a "first-inventor-to-file" system, making filing strategy and timing critical. Ongoing developments—such as changes in USPTO post-grant procedures, evolving case law on intent and damages, and enforcement trends under the DTSA (Defend Trade Secrets Act, 2016) and ITC (International Trade Commission)—continue to shape global IP strategies. (USPTO, 2024) In China, patents are granted by the China National Intellectual Property Administration (CNIPA) under a "first-to-file" system. Recent reforms have strengthened patentability and examination standards. The 2021 Patent Law Amendment, together with the Supplemental Protection Certificate (SPC) Guidelines, introduced punitive damages and raised statutory limits on damages. Furthermore, CNIPA and related authorities have issued updated guidelines (2024–2025) to enhance both administrative and judicial mechanisms for resolving IP disputes. (Jun, 2021)

Patent quality is often assessed through citation analysis, with only about 1% of patents cited more than 24 times, while roughly half receive just two to three citations. Additional indicators of innovation performance include portfolio strength, technology cycle time, science linkage, and the Current Impact Index. Research shows that firms with higher impact indices and stronger scientific linkages tend to achieve greater market share and higher returns on investment (Tidd & Bessant, 2018). Nevertheless, patents alone are an imperfect proxy for innovation quality, as a significant proportion remain unused; in Japan, for example, only one in five patents is typically applied in industry. In Japan, the Japan Patent Office (JPO) administers patents, utility models, designs, and trademarks under a first-to-file system. Alongside patents, utility models offer a faster and less costly form of protection for incremental innovations. A distinctive feature of Japanese IP law is the treatment of employee inventions: employers must provide reasonable compensation to inventors when rights are transferred to the company, and many firms maintain internal regulations to govern remuneration. Enforcement is handled through civil litigation in district courts and the Intellectual Property High Court, as well as through customs and criminal measures in cases of large-scale infringement. Despite the country's strong IP framework, a considerable share of patents remain unused, prompting government initiatives to encourage greater commercialisation and licensing (JPO, 2023b). In the European Union, IP protection operates across multiple layers. The EU Intellectual Property Office (EUIPO) grants EU trademarks and Community designs, while national offices administer parallel national rights. Patents are granted by the European Patent Office (EPO); since 2023, applicants have the option of requesting a Unitary Patent, which provides uniform protection across participating member states, enforced by the newly established Unified Patent Court (UPC). This system enables centralised litigation for both infringement and revocation, representing a major shift in European patent enforcement. EU enforcement policy is also notable for its emphasis on border measures and coordinated customs action against counterfeit goods. Empirical studies confirm that EU firms that actively manage IP rights demonstrate stronger economic performance, including higher growth and revenue per employee (EUIPO, 2023).

In OECD countries, patenting activity is dominated by the United States, Japan, and Germany. Larger and more developed markets are generally more attractive locations for patent applications, as firms seek broader protection where commercial opportunities are greater. However, barriers such as lengthy examination and granting procedures, as well as higher costs (e.g., application, translation, and legal fees), often discourage foreign applicants (Eaton, 1999; Eaton et al., 2016). For instance, patenting in Japan is considered particularly costly for foreign inventors. When successful, inventors often extend protection to neighbouring markets; for example, Japan is the largest foreign patent holder in both the US and Canada. The ratio of foreign-to-domestic patent applications highlights these dynamics. For China and Japan, the ratio is around 1.8, while it is significantly higher for the United States (7.7), WIPO international applications (10.8), and the European Patent Office (EPO) (14.9). These figures suggest that the US and many European nations are not only major technology producers but also highly attractive markets for the commercialisation of new inventions.

The technological distribution of patents also varies by country. In China, tobacco-related technologies dominate applications, while in Japan, patents are concentrated in acyclic and carbocyclic chemicals as well as medical, dental, and toiletry treatments. German patents are more frequently linked to cosmetics and toiletries (Mattos & Speziali, 2017). In the United States, about 20% of published applications fall into communications systems, batteries and cells, electronic equipment, and semiconductor devices. Furthermore, China accounted for 36.8% of all green and low-carbon technology invention patents granted worldwide between 2016 and 2022. Thirteen Chinese institutions ranked among the top 50 global assignees of such patents, second only to Japan with 15 (CNIPA, 2023).

In Japan, however, total patent applications have steadily declined since 2006, with a one-third reduction over the past two decades. To address this problem, the Japan Patent Office (JPO) introduced an action plan encouraging each prefecture to set KPIs tailored to local strengths, with patent growth designated as a key performance indicator in some regions (Suzuki, 2023). Patent activity also reflects regional industrial specialisation: for example, nuclear engineering patents are concentrated in areas with nuclear power plants and research institutes, whereas agricultural and fisheries patents are more geographically dispersed (Shimanishi, 2019). Within Europe, high-technology applications to the EPO are concentrated in a small number of Member States. Denmark and Austria are the only EU countries with double-digit application ratios, while Sweden, Finland, Germany, the Netherlands, Belgium, and France show the highest per-capita rates (17.7–22.2 applications per million inhabitants). The EPO grants patents valid across 38 EPC contracting states, which include EU and EFTA members as well as several candidate countries. Applications can be filed directly under the EPC or through the PCT (Euro-PCT). To ensure accuracy, fractional counting is applied to multi-inventor applications, based on inventors' countries of residence (Eurostat, 2013). Patent offices have also emphasised quality management. The EPO, accredited under ISO 9001, has improved examination, information services, and post-grant activities. It provides search reports with written opinions within six months, compared with up to 20 months at the USPTO, where examination delays may affect competitiveness. The USPTO, however, maintains ISO 9000 certification for its IP rights issuance and quality control systems, highlighting its commitment to international standards (USPTO, 2020). Ultimately, patents serve as strategic instruments for businesses, protecting innovations against unauthorised use and enabling firms to preserve competitive advantage. Exclusive patent rights, generally lasting 20 years from the filing date, prevent others from making, using, or profiting from an invention without the patent holder's consent in the jurisdiction where the patent is granted.

3. METHODOLOGY

A key objective of this research is to support a more comprehensive approach to managing technological innovation, with a particular focus on intellectual property (IP) protection. The study builds upon a bibliometric analysis of professional literature, which helped identify priority areas and emerging trends in Technology innovation management. To explore patent protection across regions, we conducted a statistical analysis of the World Intellectual Property Organisation (WIPO) database. We categorised the data, analysed trends, and used descriptive statistics to characterise developments in the distribution and patterns of IP data. Through targeted analytics, we effectively distilled a large dataset to reveal meaningful insights. Our methodological framework was further shaped by a review of case studies in technology analysis, assessment, planning, open innovation, and IP protection. For this statistical component, we applied WIPO's open-source tools and international classifications to evaluate which regions filed patent applications and which rights were granted. This allowed for a more nuanced understanding of technological development across various technology clusters, offering a more robust alternative to keyword-based categorisation. While the primary aim of this study was to quantify the total number of relevant patent rights rather than to analyse specific types of technological progress, the complexity of identifying clear trends in the data underscored the importance of a general understanding of patent analysis. This was especially relevant given the influence of differing national IP regulations and systems. Ultimately, the data provide a strategic overview of global developments in IP protection and offer valuable insights for managing technological innovation. They also serve as a foundation for assessing the economic impact of innovation across regions and for examining more specialised innovation processes.

4. RESULTS OF LONG-TERM PATENT ANALYSIS

If we examine the number of resident patent applications from 2000 to 2023, China clearly dominates, followed by Japan, the United States, and EU countries. Approximately 41% of all patent applications during this period were filed in China, 19% in Japan, 15% in the US, and 13% in the EU. For instance, the number of patents filed in China increased by 5.906% over the given timeframe. In China, industrial property rights include trademarks, utility model patents, design patents, and invention patents. Invention patents are valid for 20 years from the filing date, while utility model patents are granted for a term of 10 years from the filing date. Patent applications in China can be submitted by individuals or organisations based in mainland China, either independently or through a legally registered patent office. However, foreign individuals, enterprises, or other organisations without a habitual residence or business office in mainland China must appoint a registered patent agency to represent them in filing a patent application. The examination process for invention patents in China involves five stages: receipt of the application, preliminary examination, publication, substantive examination, and grant. Once a patent is granted, the patentee must pay the annual fee for each subsequent year before the expiration of the current term. Failure to pay the annual fee or surcharge on time—or in full by the end of the grace period—will result in termination of the patent right from the date of expiration of the previous term. (CNIPA, 2024) China's economy is currently transitioning from a phase of rapid expansion to one focused on high-quality development, with innovation playing a central role in this transformation (Cui et al., 2021). In the context of ongoing geopolitical uncertainty, the Chinese government has increasingly emphasised innovation and may intervene in economic activities to safeguard strategic interests. In 2024, the Chinese Inter-Ministerial Joint Meeting on Building a Strong Nation with Intellectual Property (IP) published the Plan to Encourage the Development of an Economically Strong Nation with Sufficient Intellectual Property. This 110-point plan outlines measures to strengthen patent examination processes, discourage frivolous IP applications, promote reforms in IP legislation, and explore the use of artificial intelligence in IP evaluation procedures (Wininger, 2024). Furthermore, the plan introduced a special initiative titled "Procuratorial Protection of Enterprises", aimed at strengthening IP enforcement. The initiative supports services that promote high-level scientific and technological self-reliance, strictly punishes trade secret infringements, and continues expanding IP protection in critical core technologies and emerging industries.

Globally, the number of patent applications filed by residents increased by 189%, whereas some countries showed weaker growth or even a decline, such as Japan (–41%). According to a recent study examining 1,250 of the world's leading R&D companies between 2005 and 2017, EU companies lag behind their US and Japanese counterparts in terms of R&D intensity. Over the observation period, the gap between the US and the EU widened, while the difference between the EU and Japan remained relatively stable (Aristovnik et al., 2023).

Approximately 80% of European exports come from industries within the EU, and industrial production accounts for more than 65% of private sector R&D investment. Between 2011 and 2016, the turnover of 79% of European businesses that adopted at least one innovation rose by over 25% (Innobarometer, 2016). The European Commission (EC), through research policies and initiatives such as the Europe 2020 strategy and Horizon 2020, fosters scientific discoveries, innovative technological processes, new business models, and non-technological innovation in services. However, several factors contribute to Europe's technological lag. Labour productivity growth varies significantly across countries: it is high in Germany and Norway, moderate in France and the UK, and lower in Italy and Spain. In many cases, these levels remain below those in the US. Long-term productivity differences between France and Italy amount to 25–30%, while productivity per worker is 12% lower in France, 15% lower in Germany, 26% lower in Spain, and 33% lower in Italy, compared with the US. According to the 2014 Global Innovation Index, countries such as Sweden, the UK, and Switzerland ranked at the top, while many other European economies lagged. Additional factors hindering innovation include the limited ability of businesses to attract foreign investment (particularly in start-ups), duplication of research efforts, insufficient international collaboration, and weak cooperation with suppliers, customers, universities, and governments. This, in turn, reduces government support for innovation and makes it harder to attract and retain skilled workers, especially in emerging economies. To strengthen Europe's global position in innovation, these issues must be addressed in parallel with advancing technological innovation.

Looking at individual years and countries, the largest number of patent applications filed by residents was recorded in Japan in 2000 (387,364), while the smallest was in China in 2000 (25,346). Since then, Japan has shown a gradual decline in patent applications. Historically, Japan was known for its comprehensive employment systems, which included profit-sharing and employee ownership schemes, corporate welfare programs, lifetime employment, seniority-based wage and promotion systems, and various mechanisms to enhance employee participation and voice. These practices are often credited with contributing significantly to Japan's post-war economic success. However, following the collapse of the stock market and real estate bubble in the early 1990s, Japan's economy experienced prolonged stagnation. To improve labour market flexibility, increase non-regular employment, enhance overall economic efficiency, and strengthen innovation support, labour market reforms were introduced under the new administration between 2003 and 2004 (Ikeda et al., 2024). In recent years, innovation support has been particularly prominent in the US, Japan, and Switzerland, where the adoption of deep learning technologies has progressed more rapidly than elsewhere. These countries consistently demonstrate faster growth in research output, patents, and scholarly publications. Japan, for example, launched a national AI strategy in 2017 and was among the first nations to make significant investments in artificial intelligence. The US continues to lead in terms of the number of AI-related companies and the scale and expertise of its AI workforce. At the same time, Switzerland benefits from strong cooperation between academia, industry, and innovation systems (Takahashi et al., 2024).

In the United States, preparing a patent application and managing the proceedings requires knowledge of USPTO regulations and procedures, patent law, and the science or technology underlying the invention. Both patent attorneys and non-attorneys (known as patent agents) may register with the USPTO to obtain authorisation to draft and prosecute patent applications. The USPTO recognises three categories of patents: utility, design, and plant patents. Applications for utility and plant patents can be either nonprovisional or provisional, whereas design inventions are not eligible for provisional applications. Before a patent is granted, utility and plant applications are generally published—unless the applicant requests non-publication. Publication occurs 18 months after the earliest effective filing date or priority date claimed in the application. Patent applications are examined by specialised technology centres, each responsible for a specific technological domain (USPTO, 2024). In terms of trends, the United States recorded its highest number of patent applications in 2016, followed by a gradual decline. Within the European Union, the largest numbers were observed in 2008 and 2015, with the lowest recorded in 2022. Overall, however, the number of patent applications filed by residents worldwide has shown a marked increase since 2000 (Table 1).

Regarding the number of patent grants obtained by residents, China again leads, followed by Japan, the United States, and the EU countries, in the same order as patent applications. During the observed period, China accounted for approximately 31% of patent grants, Japan 22%, the US 17%, and the EU countries 15%.

Table 1. Total patent applications
Source: Own calculation based on WIPO, 2025

	China	Japan	USA	EU	World
2000	25346	387364	164795	203200	875000
2001	30038	386767	177513	206900	896400
2002	39806	369458	184245	196400	889200
2003	56769	358184	188941	201700	925000
2004	65786	368416	189536	205200	966700
2005	93485	367960	207867	205800	1038900
2006	122318	347060	221784	212900	1075200
2007	153060	333498	241347	216000	1125100
2008	194579	330110	231588	220400	1162200
2009	229096	295315	224912	213000	1146400
2010	293066	290081	241977	221800	1237100
2011	415829	287580	247750	216400	1365300
2012	535313	287013	268782	218700	1519600
2013	704936	271731	287831	219100	1708900
2014	801135	265959	285096	215000	1799400
2015	968252	258839	288335	220400	1973800
2016	1204981	260244	295327	217200	2215800
2017	1245709	260292	293904	212900	2251100
2018	1393815	253630	285095	215000	2386200
2019	1243568	245372	285113	213000	2239200
2020	1344817	227348	269586	206800	2311500
2021	1426644	222452	262244	201000	2383700
2022	1464605	218813	252316	194100	2409700
2023	1522292	228936	275897	201100	2527400
SUM	**15575245**	**7122422**	**5871781**	**5054000**	**38428800**

Growth in the number of granted patents was also highest in China (13,163%), while Japan recorded only 41%, the US 74%, and the EU 47%. In Japan, the number of domestic patent applications for business-related inventions has been steadily declining. After the surge in 2000, applications fell, but a resurgence occurred in 2012, with 13,032 applications submitted in 2021. This increase is attributed to the reactivation of R&D in the solution business following the structural shift from "products" to "services." Furthermore, the proliferation of smartphones, social networking platforms, AI, and IoT technologies has supported the emergence of new ICT-based services, particularly in industries such as finance. Although initially slow, the grant rate for business-related inventions has risen steadily and now remains stable at about 70%, consistent with the overall average for technical fields (JPO, 2023a).

In Europe, Germany, France, the UK, and Italy represent the top four countries in terms of patenting activity. Half of all academic patent applications originate from a small number of universities (around 5%). Over the past two decades, however, two-thirds of university-originated applications have been filed by external organisations, primarily firms, of which 30% were SMEs. The share of academic patent applications has grown from 24% in 2000 to 45% in 2019, reflecting significant changes in IP legislation and practice. This trend is supported by dedicated knowledge transfer offices, with a primary focus on science-based disciplines. Nonetheless, only a small proportion of universities (approximately 8%) account for the majority (62%) of applications. Despite their smaller output, less patent-intensive universities remain critical to their respective national innovation ecosystems (EPO, 2024a). Globally, the number of patent grants increased by 345% over the monitored period. In terms of individual years, the largest increase in grants was recorded in China in 2023 (819,234) and in Japan in 2013 (225,571). The US reached its peak in 2020, while EU countries reached theirs in 2019. The smallest increase was observed in China in 2001 (5,395). Since then, a decline in patent grants has been observed in Japan (since 2013), the US (since 2020), and the EU (since 2019), which may be partly attributed to the impact of the COVID-19 pandemic (Table 2).

Table 2. Total patent grants
Source: Own calculation based on WIPO, 2025

	China	Japan	USA	EU	World
2000	6177	112269	85071	74060	309000
2001	5395	109375	87606	83750	316900
2002	5868	108515	86976	90000	330600
2003	11404	110835	87901	108330	358600
2004	18241	112527	84271	100670	365000
2005	20705	111088	74637	93380	369900
2006	25077	126804	89823	100970	451200
2007	31945	145040	79527	93160	465400
2008	46590	151765	77501	100890	465300
2009	65391	164459	82382	108320	486600
2010	79767	187237	107792	103330	552500
2011	112347	197594	108626	94740	608500
2012	143808	224917	121026	98120	695700
2013	143535	225571	133593	100740	720800
2014	162680	177750	144621	102770	707000
2015	263436	146749	140969	104860	755100
2016	302136	160643	143723	116720	828800
2017	326970	156844	150949	116320	865400
2018	345959	152440	144413	123870	880300
2019	360919	140865	167115	129520	917200
2020	440691	140329	164562	124170	1000700
2021	584891	141853	149538	113870	1131500
2022	695591	155117	141938	100390	1223900
2023	819234	158587	148071	109130	1373600
SUM	**5018757**	**3619173**	**2802631**	**2492080**	**16179500**

From the perspective of the patent grant rate among resident applicants, the highest value was observed in Japan in 2013 (0.83), while the lowest occurred in China in 2015 (0.15). This indicates that only 15% of patent applications in China were granted in that year. Because of the rigorous legal, technical, and formal requirements for patentability, not all technological patent applications are successful. Many are rejected during examination or opposition proceedings. On average, Japan achieved the highest patent grant rate (0.53), while China recorded the lowest (0.27). In EU countries, the average rate was 0.49, and in the US, it was 0.47. This means that in these regions, only about half of patent applications were granted. Globally, the average grant rate was 0.41, whereas in the US, Japan, and the EU it was above this level. This may reflect both a higher quality of submitted patent applications and more favourable institutional conditions.

High-quality patents contribute to innovation, economic growth, and, ultimately, improved quality of life. In contrast, low-quality innovations increase the costs of patent procedures and can waste resources, including R&D investments. The EU and the US reached their highest average grant rates during the COVID-19 period (2019–2020), whereas China achieved its peak in 2023. For example, during the COVID-19 pandemic, the European Patent Office (EPO) received 390 patent applications related to coronavirus innovations. These included inventions addressing all coronavirus strains (affecting both humans and animals), as well as related technologies such as diagnostics, detection, vaccines, and therapeutics. Within the same period, the EPO granted 152 European patents for such inventions. According to EPO data (2023), the patenting of coronavirus-related technologies has generally increased since 2014, reflecting sustained demand in this field. Overall, the global trend shows that the share of patent applications granted to resident applicants under WIPO has been gradually rising, meaning that a larger proportion of applications ultimately result in patents (Figure 1).

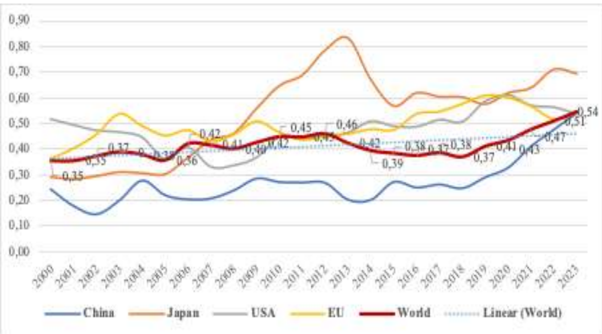

Figure 1. Rate of patent registration
Source: Own calculation based on WIPO, 2025

In 2023, despite a challenging macroeconomic environment, the number of patent applications worldwide exceeded 3.5 million for the first time, marking the fourth consecutive year of growth. The year witnessed several noteworthy technological advances—including modular quantum computing architectures, novel treatments for Alzheimer's disease, progress in robotics, and immersive computing. However, generative AI can be regarded as the most significant technological milestone of 2023 (Rao, 2024). Owing to its cross-disciplinary transformative potential, it is likely to remain a key driver of social, economic, and scientific development over the next decade. Global patent filings were led by China (1.64 million), followed by the United States (518,364), Japan (414,413), and Germany (133,053). Together, the offices of China, Japan, and the Republic of Korea accounted for 91.1% of all Asian patent filing activity in 2023, underscoring the strong concentration of intellectual property (IP) filings in the region. The primary source of global growth was the sharp rise in resident filings. Computer technology continued to dominate published patent applications, accounting for 12.4% of the total in 2022—the most recent year with complete publication data, owing to the lag between application and publication. Other major fields included electrical machinery (6.8%), measurement (5.9%), medical technology (5.4%), and digital communication (5.3%). Among the top ten technology domains, computer technology (+10.7%) was the only one to achieve double-digit growth from 2012 to 2022. A notable increase was also observed in energy-related technologies (solar, fuel cell, wind, geothermal, and hydro), where published patent applications rose from approximately 29,400 in 2007 to over 44,700 in 2022 (WIPO, 2024a).

Patents provide both firms and nations with a significant competitive advantage, although this advantage is often strongest within domestic markets. Even when innovations represent breakthroughs, securing patent protection across multiple jurisdictions can be prohibitively expensive. This is particularly the case because many patents are linked to technical standards and may have only incremental or limited standalone value (Quinn, 2024). The principal advantage of filing an international application lies in the procedural flexibility it offers applicants can defer the decision on where to seek patent protection for up to 30 months. This period is especially valuable, since within the 12 months permitted under the Paris Convention, the technical feasibility and commercial potential of an invention may not yet be sufficiently established to warrant protection across several national or regional systems.

In 2023, despite global economic pressures, a record 272,600 international patent applications were filed through the Patent Cooperation Treaty (PCT) system (WIPO, 2024b). By contrast, more than 3.5 million patent applications were filed worldwide in the same year. This indicates that only about 7–8% of global patent applications are initially submitted via the PCT system. With respect to the annual increase in patent registrations by residents, China recorded the highest growth in 2003 (94%), while Japan registered the lowest in 2014 (-21%). In the United States, the peak annual increase occurred in 2010 (31%), and in the EU countries in 2001 (13%). On average, China achieved the largest annual increase in patent registrations (26%), whereas Japan reported the smallest (1.9%). Globally, the average annual growth rate was 6.8%, meaning that only China achieved an above-average increase. Unlike common-law jurisdictions, China's legal system is based on civil law, relying primarily on statutes rather than case law. In practice, Chinese courts interpret and apply patent law using statutes such as the Patent Law, judicial interpretations, guiding case precedents, and administrative rules, including the Rules for the Implementation of the Patent Law. To strengthen enforcement, China has established 75 national IP protection centres across 29 provinces, municipalities, and autonomous regions.

According to the latest data from the China National Intellectual Property Administration (CNIPA, 2024), the average examination period for invention patents has been reduced to 15.6 months, and the country now maintains 4.66 million active invention patents. Looking forward, China is expected to continue enhancing its patent examination framework in emerging fields such as artificial intelligence, gene technology, quantum information, and medical sciences.

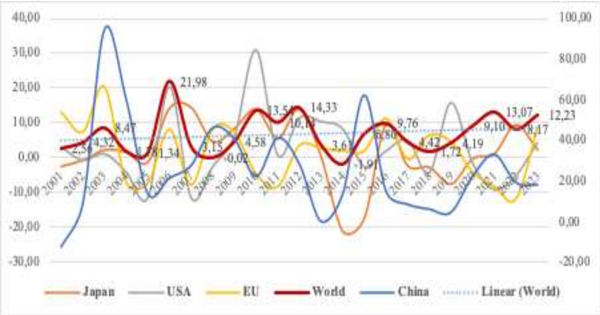

Figure 2. Annual patent registration growth (%)
Source: Own calculation based on WIPO, 2025

Since 2000, global development issues have increasingly encompassed both alleviating poverty and promoting breakthrough technologies. Promoting technology also requires addressing socioeconomic and environmental challenges. The emergence of the digital economy has contributed to global expansion and has become a significant driver of GDP growth in China. China's digital economy grew by 20.9% to reach €3.9 trillion in 2018, accounting for 34.8% of the country's overall GDP. Industry 4.0, or the digital revolution, has made China's cutting-edge products and technologies more widely available. In the future, China may leverage additional technological advancements, particularly online, to maximise innovation, foster new economic linkages, and participate more actively in the global industrial chain (Deloitte, 2019). Among Asian nations, Southeast Asia contributed the most to the expansion of industrial production. Historically, with spices as the most important commodity and increasingly high-tech products today, Southeast Asia has been a vital component of the world trading system (Geiger, 2014). Although technologies still constitute a significant portion of many industrial items, this development suggests that trade now increasingly involves more sophisticated products (UNCTAD, 2020).

Due to favourable conditions, including costs, taxes, and pricing, many leading corporations are investing more heavily in developing nations. Prominent multinational firms focus on technology projects in these countries, emphasising digital infrastructure, renewable energy, and artificial intelligence (AI). For example, the World Bank highlights that businesses play a key role in adopting advanced technologies, which can enhance economic growth and productivity in developing countries (World Bank, 2022). Certain forms of assistance, such as tax breaks, grants, and guarantees, may also be particularly effective in supporting technological innovation in middle-income nations. However, this dynamic has a limited effect on patent applications. Overall, incentives for innovation, including technological innovation, remain lower in emerging economies. Most OECD countries, for instance, offer R&D tax credits based on expenditures. Specific tax contributions are provided by Austria, the Czech Republic, Denmark, Hungary, Turkey, and the United Kingdom. Wage deductions for withholding tax on R&D wages are available in Belgium, Hungary, the Netherlands, Spain, and Turkey. Broader tax benefits for SMEs' R&D are offered by Australia, Canada, France, Hungary, Japan, Korea, Norway, and the United Kingdom (OECD, 2020b). Globally, rapidly expanding middle-income countries are gradually catching up to high-income nations in terms of income inequality. Long-term growth and sustainable earnings are essential to raise living standards for all while respecting local cultures and demographics.

If we examine the development of technology patents in 2000, 2010, and 2023, we observe a clear upward trend. In 2023, approximately twice as many patents were granted as in 2010 and four times as many as in 2000 in the analysed regions. In 2000 and 2010, the USA and Japan dominated patent activity, while China and the EU lagged. By 2023, China and the USA had become the dominant players, whereas Japan and the EU trailed. China experienced the most dramatic growth, increasing its number of technology patents by 7,600%. By contrast, the USA doubled its patents (100%), the EU countries increased by 57%, and Japan saw a decline of 33% over the same period. Several factors explain China's rapid progress and the relative stagnation of other countries. Since the early 2000s, China has made innovation a central pillar of its economic policy (e.g., the "Indigenous Innovation" strategy and Made in China 2025). Universities, companies, and even local governments have been incentivised with subsidies, tax breaks, and prestige rankings tied to patent filings. China has transformed from a manufacturing-based economy to one increasingly driven by high-tech industries such as telecommunications, AI, semiconductors, and green technologies. With growing R&D budgets and increased investment from both private and state-owned enterprises, patent activity has surged. A large proportion of Chinese patents are filed domestically with the China National Intellectual Property Office (CNIPA) and have not been extended abroad. In contrast, American, Japanese, and European firms typically seek international patents via the PCT or EPO, which are costlier but provide broader protection (Fisch et al., 2017). China's R&D spending has risen from around 0.9% of GDP in 2000 to approximately 2.6% in 2023, approaching the levels of the US and the EU (OECD, 2025). The slower growth in the US, Japan, and the EU reflects their already well-developed patent systems, high per-capita patent activity, and a large number of high-quality technology patents. China's exponential growth stems from a lower starting point, representing a "catch-up" process. In China, patents are used not only to protect inventions but also as strategic tools for trade, licensing, and setting industry standards. For instance, in 5G and telecommunications, companies like Huawei and ZTE have deliberately built large patent portfolios to strengthen global competitiveness.

Across technology categories, the most patented areas were Electrical machinery, apparatus, and energy; Audio-visual technology; and Computer technology, whereas the least patented were Micro-structural and nano-technology, Analysis of biological materials, and IT methods for management. In China, the dominant patent categories shifted over time: Pharmaceuticals in 2000, Electrical machinery, apparatus, and energy in 2010, and Computer technology in 2023. After joining the WTO in 2001, China integrated into global trade, and domestic pharmaceutical R&D was incentivised to align with international standards. In the 2000s, China focused on becoming the “world’s factory” for electronics and electrical equipment. In the 2010s–2020s, the focus shifted toward high-tech sectors, including AI, 5G, semiconductors, and cloud computing (WIPO, 2025). The USA consistently led in Computer technology patents (2000, 2010, 2023). As the birthplace of modern computing — including semiconductors, personal computers, and the internet — the US became a global hub for ICT innovation. Silicon Valley companies such as Intel, IBM, Microsoft, Apple, Google, Meta, and NVIDIA have shaped the sector since the 1970s, with corporate R&D investments often exceeding the national R&D budgets of entire countries. In Japan, the most patented categories were Electrical machinery, apparatus, and energy (2000); Computer technology; and Electrical machinery, apparatus, and energy (2023). Japan has been a global leader in consumer electronics, semiconductors, batteries, and industrial machinery since the 1970s (Sony, Panasonic, Toshiba, Hitachi, Mitsubishi, Sharp). Global innovation shifted toward ICT in the 2000s–2010s, leading Japanese firms like Fujitsu, NEC, Toshiba, and Hitachi to focus on hardware and computing infrastructure. Recently, Japan has refocused on advanced manufacturing and green technology. Japan remains the world’s largest producer of industrial robots and automation systems, which fall under Electrical machinery, apparatus, and energy (JPO, 2023b). In the EU, patents were concentrated in Furniture and games (2000, 2010) and Transport (2023). Europe has a long tradition in design industries, including furniture, fashion, and consumer products. These patents often come from Italy, Germany, and Scandinavia, covering both functional and design innovations. The EU also has strong toy/game companies (e.g., LEGO in Denmark, Ravensburger in Germany) that invest heavily in related patents. Europe’s largest industrial sector is transport equipment — cars, trucks, trains, and aircraft. Germany (VW, BMW, Mercedes-Benz), France (Renault, Airbus), Italy (Fiat), and Sweden (Volvo, Scania) dominate global transport innovation (EPO, 2024b). Overall, these data reflect regional specialisations and the focus of technological innovation activity (Table 3).

Table 3. Patent grants by technology, Total count by filing office
Source: Own calculation based on WIPO, 2025

Year	**2000**				**2010**				**2023**			
Field of technology	**China**	**USA**	**Japan**	**EU**	**China**	**USA**	**Japan**	**EU**	**China**	**USA**	**Japan**	**EU**
1 - Electrical machinery, apparatus, energy	782	9504	8540	2000	9173	14256	15592	2010	54821	18885	18238	10918
2 - Audio-visual technology	392	7887	7818	5682	7658	12126	14065	7635	21572	14488	7714	3571
3 - Telecommunications	221	5802	5047	2836	4649	10916	7887	3171	14544	8425	3393	3294
4 - Digital communication	83	3679	2102	2665	9097	9523	5686	3184	51671	30517	6765	9691
5 - Basic communication processes	108	3096	2081	1419	1551	5230	2291	4117	6906	3512	981	920
6 - Computer technology	222	12101	6393	1105	8321	33424	12429	1249	152872	52356	13252	9306
7 - IT methods for management	2	739	250	2867	221	3534	1577	4282	22253	7341	6374	916
8 - Semiconductors	213	9163	6361	136	5838	14280	10308	257	20791	16281	8022	3230
9 - Optics	244	7502	7786	1399	5723	10835	13295	2216	15192	9984	8034	3549
10 - Measurement	316	6882	6710	2425	7185	10732	8984	2358	69439	14369	10695	10032
11 - Analysis of biological materials	30	1067	405	4973	412	1456	1087	7419	4857	1699	1112	1094
12 - Control	99	2732	2447	831	2219	4418	3561	1345	20584	7563	5804	3364
13 - Medical technology	268	8040	2448	1883	3496	10254	7782	2170	27907	20363	11330	10797
14 - Organic fine chemistry	812	4728	2235	4917	3251	5249	3987	7892	17300	3962	3416	2997
15 - Biotechnology	235	3864	1258	4229	2199	3979	2284	5102	19233	5249	3456	2515
16 - Pharmaceuticals	1508	4001	1233	1624	5816	5118	2722	3068	14477	6365	4732	3872
17 - Macromolecular chemistry, polymers	394	2794	3255	3791	2536	2614	3848	6274	16056	2640	4401	2379
18 - Food chemistry	540	1298	1379	2026	1932	1105	1780	2154	7655	1771	2266	1188

19 - Basic materials chemistry	749	3581	2318	1885	3394	3054	4061	5227	17078	3640	3874	2924
20 - Materials, metallurgy	738	2133	3396	3257	5129	2087	4856	3599	26788	3137	4505	2472
21 - Surface technology, coating	212	2579	3301	3469	2795	4011	4604	3830	13889	3367	4397	2038
22 - Micro-structural and nano-technology	0	105	47	1698	236	134	341	2128	2469	502	194	297
23 - Chemical engineering	461	3660	2478	24	2990	3814	4064	317	36198	4839	3160	3630
24 - Environmental technology	174	1719	1937	3613	1925	2093	3260	3832	19910	2447	2216	2152
25 - Handling	287	4401	3607	1864	2597	4372	7165	2347	29987	5943	7772	5414
26 - Machine tools	375	4504	3838	4042	3913	3650	5383	5139	38677	4172	4614	4106
27 - Engines, pumps, turbines	257	4143	3712	3987	2538	4158	7143	4691	13254	6012	3915	5733
28 - Textile and paper machines	389	4238	4567	3497	3214	3868	6700	5613	12082	2902	4220	2224
29 - Other special machines	497	4960	4505	2981	3443	4647	6102	3157	33130	7627	5940	6852
30 - Thermal processes and apparatus	222	1721	3201	5346	2615	1344	3274	5884	13333	2942	3473	3052
31 - Mechanical elements	248	4886	3659	2260	2904	4337	6468	2311	16545	6457	4983	6242
32 - Transport	303	7207	4936	4922	3317	6800	9951	5927	32616	14960	10245	13539
33 - Furniture, games	90	4949	2834	6385	1754	5043	7850	10581	11414	5808	14015	3725
34 - Other consumer goods	233	3730	2531	2733	2138	3153	3745	3302	10781	4881	4115	4022
35 - Civil engineering	303	4419	6048	2390	3700	4745	7512	2982	34233	7021	7335	7168
SUM	**12007**	**157814**	**312427**	**101161**	**129879**	**220359**	**211644**	**136770**	**920514**	**312427**	**208958**	**159223**
RANK	**4.**	**1.**	**2.**	**3.**	**4.**	**1.**	**2.**	**3.**	**1.**	**2.**	**3.**	**4.**

Innovation efforts are frequently redirected by crises. To save expenses, businesses prioritise process enhancements, digitisation, and automation above "frontier" exploration. Long-term breakthrough innovation can be sparked by crises. Governments frequently implement stimulus packages or green transition policies that finance research and development, and businesses under pressure may innovate to survive. Because advanced countries like the US, EU, and Japan already have significant baseline patenting activity, they typically experience a decline or stagnation during crises (saturation effect). Because their governments utilise crises as a chance to promote innovation-led growth through industrial policy and subsidies, emerging nations like China occasionally see an upsurge in patent filings during global downturns. (WIPO, 2022) To cope with the crisis, nations have used and still use their financial resources and structural advantages (OECD, 2012). While many smaller businesses went bankrupt due to the significant decline in demand and loss of clients, major, innovative enterprises with a higher technology level also fared better throughout the crisis. Particularly when it comes to improved medical technology, mobile connectivity, or the use of the Internet for social assistance, education, job openings, etc., positive technological advancements can lessen the humanitarian effects of crises and wars. For instance, in the past, this compelled leaders to urge Silicon Valley corporations to utilise technology in more creative methods to aid the needy (Marr, 2015).

5. CONCLUSIONS

Indicators and international comparisons of patents are widely recognised as proxies for the economic and technological development of regions or states. They are often examined alongside indicators such as GDP, R&D expenditure, population size, unemployment rate, number of scientific publications, purchasing power, and the number of new market-introduced products. Comparing patent metrics with these additional indicators enables a more comprehensive assessment of the technological and economic performance of firms and regions. However, such comparisons often require expert evaluation over an extended period to yield objective and contextually valid results. Empirical evidence suggests that patent analyses correlate strongly with expert assessments—whether at the business level or with respect to specific innovations. Consequently, patent analysis frequently serves as an initial step in technological assessment and strategic planning.

In the present analysis, based on the WIPO (World Intellectual Property Organisation) database, external expert evaluations were not feasible; nonetheless, the results reveal distinct technological and socio-economic trends. Although the present study focuses on macro-level indicators, the integration of national economic and patent statistics at the regional or sectoral level remains a promising avenue for more detailed analyses. The findings of this study suggest that since the beginning of the 21st century, global development trajectories have increasingly integrated poverty reduction and technological progress within a unified framework of sustainable growth. This transformation underscores the growing interdependence between innovation systems, socio-economic advancement, and environmental stewardship (UNCTAD, 2020; World Bank, 2022). The expansion of the digital economy has redefined global competitiveness—most notably in China, where digital industries accounted for 34.8% of GDP in 2018 and have become a critical driver of national growth (Deloitte, 2019). China's economic transformation reflects a deliberate shift from manufacturing-based production toward innovation-driven industrial structures. Government initiatives such as Indigenous Innovation and Made in China 2025 have fostered extensive accumulation of intellectual property, supported by rising investment in research and development, from 0.9% of GDP in 2000 to 2.6% in 2023 (OECD, 2025). Consequently, China's technological patent output expanded by approximately 7,600% between 2000 and 2023, indicating the institutionalisation of innovation as a core pillar of national policy and a principal determinant of its emerging technological leadership.

A comparative analysis of technology patents in 2000, 2010, and 2023 reveals a substantial intensification of global patenting activity, with the number of patents granted doubling between 2010 and 2023 and quadrupling since 2000. While the United States and Japan dominated the early 2000s, by 2023, China and the United States had emerged as global leaders, signalling a major shift in innovation capacity eastward. The relative stagnation observed in Japan and the European Union reflects the maturity of their innovation systems, characterised by high patent intensity per capita and a concentration of high-value technological outputs (OECD, 2020b, OECD, 2024). Regional patterns of technological specialisation reveal divergent innovation pathways. In China, patenting transitioned from pharmaceuticals in 2000 to electrical machinery and computer technologies in subsequent decades. The United States has maintained dominance in computer and ICT technologies, supported by a robust corporate R&D ecosystem centred in Silicon Valley (Fisch et al., 2017). Japan's sustained focus on electrical machinery and energy—later reinforced by leadership in robotics and automation—illustrates its strategic emphasis on advanced manufacturing (JPO, 2023b). In contrast, the European Union demonstrates a more design-oriented pattern, with patents concentrated in furniture and games in 2000 and 2010, and in transport technologies by 2023, reflecting its industrial legacy in engineering, mobility, and product design (EPO, 2023; EPO, 2024b; Geiger, 2014).

This study's main goals were to highlight crucial elements of innovation management and technology development, particularly across economies and geographical areas, and to compare patents and related activities methodically. Additionally, it was vital to discuss how growing countries and businesses might contend with global competitiveness in terms of manpower, technology, and economics. Technology should boost waste treatment and process automation, boost corporate efficiency, and enhance the standard of goods and services, as well as society. However, if a business makes significant investments in technology but little in people, the crisis may worsen. Consequently, such technology may result in increased expenses, inefficient manufacturing, business duplication, health harm, or pollution of the environment. Utilising the beneficial features of technological innovation and minimising its negative impacts is the duty of managers, as well as scientists, inventors, and customers. How technological patents contribute to improving conditions for people's employment, higher quality and added value of production, and greater sustainability of business are topics for further research.

References:

Adeleye, N., & Eboagu, C. (2019). Evaluation of ICT development and economic growth in Africa. *NETNOMICS: Economic Research and Electronic Networking, 20*(1), 31–53. DOI: 10.1007/s11066-019-09131-6

Alam, M. S., Atif, M., Chien-Chi, C., & Soytaş, U. (2019). Does corporate R&D investment affect firm environmental performance? Evidence from G-6 countries. *Energy Economics, 78*, 40–411.

Andrade, L. L. P., & Badaró, R. (2020). SENAI CIMATEC in the scenario of coronavirus pandemic. *The Journal of Bioengineering and Technology Applied to Health, 3*(1).

Aristovnik, A., Yang, G., Song, Y., & Ravšelj, D. (2023). Industrial performance of the top R&D enterprises in world-leading economies: A metafrontier approach. *Socio-Economic Planning Sciences, 89*, 101698. DOI: 10.1016/j.seps.2023.101698

Armani, U., & Esteban, M. (2021). Digital and development cooperation: The Global Gateway and a future EU-Japan Digital Partnership. *ARI, 25*, 1–7.

Armstrong, C. S., Glaeser, S., Park, S. Y., & Timmermans, O. (2024). The assignment of intellectual property rights and innovation. *Singapore Management University*. https://ssrn.com/abstract=3724041 or http://dx.doi.org/10.2139/ssrn.3724041

Arroyabe, J. C. F., Schumann, M., Sena, V., & Lucas, P. (2021). Understanding the network structure of agri-food FP7 projects: An approach to the effectiveness of innovation systems. *Technological Forecasting and Social Change, 162*, 120372. DOI: 10.1016/j.techfore.2020.120372

Asokan, D. R., Huq, F. A., Smith, C. M., & Stevenson, M. (2022). Socially responsible operations in the Industry 4.0 era: Post-COVID-19 technology adoption and perspectives on future research. *International Journal of Operations & Production Management, 42*(13), 185–217.

Bekkers, R., & West, J. (2009). Patent pools and standard-setting in the ICT industry: An empirical analysis. *Research Policy, 38*(2), 266–280.
Bhatia, A. (2020). Future tech: Five patents that show what top tech companies are working on. *The Indian Express*. https://indianexpress.com/article/technology/tech-news-technology/future-tech-five-patents-that-show-what-top-tech-companies-are-working-on-6197550/
Blagrave, P., & Vesperoni, E. (2018). The implications of China's slowdown for international trade. *Journal of Asian Economics, 56*, 36–47.
Blind, K., Ramel, F., & Rochell, C. (2022). The influence of standards and patents on long-term economic growth. *Journal of Technology Transfer, 47*, 979–999. DOI: 10.1007/s10961-021-09864-3
Bonnie, E. (2015). Complete collection of project management statistics 2015. *Wrike*. https://www.wrike.com/blog/complete-collection-project-management-statistics-2015/
Brynjolfsson, E., & Collis, A. (2019). How should we measure the digital economy? *Harvard Business Review, 97*(6), 140–148.
Bundy, J., Pfarrer, M. D., Short, C. E., & Coombs, W. T. (2016). Crises and crisis management: Integration, interpretation, and research development. *Journal of Management, 43*(6), 1661–1692. DOI: 10.1177/0149206316680030
Buntz, B. (2024). Exclusive infographic: Tech giants increase patent lead in 2024. *R&D World*. https://www.rdworldonline.com/exclusive-infographic-tech-giants-increase-patent-lead-in-2024/
Cashin, P., Mohaddes, K., & Raissi, M. (2017). China's slowdown and global financial market volatility: Is world growth losing out? *Emerging Markets Review, 31*, 164–175.
Chebbouba, S. (2025). A comparative study of innovation pathways in East Asia: Japan, South Korea, China, and Taiwan. *Journal of Innovations in Business and Industry, 3*(4), 223–236. DOI: 10.61552/JIBI.2025.04.002
Chege, S. M., Wang, D., & Suntu, S. L. (2020). Impact of information technological innovation on firm performance in Kenya. *Information Technology for Development, 26*(2), 316–345.
Chen, H. (2022). Industrial production evaluation with the consideration of technology accumulation. *Structural Change and Economic Dynamics, 62*, 72–84.
Cheng, C., Wang, L., Xie, H., & Yan, L. (2023). Mapping digital innovation: A bibliometric analysis and systematic literature review. *Technological Forecasting and Social Change, 194*, 122706.
Chesbrough, H. W. (2006). *Open innovation: The new imperative for creating and profiting from technology*. Harvard Business Review Press.
Cizmovic, M., Shachmurove, Y., & Vulanovic, M. (2020). Real effective exchange rates and deindustrialization: Evidence from 25 post-communist Eastern European countries. *Post-Communist Economies*. DOI: 10.1080/14631377.2020.1867429
CNIPA. (2023). CNIPA report establishes China as a key force in global green and low-carbon technological innovation. *The China National Intellectual Property Administration*. https://english.cnipa.gov.cn/art/2023/8/30/art_2975_187092.html
CNIPA. (2024). Patent. *The China National Intellectual Property Administration*. https://english.cnipa.gov.cn/col/col2995/index.html
Comino, S., & Manenti, F. M. (2022). Patent portfolios and firms' technological choices. *Journal of Economics, 137*, 97–120. DOI: 10.1007/s00712-022-00783-x
Cui, X., Wang, C., Liao, J., Fang, Z., & Cheng, F. (2021). Economic policy uncertainty exposure and corporate innovation investment: Evidence from China. *Pacific-Basin Finance Journal, 67*, 101533.
Dan, S. M., Spaid, B. I., & Noble, C. H. (2016). Exploring the sources of design innovations: Insights from the computer, communications and audio equipment industries. *Research Policy, 47*(8), 1495–1504. DOI: 10.1016/j.respol.2018.05.004
DELOITTE. (2019). Rising innovation in China, China innovation ecosystem, development report 2019. *Deloitte*. https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/innovation/deloitte-cn-innovation-china-innovation-ecosystem-report-en-191101.pdf
Dekker, M., & Thakkar, A. (2018). Digitalisation – The next frontier for the offshore industry. In *Proceedings of the Offshore Technology Conference, Houston, Texas, USA* (OTC-28815-MS). DOI: 10.4043/28815-MS
Dierksmeier, C., & Seele, P. (2020). Blockchain and business ethics. *Business Ethics: A European Review, 29*(2), 348–359.
Eaton, J. (1999). Technology and the global economy. *National Bureau of Economic Research*. http://www.nber.org/reporter/summer99/eaton.html
Eaton, J., Kortum, S., Neiman, B., & Romalis, J. (2016). Trade and the global recession. *American Economic Review, 106*(11), 3401–3438. DOI: 10.1257/aer.20101557
EPO. (2023). Q&A on patents and coronavirus. https://www.epo.org/en/news-events/press-centre/fact-sheet/446605#q8
EPO. (2024a). University research generates over 10% of all inventions in Europe, new EPO report finds. https://www.epo.org/en/news-events/press-centre/press-release/2024/1252722
EPO. (2024b). Patent index 2024. https://www.epo.org/en/about-us/statistics/patent-index-2024

Espadinha-Cruz, P., Neves, A., Matos, F., & Godina, R. (2023). Development of a maturity model for additive manufacturing: A conceptual model proposal. *Heliyon, 9*(5), e16099. DOI: 10.1016/j.heliyon.2023.e16099

EUIPO. (2023). EU enforcement of intellectual property rights: Results at the EU border and in the internal market. https://euipo.europa.eu

Eurostat. (2013). Archive: Patent statistics. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Archive:Patent_statistics&oldid=112826

Fernández-Portillo, A., Almodóvar-González, M., & Hernández-Mogollón, R. (2020). Impact of ICT development on economic growth. A study of OECD European Union countries. *Technology in Society, 63*, 101420. DOI: 10.1016/j.techsoc.2020.101420

Fisch, C., Sandner, P., & Regner, L. (2017). The value of Chinese patents: An empirical investigation of citation lags. *China Economic Review, 45*, 22–34. DOI: 10.1016/j.chieco.2017.05.011

Flögel, F., & Gärtner, S. (2020). The COVID-19 pandemic and relationship banking in Germany: Will regional banks cushion an economic decline or is a banking crisis looming? *Royal Dutch Geographical Society*. https://onlinelibrary.wiley.com/doi/epdf/10.1111/tesg.12440

FORBES. (2020). GLOBAL 2000, The world's largest public companies. https://www.forbes.com/global2000/#25ad896c335d

Freeman, R. E., Harrison, J. S., & Zyglidopoulos, S. (2018). *Stakeholder theory: Concepts and strategies (Elements in Organization Theory)*. Cambridge University Press.

Garcia, R., & Calantone, R. (2002). A critical look at technological innovation typology and innovativeness terminology: A literature review. *Journal of Product Innovation Management, 19*(2), 110–132.

Geiger, T. (2014). Top 10 most competitive economies in Asia Pacific. *World Economic Forum*. https://www.weforum.org/agenda/2014/09/top-10-competitive-economies-asia-pacific/

Graham, N. (2020). Science, ecology and the greening of carbon-extractive development, forces of production, climate change and Canadian fossil capitalism. *Brill, 179*(3), 177–203.

Grubka, R. M., Pichko, N. S., Petryayeva, I. A., & Mikhailov, A. N. (2019). Some features of the design and technological preparation of the production of spur gears with spatially modified teeth. *Materials Today: Proceedings, 19*(5), 2483–2487. DOI: 10.1016/j.matpr.2019.08.163

Grunwald, A. (2019). *Technology assessment in practice and theory* (1st ed.). Routledge.

Gupta, K., Jain, N. K., & Laubscher, R. (2017). Advances in gear manufacturing. In *Advanced gear manufacturing and finishing* (pp. 67–125). Academic Press. DOI: 10.1016/B978-0-12-804460-5.00004-3

Günsel, A. (2015). Research on effectiveness of technology transfer from a knowledge-based perspective. *Procedia - Social and Behavioral Sciences, 207*, 777–785. DOI: 10.1016/j.sbspro.2015.10.165

Hall, B. H., Jaffe, A., & Trajtenberg, M. (2005). Market value and patent citations. *RAND Journal of Economics, 36*(1), 16–38.

Hasbi, M., & Dubus, A. (2020). Determinants of mobile broadband use in developing economies: Evidence from Sub-Saharan Africa. *Telecommunications Policy, 44*(5), 101944. DOI: 10.1016/j.telpol.2020.101944

Hindman, M. (2018). *The internet trap: How the digital economy builds monopolies and undermines democracy*. Princeton University Press.

Hohn, M. M., & Durach, C. F. (2021). Additive manufacturing in the apparel supply chain—impact on supply chain governance and social sustainability. *International Journal of Operations & Production Management, 41*(7), 1035–1059.

IIFL. (2024). Types of e-business risks. *IIFL Finance*. https://www.iifl.com/blogs/business-loan/types-of-e-business-risks

Ikeda, Y., Kato, M., & Kleinknecht, A. (2024). Flexible labour, innovation regimes and the erosion of the Japanese model: Evidence from the Basic Survey on Wage Structure. *Structural Change and Economic Dynamics, 70*, 333–339. DOI: 10.1016/j.strueco.2024.04.003

Infotechlead. (2021). IDC's digital transformation predictions that will impact ICT spending. https://infotechlead.com/it-statistics/idcs-digital-transformation-predictions-that-will-impact-ict-spending-69470

INNOBAROMETER. (2016). Innobarometer 2016 – EU business innovation trends. *EU Open Data Portal*. http://data.europa.eu/euodp/en/data/dataset/S2064_433_ENG

ITU. (2020). Measuring digital development ICT price trends 2019. file:///C:/Users/jemalmar/Desktop/ITU-Measuring_Digital_Development_ICT_Price_Trends_2019.pdf

JPO. (2023a). Recent trends in business-related inventions. https://www.jpo.go.jp/e/system/patent/gaiyo/recent_trends_biz_inv.html

JPO. (2023b). JPO status report 2023. https://www.jpo.go.jp/e/resources/report/statusreport/2023/index.html

Jun, A. T. X. (2021). What do you need to know about China's new patent law 2021? *Plass*. https://www.plass.com/jp/jishi/what-do-you-need-know-about-chinas-new-patent-law-2021

Kokkodis, M. (2020). Dynamic, multi-dimensional, and skillset-specific reputation systems for online work. *Information Systems Research*. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3671201

Kolerová, K., & Otčenášková, T. (2015). Case studies of sharing processes within organisations. *Procedia Economics and Finance, 23*(1), 256–261.

Kose, M. A., Lakatos, C., Ohnsorge, F., & Stocker, M. (2017). The global role of the US economy: Linkages, policies and spillovers. *World Bank Group*. https://documents1.worldbank.org/curated/en/649771486479478785/pdf/WPS7962.pdf

Kumar, U., & Ahmad, W. (2024). Navigating the "twin titans" of global manufacturing: The impact of US and China on industrial production forecasting in G20 nations. *Pacific-Basin Finance Journal, 87*, 102509. DOI: 10.1016/j.pacfin.2024.102509

Kumar, S. A., & Suresh, N. (2009). *Operation management*. New Age International Publisher.

Kutin, A., Shayhulova, A., & Ivashin, S. (2019). Cascade method for technological preparation of production in digital technology application. In *Proceedings of the International Conference on Aviamechanical Engineering and Transport (AviaENT 2019)* (pp. 205–210). ISBN: 978-94-6252-841-3.

Le, T. (2019). Global issues of information technologies. In Z. J. Zhang (Ed.), *Global information diffusion and management in contemporary society*. IGI Global.

Li, J., Cheng, H., Guo, H., & Qiu, S. (2018). Survey on artificial intelligence for vehicles. *Automotive Innovation, 1*, 2–14.

Li, Z., Wang, Y., Li, H., & Dai, P. (2025). ICT innovation, information environment and stock price crash risk: Evidence from patent data. *International Review of Economics & Finance, 103*, 104419. DOI: 10.1016/j.iref.2025.104419

Marr, B. (2015). Big data, technology and the Middle East refugee crisis. *Fortune*. https://www.forbes.com/sites/bernardmarr/2015/10/15/big-data-technology-and-the-middle-east-refugee-crisis/?sh=604716c1210d

Matos, F., & Jacinto, C. (2018). Additive manufacturing technology: Mapping social impacts. *Journal of Manufacturing Technology Management, 30*(1), 70–97.

Mattos, L. H. S., & Speziali, M. G. (2017). Patent landscape: Technology development behind science in the flavor and fragrances (F&F) area. *World Patent Information, 51*, 57–65. DOI: 10.1016/j.wpi.2017.11.006

McCoy, N. R., Phillips, B., & Stewart, A. C. (2019). Accounting for human capital: Implications of automation and operational performance. *The Journal of Corporate Accounting and Finance, 30*(4), 111–115. DOI: 10.1002/jcaf.22408

McKinsey Global Institute. (2023). Treating rare diseases: How digital technologies can drive innovation? https://www.mckinsey.com/industries/life-sciences/our-insights/treating-rare-diseases-how-digital-technologies-can-drive-innovation

Min, S., Kalwani, M. U., & Robinson, W. T. (2006). Market pioneer and early follower survival risks: A contingency analysis of really new versus incrementally new product-markets. *Journal of Marketing, 70*(1), 15–33.

Myovella, G., Karacuka, M., & Haucap, J. (2020). Digitalization and economic growth: A comparative analysis of Sub-Saharan Africa and OECD economies. *Telecommunications Policy, 44*(2), 101856. DOI: 10.1016/j.telpol.2019.101856

NAM. (2025). Manufacturing in the United States. *The National Association of Manufacturers*. https://nam.org/mfgdata/facts-about-manufacturing-expanded/

OECD. (2012). OECD science, technology and industry outlook 2012. https://www.oecd.org/sti/sti-outlook-2012-chapter-1-innovation-in-the-crisis-and-beyond.pdf

OECD. (2020a). OECD economic outlook. https://www.oecd-ilibrary.org/economics/oecd-economic-outlook_16097408

OECD. (2020b). Gross domestic spending on R&D. https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htm

OECD. (2024). Gross domestic spending on R&D. https://www.oecd.org/en/data/indicators/gross-domestic-spending-on-r-d.html?oecdcontrol-8027380c62-var3=2000

OECD. (2025). R&D spending growth slows in OECD, surges in China; government support for energy and defence R&D rises sharply. https://www.oecd.org/en/data/insights/statistical-releases/2025/03/rd-spending-growth-slows-in-oecd-surges-in-china-government-support-for-energy-and-defence-rd-rises-sharply.html

Orlando, T., & Rodano, G. (2020). Firm undercapitalization in Italy: Business crisis and survival before and after COVID-19. *Questioni di Economia e Finanza, 590*, Bank of Italy, Economic Research and International Relations Area.

Paoletti, I. (2018). Mass customization in the era of Industry 4.0: Towards immaterial building technology. In M. Hemmerling & L. Cocchiarella (Eds.), *Informed architecture*. Springer. DOI: 10.1007/978-3-319-53135-9_8

Pesch, R., Endres, H., & Bouncken, R. B. (2021). Digital product innovation management: Balancing stability and fluidity through formalization. *Journal of Product Innovation Management, 38*(6), 726–744.

Planko, J., Cramer, J., Hekkert, M. P., & Chappin, M. M. (2017). Combining the technological innovation systems framework with the entrepreneurs' perspective on innovation. *Technology Analysis & Strategic Management, 29*(6), 614–625.

Pradhan, R. P., Arvin, M. B., & Hall, J. H. (2014). Causal nexus between economic growth, banking sector development, stock market development, and other macroeconomic variables: The case of ASEAN countries. *Review of Financial Economics, 23*(4), 155–173. DOI: 10.1016/j.rfe.2014.07.002

Rao, R. (2023). Breakthroughs in quantum computing. *Wevolver*. https://www.wevolver.com/article/breakthroughs-in-quantum-computing

Reuters. (2025). Japan's factory activity contracts further in September. https://www.reuters.com/markets/asia/japans-factory-activity-contracts-further-september-pmi-shows-2025-09-24/

Rose, G. (2016). *The fourth industrial revolution: A Davos reader*. Council on Foreign Relations.

Quinn, G. (2024). The path to worldwide patent rights. *IPWatchdog*. https://ipwatchdog.com/2024/05/28/path-worldwide-patent-rights/id=177066/

Schacher, D. (2018). Methodology for implementing innovative ventures in emerging countries – Case study of the starting phase of a Chinese-Israeli automotive green-field company. *Procedia Manufacturing, 21*, 149–156.

Schwab, K. (2017). *The fourth industrial revolution*. Crown Business.

Shimanishi, T. (2019). Sengo nihon no tokkyo shutsugan no chiriteki bunpu 1980-2010 nen (The geographical distribution of the patent application in postwar Japan, 1980-2010). *Kezai Ronshu, The Economic Review of Tokyo University, 44*(2), 211–223. http://id.nii.ac.jp/1060/00010443/

Stasiuk-Piekarska, A. K., Hadaś, Ł., Wyrwicka, M. K., & Piekarski, J. (2017). Use of network thinking methodology for analysing factors affecting organizational risk management in customized manufacturing systems. In *Proceedings of the 24th International Conference on Production Research (ICPR 2017)*. ISBN: 978-1-60595-507-0.

Sutherland, W., & Jarrahi, M. H. (2018). The sharing economy and digital platforms: A review and research agenda. *International Journal of Information Management, 43*, 328–341.

Suzuki, S. (2023). Comparison of characteristics of patent applications among regions in Japan where patent applications are increasing. *World Patent Information, 74*, 102220. DOI: 10.1016/j.wpi.2023.102220

Swann, G. M. P., & Lambert, R. (2017). Standards and innovation: A brief survey of empirical evidence and transmission mechanisms. In *Handbook of innovation and standards* (pp. 21–37). Edward Elgar Publishing.

Szu-chia, S. L. (2015). *Innovative sense through perspectives of patent bibliometrics analysis*. Airiti Press.

Taglioni, D., & Winkler, D. (2016). *Making global value chains work for development*. World Bank Publications.

Takahashi, C. K., de Figueiredo, J. C. B., & Scornavacca, E. (2024). Investigating the diffusion of innovation: A comprehensive study of successive diffusion processes through analysis of search trends, patent records, and academic publications. *Technological Forecasting and Social Change, 198*, 122991. DOI: 10.1016/j.techfore.2023.122991

Tao, F., Zhu, P., Qiu, C., & Wang, X. (2023). Research on the impact of digital technological innovation on enterprise market value. *The Journal of Quantitative & Technological Economics, 40*(5), 68–91.

Tidd, J., & Bessant, J. (2018). *Managing innovation, integrating technological, market and organizational change* (6th ed.). John Wiley and Sons.

Triguero, Á., Córcoles, D., & Cuerva, M. C. (2018). R&D and patents: Causality analysis in Spanish manufacturing firms. *Economics of Innovation and New Technology, 27*(6), 567–589. DOI: 10.1080/10438599.2018.1449726

UNCTAD. (2020). Global trade update. https://unctad.org/system/files/official-document/ditcmisc2020d2_en.pdf

USPTO. (2020). Patent process overview. https://www.uspto.gov/patents-getting-started/patent-process-overview#step1

USPTO. (2024). Applying for patents. https://www.uspto.gov/patents/basics/apply#search

Venkataraman, R. R., & Pinto, J. K. (2019). *Operations management: Managing global supply chains* (2nd ed.). SAGE Publications.

Vermicelli, S., Cricelli, L., & Grimaldi, L. M. (2020). How can crowdsourcing help tackle the COVID-19 pandemic? An explorative overview of innovative collaborative practices. *R&D Management*, 1–12. DOI: 10.1111/radm.12443

Wahrmann, D., Hildebrandt, A. C., Schuetz, C., Wittmann, R., & Rixen, D. (2019). An autonomous and flexible robotic framework for logistics applications. *Journal of Intelligent & Robotic Systems, 93*, 419–431. DOI: 10.1007/s10846-017-0746-8

Wamba, S. F., & Queiroz, M. M. (2022). Industry 4.0 and the supply chain digitalisation: A blockchain diffusion perspective. *Production Planning & Control, 33*(2–3), 193–210.

Wang, J., & Hsu, C. C. (2020). A topic-based patent analytics approach for exploring technological trends in smart manufacturing. *Journal of Manufacturing Technology Management, 32*(1), 110–135. DOI: 10.1108/JMTM-03-2020-0106

Wang, Z., Zhang, M., Sun, H., & Zhu, G. (2016). Effects of standardization and innovation on mass customization: An empirical investigation. *Technovation, 48–49*, 79–86. DOI: 10.1016/j.technovation.2016.01.003

Waschull, S., Bokhorst, J. A. C., & Wortmann, J. C. (2017). Impact of technology on work: Technological functionalities that give rise to new job designs in Industry 4.0. In H. Lödding, R. Riedel, K. D. Thoben, G. von Cieminski, & D. Kiritsis (Eds.), *Advances in production management systems. The path to intelligent, collaborative and sustainable manufacturing. APMS 2017* (pp. 274–281). Springer. DOI: 10.1007/978-3-319-66923-6_32

World Bank. (2022). Technology adoption by firms in developing countries. *World Bank*. https://www.worldbank.org/en/topic/competitiveness/publication/technology-adoption-by-firms-in-developing-countries

WEF. (2025). Made in China 2.0: The future of global manufacturing? *World Economic Forum*. https://www.weforum.org/stories/2025/06/how-china-is-reinventing-the-future-of-global-manufacturing/

Wininger, A. (2024). Powerful intellectual property country in 2024. https://www.chinaiplawupdate.com/2024/05/china-releases-the-plan-for-promoting-the-construction-of-a-powerful-intellectual-property-country-in-2024/
WIPO. (2017a). WDI 2017 maps. https://www3.wipo.int/ipstats/index.htm?tab=patent
WIPO. (2017b). Patents. http://www.wipo.int/patents/en/faq_patents.html#accordion__collapse__09_a
WIPO. (2022). World intellectual property report 2022, the direction of innovation. https://www.wipo.int/en/web/world-ip-report/2022/index
WIPO. (2024a). World intellectual property indicators report: Global patent filings reach record high in 2023. https://www.wipo.int/pressroom/en/articles/2024/article_0015.html
WIPO. (2024b). Five million PCT applications published. https://www.wipo.int/edocs/pctndocs/en/2024/pct_news_2024_12.pdf
WIPO. (2025). WIPO IP statistics data center. https://www3.wipo.int/ipstats/key-search/indicator?tab=patent
Xu, S., Zhu, K., & Gibbs, J. (2004). Global technology, local adoption: A cross-country investigation of internet adoption by companies in the United States and China. *Electronic Markets, 14*(1), 13–24. DOI: 10.1080/1019678042000175261
Yetis, H., Karakose, M., & Baygin, N. (2022). Blockchain-based mass customization framework using optimized production management for industry 4.0 applications. *Engineering Science and Technology, an International Journal, 36*, 101151. DOI: 10.1016/j.jestch.2022.101151
Yin, X., Jin, Y., Li, Z., & Liu, Y. (2025). How does open innovation promote circular economy practices? Evidence from Chinese listed companies. *Journal of Innovation & Knowledge, 10*(3), 100702. DOI: 10.1016/j.jik.2025.100702
Ymous, A., Spiel, K., Keyes, O., Williams, R. M., Good, J., Hornecker, E., & Bennett, C. L. (2020). CHI EA '20: Extended abstracts. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. https://dl.acm.org/doi/proceedings/10.1145/3334480
Zhang, M.-C., & Wang, G. (2025). Female CEOs, digital transformation and green innovation of small and medium-sized enterprises. *Finance Research Letters, 86*(D), 108606. DOI: 10.1016/j.frl.2025.108606
Zhong, H., Winton, L., & Krosinsky, C. (2020). China and innovation. In *Modern China* (pp. 29–53). Springer. DOI: 10.1007/978-3-030-39204-8_3
Zhou, H., Wang, R., Zhang, X., & Chang, M. (2024). The impact of digital technology adoption on corporate supply chain concentration: Evidence from patent analysis. *Finance Research Letters, 64*, 105413. DOI: 10.1016/j.frl.2024.105413
Zhuo, C., & Chen, J. (2023). Can digital transformation overcome the enterprise innovation dilemma: Effect, mechanism and effective boundary. *Technological Forecasting and Social Change, 190*, 122378.

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