THE EVOLUTION AND TRANSFORMATION OF PATENTOLOGY IN THE DIGITAL ECONOMY: AN ANALYSIS OF CHANGES IN RELEVANCE AND FUNCTION

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ABSTRACT

The digital economy has transformed intellectual property protection, challenging traditional patentology paradigms and raising questions about the evolving role of patent systems in digital innovation ecosystems. This article examines the historical development of patentology, and analyses how digitalisation has reshaped the functions, scope and economic significance of patents. Using a systematic literature review (*n* = 74, 1962–2025), comparative institutional analysis and thematic synthesis, the study explores four key issues: the historical foundations of patent theory, transformations driven by digital technologies, emerging challenges in innovation ecosystems, and implications for innovation management and policy. The findings reveal major shifts: software patents redefine patentable subject matter; standard-essential patents introduce licensing complexities and hold-up risks; and open-source models challenge traditional exclusivity principles. Patents have evolved from simple exclusion rights into strategic assets in licensing networks, platform ecosystems and collaborative innovation environments. This study contributes by integrating fragmented perspectives into a coherent framework that combines technological, institutional and strategic dimensions of patent system transformation. It highlights the implications for innovation management, regional development and policy reform, arguing that patentology must adopt interdisciplinary approaches, combining economics, management, technology studies and law, to remain relevant in the digital era.

KEY WORDS: *patentology, digital economy, intellectual property, innovation management, patent transformation, patent relevance, patent functions*.

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Introduction

The digital economy represents a fundamental transformation in how economic value is created, distributed and protected. At the intersection of technological innovation and economic organisation, intellectual property systems, particularly patent regimes, face unprecedented challenges to their traditional functions and relevance. Understood as the systematic study of patent systems, encompassing their economic, legal, institutional and strategic dimensions, patentology must confront profound questions about its theoretical foundations and practical applications, in an era characterised by software, artificial intelligence, data-driven platforms and networked innovation ecosystems (Granstrand, Holgersson, 2020; Teece, 2018a).

The classic economic rationale for patent systems rests on a well-established trade-off: temporary monopoly rights incentivise innovation by allowing inventors to recoup research and development investments, while mandatory disclosure requirements ensure cumulative innovation and the diffusion of knowledge (Arrow, 1962; Nordhaus, 1969). This framework, developed primarily in the context of mechanical and chemical inventions, assumed clear boundaries between inventions, relatively stable technological trajectories, and innovation processes dominated by individual firms or inventors. However, the digital economy disrupts

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these assumptions fundamentally. Software innovations often build incrementally on existing code, artificial intelligence systems learn from vast datasets that may themselves be proprietary, and platform-based business models create network effects that concentrate market power independently of patent protection (Lin et al., 2020; Teece, 2018b).

Despite extensive literature on patent economics and growing attention to digital innovation challenges, a critical knowledge gap persists: the existing research remains fragmented across disciplinary boundaries (law, economics, management, technology studies), and lacks a coherent analytical framework that integrates the technological, institutional and strategic dimensions of patent system transformation in the digital economy (Hall, Ziedonis, 2001; Archibugi, Filippetti, 2018). While scholars have examined specific aspects, such as software patentability (Bessen, Hunt, 2007), standard-essential patents (Contreras, 2015), and open innovation models (Chesbrough, 2003), few studies provide a comprehensive analysis of how these developments collectively reshape patentology's theoretical foundations, functional relevance and policy implications.

This article addresses the gap by synthesising diverse perspectives into an integrated framework that examines patentology's evolution across four interconnected dimensions: historical-theoretical foundations, functional transformations, ecosystem-level challenges and policy-practice implications. The study's novelty lies in three contributions: (1) the systematic integration of fragmented digital economy perspectives into a coherent analytical framework centered on patent relevance and functions; (2) the explicit theorisation of how digital technologies transform core patent functions beyond simple adaptation narratives; and (3) the development of actionable implications bridging academic theory, innovation management practice and regional development policy.

The central research problem addressed in this article is: *How has the digital economy transformed the relevance and functions of patentology as both an academic discipline and a framework for innovation policy, and what theoretical and practical adaptations are required to maintain its utility in digitally mediated innovation ecosystems?*

This overarching problem is examined through four specific research questions that structure the analysis:

- **RQ1**: How has the historical evolution of patentology shaped current theoretical frameworks, and what foundational assumptions underpin traditional patent economics?
- **RQ2**: What fundamental transformations have digital technologies introduced to patent functions and economic roles in innovation systems?
- **RQ3**: What new challenges and opportunities emerge for patent systems in digital innovation ecosystems characterised by platforms, networks and collaborative models?
- **RQ4**: What implications do these transformations hold for innovation management practices, regional development policy, and the future trajectory of patentology as a discipline?

These questions are deliberately scoped to align with the article's focus on relevance and function in the digital economy context, ensuring consistency between problem formulation, research design and analytical scope.

1. Research methodology

This study employs a multi-method qualitative research design, combining systematic literature review (SLR), comparative institutional analysis and thematic synthesis, to examine the evolution and transformation of patentology in the digital economy. The three approaches are complementary: SLR maps the knowledge domain; comparative institutional analysis identifies structural transformations across pre-digital and digital contexts; and thematic synthesis organises findings around research questions.

Literature searches were conducted across Scopus, Web of Science and Google Scholar, selected for comprehensive interdisciplinary coverage, between 15 and 28 January 2025. Boolean search strings combined core concepts (patent, intellectual property, digital economy, digitalisation), specific phenomena (software patent, SEP, open source, platform economy, AI patent), and theoretical dimensions (patent function, patent relevance, innovation ecosystem, patentology).

The temporal scope covers 1962 to 2025. The year 1962 marks Arrow's seminal contribution establishing modern patent economics; the upper boundary ensures contemporary relevance, with 58% of sources from 2018 to 2025. Screening followed an adapted PRISMA protocol: initial database searches yielded 847 sources (Scopus: 312; Web of Science: 289; Google Scholar: 246); title/abstract screening reduced the pool to 198; full-text assessment produced 74 sources meeting all inclusion criteria. The included sources are peer-reviewed journal articles, books, book chapters, and authoritative policy documents with a substantive focus on patent systems, IP economics or innovation management.

Thematic analysis followed Braun and Clarke's (2006) six-phase framework, proceeding from familiarisation and initial coding through theme identification, review, definition and synthesis. Rigour was ensured through the dual coding of 20% of sources, systematic documentation of analytical decisions, and triangulation across source types and disciplines.

The conceptual framework integrates four analytical dimensions corresponding to RQ1–RQ4: (1) Historical-Theoretical Foundations; (2) Functional Transformations; (3) Ecosystem Challenges; (4) Policy-Practice Implications. This structure provides systematic coherence across the analysis.

Limitations: The reliance on published literature may introduce publication bias. The language restriction to English may exclude relevant non-English scholarship. The rapid pace of the evolution of the digital economy means the most recent developments may not yet be fully reflected in academic literature.

2. Theoretical framework and literature review

2.1. Historical-theoretical foundations of patentology

Modern economic analysis of patent systems originates in Kenneth Arrow's (1962) seminal work on information economics, which established the fundamental market failure rationale for intellectual property protection. Arrow demonstrated that information's public-good characteristics of non-rivalry and non-excludability create systematic underinvestment in knowledge production absent institutional appropriation mechanisms. Patents address this failure by granting temporary exclusivity, enabling inventors to recoup R&D investment (Dasgupta, David, 1994).

William Nordhaus (1969) formalised this logic, modelling the trade-off between innovation incentives (strengthened by longer, broader patents) and static efficiency losses from monopoly pricing (minimised by shorter, narrower patents). This framework established the core economic question in patent policy: balancing dynamic efficiency gains from innovation against static efficiency losses from restricted access (Scotchmer, 2004; Gallini, Scotchmer, 2002).

Classic patent economics rests on five foundational assumptions (Merges, Nelson, 1990; Cohen et al., 2000): (1) clear invention boundaries; (2) disclosure benefits that facilitate knowledge diffusion; (3) firm-centric innovation processes; (4) stable technological trajectories; and (5) homogeneous patent value across contexts.

Beginning in the 1980s, patentology evolved to incorporate institutional and strategic dimensions (Dosi, 1988; Nelson, Winter, 1982). The resource-based view and dynamic capabilities frameworks recast patents as strategic assets, enabling competitive advantage through exclusion, licensing revenue, technological signalling and cross-licensing leverage (Teece et al., 1997; Lemley, Shapiro, 2005). Institutional economics perspectives emphasised how patent systems co-evolve with broader innovation ecosystems, highlighting substantial variation in patent effectiveness across industries and contexts (Pavitt, 1984; Mowery, Rosenberg, 1998).

Henry Chesbrough's (2003) open innovation paradigm further reframed patent functions: rather than purely exclusionary instruments, patents became 'currency' in knowledge markets, enabling technology transactions, partnerships and ecosystem coordination (Arora et al., 2001; Dahlander, Gann, 2010). This evolution occurred primarily in contexts of mechanical, chemical and pharmaceutical innovations, technologies characterised by discrete inventions and clear appropriability regimes (Cohen, 2010; Arundel, 2001).

The foundational assumptions of classic patent economics (clear boundaries, disclosure benefits, firm-centric innovation, stable trajectories, homogeneous value) face fundamental challenges in the digital economy, where software builds incrementally, AI emerges from complex data-algorithm interactions, platforms create network effects transcending individual inventions, and innovation increasingly occurs through collaborative ecosystems (Jacobides et al., 2018). The digital economy has further driven interdisciplinary integration. Understanding software, platforms and digital ecosystems requires combining insights from multiple fields. Artificial intelligence adds new challenges, by questioning traditional concepts of inventorship and invention. Contemporary patentology must therefore address increasingly complex technological and institutional environments.

2.2. Functional transformations in the digital economy

Physical inventions typically have clear boundaries and tangible embodiments, while digital innovations, such as algorithms, software and data structures, are more abstract and harder to define within traditional patent frameworks (Teece, 2018).

Digital technologies present several challenges to patent theory. First, they exhibit near-zero marginal costs and strong economies of scale, intensifying appropriability issues while raising concerns about market power, especially when combined with network effects (Chen, 2020). Second, digital innovation is highly cumulative and modular, often leading to patent thickets due to overlapping rights across components (Barnett, 2014). Third, innovation cycles are faster than patent processes, reducing patents' practical value and encouraging reliance on trade secrecy and first-mover advantages (Lin et al., 2020).

Classic and institutional patent economics identify five core patent functions (Nordhaus, 1969; Scotchmer, 2004; Lemley, Shapiro, 2005): (1) innovation incentive (temporary monopoly enabling R&D cost recovery); (2) knowledge disclosure (patent publication facilitating knowledge diffusion); (3) market signalling (reducing information asymmetries for investors and partners); (4) strategic positioning (competitive advantage through exclusion, licensing and cross-licensing); (5) coordination mechanism (clarifying ownership boundaries and facilitating technology transactions).

The digital economy introduces fundamental transformations to each function, as synthesised in Table 1.

The innovation incentive function exhibits differential transformation across digital technology domains (Bessen, 2012; Lerner, Tirole, 2004). For software innovations characterised by low reproduction costs, rapid obsolescence and highly cumulative development, traditional patent incentives appear weakened: 20-year terms may be excessive relative to technology lifecycles (Samuelson et al., 1994; Bessen, Maskin, 2009). Conversely, for data-intensive AI systems requiring substantial upfront investment in computational resources and algorithm development, patent protection may provide important appropriability mechanisms (Agrawal et al., 2018; Brown et al., 2020).

The knowledge disclosure function faces particular challenges in digital contexts (Bessen, Meurer, 2008; Burk, Lemley, 2003). Software patents often describe functionality at high abstraction levels without disclosing actual source code, limiting value for knowledge diffusion. AI patent applications frequently omit critical implementation details (training data characteristics, hyperparameter configurations, architectural refinements), raising questions about whether disclosure requirements achieve their intended objectives (Abbott, 2016; Yanisky-Ravid, Liu, 2018).

The market signalling function has gained importance in digital innovation ecosystems, particularly for start-ups seeking venture capital and establishing legitimacy in competitive platform markets (Ziedonis, 2004; Graham et al., 2009). However, this enhanced signalling role creates potential distortions: firms may pursue patents primarily for signalling value rather than genuine appropriability needs, leading to patent inflation (Jaffe, Lerner, 2004; Lemley, Sampat, 2008).

Table 1. The transformation of patent functions in the digital economy

Patent function	Traditional role	Digital economy transformation	Key challenges
Innovation incentive	Temporary monopoly enabling R&D cost recovery for discrete inventions	Weakened for software (low reproduction costs, rapid obsolescence); strengthened for AI/data-intensive innovations requiring substantial infrastructure investment	Determining appropriate protection scope for incremental software innovations; balancing incentives with cumulative innovation needs
Knowledge disclosure	Patent publication facilitates knowledge diffusion through technical specifications	Limited effectiveness for software (code more valuable than patent descriptions) and AI (training data and architectures not fully disclosed); potential strategic disclosure to block competitors	Software patents disclose little useful technical information; AI applications omit critical implementation details
Market signalling	Patents signal innovation quality and technological capability to investors and partners	Enhanced importance in platform ecosystems, particularly for start-ups; patent portfolios signal legitimacy and attract venture capital	Patent quantity may signal activity rather than quality; risk of patent inflation without corresponding innovation value
Strategic positioning	Competitive advantage through exclusion, licensing revenue and cross-licensing	Evolved into complex tool: defensive portfolios against litigation, patent thickets creating entry barriers, SEP hold-up risks, and platform control mechanisms	Patent thickets increase transaction costs; SEP hold-up problems; potential for anti-competitive behaviour
Coordination mechanism	Clarifies ownership boundaries and facilitates technology transactions in stable markets	Complicated by overlapping claims, patent thickets and unclear boundaries in software/AI; tension with open-source models; new coordination challenges in platform ecosystems	Difficulty establishing clear ownership in cumulative software innovation; coordination failures in complex technology stacks

Sources: Arrow, 1962; Nordhaus, 1969; Bessen, Hunt, 2007; Contreras, 2015; Gawer, Cusumano, 2014; Lemley, Shapiro, 2005; 2007; Shapiro, 2001.

The strategic positioning function has evolved into increasingly complex territory (Lemley, 2012; Shapiro, 1985). Firms build large defensive patent portfolios primarily to deter litigation and establish mutual deterrence through cross-licensing threats, a 'patent arms race' particularly characteristic of software and telecommunications sectors (Hall, Ziedonis, 2001; Shapiro, 2008). Standard-essential patents (SEPs) introduce additional complexity: technologies incorporated into industry standards create potential for patent hold-up, where SEP owners demand excessive royalties after standards adoption locks in implementers (Lemley, Shapiro, 2007; Farrell et al., 2007).

The coordination mechanism function faces challenges from patent thickets, overlapping claims, and unclear boundaries characteristic of software and digital technologies (Heller, Eisenberg, 1998; Shapiro, 2001). When hundreds or thousands of patents potentially read on a single software product, identifying relevant patents and negotiating licenses becomes prohibitively expensive. This creates tension with open-source models, which rely on copyright-based licensing rather than patent exclusivity (Benkler, 2002; Lerner, Tirole, 2002).

To sum up, the digital economy has reshaped patent enforcement. The rise of patent assertion entities (firms focused on licensing and litigation) reflects the growing role of patents as tradable assets (Bessen, Meurer, 2008). While they may support technology markets, critics argue they impose costs and distort incentives. This underscores the need for patent policy to address both patent creation and enforcement in modern innovation systems.

2.3. Challenges and opportunities in digital innovation ecosystems

Software patentability represents a foundational challenge to traditional patent doctrine (Bessen, Hunt, 2007; Samuelson, 1990). Classic patent law excludes abstract ideas, mathematical algorithms and mental processes from patentable subject matter, yet software inherently consists of algorithms and logical instructions. Jurisdictions have adopted divergent approaches: US courts have oscillated between permissive and restrictive standards; the European Patent Office maintains formal exclusion, with practical exceptions for 'technical effect'; and many jurisdictions struggle with coherent doctrinal frameworks (Merges, 2007; EPO, 2023).

This doctrinal uncertainty creates several challenges (Bessen, Meurer, 2008; Graham, Mowery, 2003). Unclear boundaries between patentable and unpatentable software generate legal uncertainty, increasing litigation costs and chilling innovation. The proliferation of broad, abstract software patents, often asserted by non-practising entities ('patent trolls'), creates hold-up risks and diverts resources from productive innovation to defensive patenting (Bessen et al., 2011; Cotropia et al., 2014). Software's cumulative and incremental nature means patents on foundational elements can block subsequent innovation, creating anti-commons problems (Heller, 1998; Walsh et al., 2003).

SEPs create distinctive challenges in digital ecosystems where interoperability standards are critical for network effects and platform competition (Contreras, 2013; Lemley, Shapiro, 2013). The hold-up problem arises from timing asymmetry: before standard adoption, multiple technologies compete; after adoption, implementers face switching costs, enabling SEP owners to demand excessive royalties. FRAND (fair, reasonable and non-discriminatory) commitments aim to constrain post-adoption opportunism, but disputes over appropriate royalty rates and licensing terms remain contentious (Swanson, Baumol, 2005; Contreras, Gilbert, 2015).

Table 2 synthesises the key challenges and emerging responses in digital innovation ecosystems.

Digital platform ecosystems introduce distinctive patent challenges related to power asymmetries and governance (Gawer, Cusumano, 2014; Gawer, 2014). Platform owners exercise substantial control over complementary innovation through technical architecture, API access, and intellectual property policies (Parker et al., 2016; Cennamo, Santalo, 2013). Patents enable platforms to shape ecosystem boundaries, control complementor behaviour, and appropriate value from ecosystem innovation, creating tension between platform incentives and ecosystem health (Eisenmann et al., 2011; Boudreau, 2010).

Open innovation models create apparent paradoxes for patent systems (Chesbrough, 2003; Chesbrough et al., 2006). Patents can facilitate open innovation by clarifying ownership boundaries, reducing transaction costs in technology transfer, and providing a basis for revenue-sharing in collaborative projects (Arora, Gambardella, 2010; Fosfuri, 2006). However, open-source software communities rely on copyright-based licensing rather than patents, with some licenses creating potential incompatibility with patent assertions (von Hippel, von Krogh, 2003; Lakhani, von Hippel, 2003). Emerging responses include patent pledges, defensive patent aggregators, and hybrid models combining patent protection for core technologies with open licensing for complementary innovations (West, 2006; Schultz, Urban, 2012).

Artificial intelligence introduces novel patentability questions challenging traditional doctrine (Abbott, 2016; Yanisky-Ravid, Liu, 2018). Key issues include: 1) *AI-generated inventions* – traditional patent law requires human inventors, but advanced AI systems increasingly produce novel solutions without direct human specification (UK IPO, 2022; USPTO, 2020); 2) *training data and algorithms* – patents typically cover architectures rather than training data, yet data quality critically determines AI performance, creating potential appropriability gaps (Agrawal et al., 2019; Scherer, 2016); and 3) *disclosure adequacy* – many AI patents describe high-level architectures without disclosing training data or implementation details necessary for reproduction (EPO, 2023; WIPO, 2023b).

Table 2. The key challenges and emerging responses in digital innovation ecosystems

Challenge domain	Specific issues	Impact on innovation	Emerging responses
Software patentability	Unclear boundaries between patentable/unpatentable subject matter; abstract patents; patent thickets	Legal uncertainty chills innovation; litigation costs divert resources; anti-commons blocks cumulative innovation	Judicial refinement of patentability standards (e.g. Alice/Mayo framework); heightened examination standards; calls for software-specific patent reforms
Standard-essential patents	Hold-up risks after standard adoption; FRAND licensing disputes; royalty stacking; injunctive relief controversies	Increased licensing costs; delayed market entry; reduced incentive for standards participation	FRAND commitments; patent pools; arbitration mechanisms; regulatory oversight; competition law enforcement
Patent thickets	Overlapping patent claims in complex technologies; unclear ownership boundaries; hundreds of patents per product	High transaction costs for licensing; innovation blocked by clearance difficulties; defensive patenting arms race	Cross-licensing agreements; patent pools; defensive patent aggregators; open innovation platforms
Platform ecosystems	Platform owner control over complementary innovation; asymmetric power in licensing; ecosystem governance challenges	Reduced complementor autonomy; potential for platform exploitation; innovation steered toward platform interests	Regulatory oversight of dominant platforms; open APIs and interoperability requirements; ecosystem-level IP policies
Open source tensions	Patent-open source license incompatibility; uncertainty over patent grants; defensive termination clauses	Legal uncertainty deters open-source adoption; fragmentation of collaborative innovation	Patent grants in open-source licenses (e.g. Apache 2.0); defensive patent pledges (e.g. Open Invention Network)
AI and data-driven innovation	Patentability of AI-generated inventions; training data ownership; inventorship questions	Uncertainty over AI innovation appropriability; potential underinvestment in AI R&D; data access barriers	AI-specific patent examination guidelines; data sharing frameworks; discussion of sui generis protection regimes
Global fragmentation	Divergent patent standards across jurisdictions; forum shopping; inconsistent enforcement	Increased compliance costs; strategic jurisdiction selection; reduced patent value in fragmented markets	Patent harmonisation efforts (PCT); regional patent systems (e.g. European Patent); bilateral agreements

Sources: Bessen, Meurer, 2008; Contreras, 2013; 2015; Gawer, Cusumano, 2014; Lemley, Shapiro, 2007; Maskus, 2012; WIPO, 2023.

The coexistence of patent-based and alternative models suggests that patent policy should accommodate diverse innovation approaches. Rather than focusing solely on exclusion, patents may increasingly function as tools for facilitating knowledge sharing and collaboration. This shift reflects a broader evolution in patentology towards understanding complex, networked innovation ecosystems.

3. Discussion: implications for innovation management and policy

3.1. Strategic patent management in digital firms

The functional transformations and ecosystem challenges analysed above require fundamental shifts in how firms approach patent strategy in digital contexts (Granstrand, 1999; Granstrand, Holgersson, 2019). Traditional patent strategy emphasised exclusion; digital innovation ecosystems require more sophisticated portfolio strategies balancing multiple objectives (Rivette, Kline, 2000; Sullivan, Sullivan, 2000):

- Defensive portfolios: building patent portfolios primarily to deter litigation and establish mutual deterrence through cross-licensing threats, particularly important in software and telecommunications sectors characterised by patent thickets (Hall, Ziedonis, 2001; Shapiro, 2008).
- Licensing revenue: strategically patenting innovations for licensing rather than internal exploitation, treating patents as revenue-generating assets in knowledge markets (Arora et al., 2001; Fosfuri, 2006).
- Signalling and legitimacy: using patents to signal technological capability to investors, partners and markets, particularly critical for start-ups in competitive digital domains (Ziedonis, 2004; Graham et al., 2009).
- Ecosystem positioning: deploying patents to shape platform ecosystem boundaries, manage complementor relationships, and influence standards development (Gawer, Cusumano, 2014; Cennamo, Santalo, 2013).

The rise of open innovation necessitates strategic decisions about when to patent, when to maintain trade secrets, and when to reveal knowledge openly (Chesbrough, 2003; Dahlander, Gann, 2010). Firms increasingly employ selective revealing strategies, including core-periphery models (patenting core technologies while openly sharing complementary innovations), and hybrid appropriability combining patents with complementary assets such as brands, data and network effects (Teece, 1986; Laursen, Salter, 2014).

This requires capabilities in technical standardisation, patent portfolio development and licensing negotiation that extend beyond traditional patent management functions. The increasing importance of standards in digital markets suggests that patent strategy must be closely integrated with standardisation strategy.

3.2. Regional and national innovation policy

The transformations in patentology have significant implications for regional and national innovation policy, particularly for regions seeking to develop digital economy capabilities (Cooke et al., 1997; Asheim, Gertler, 2005). Policymakers face pressure to reform patent systems across several dimensions:

1. Software patent standards: refining patentability standards to reduce abstract, overly-broad software patents, while maintaining protection for genuine innovations requiring substantial investment (Burk, Lemley, 2002; Lemley, 2013).
2. SEP governance: strengthening governance mechanisms for standard-essential patents to mitigate hold-up risks, while maintaining incentives for standards participation (Contreras, 2013; Lemley, Shapiro, 2013).
3. Patent quality improvement: addressing quality concerns through enhanced examination resources, post-grant review mechanisms, and stronger validity standards (Frakes, Wasserman, 2017; Lemley, Sampat, 2010).
4. AI-specific frameworks: developing examination guidelines and potentially sui generis protection regimes tailored to AI innovation characteristics (EPO, 2023; WIPO, 2019).

Regional development policy should consider how patent systems interact with broader innovation ecosystem dynamics (Cooke, 2001; Asheim et al., 2019). Key interventions include: supporting regional innovation clusters through infrastructure investment, talent development, and institutional frameworks facilitating knowledge exchange; strengthening university-industry technology transfer through reformed IP policies and flexible licensing terms (Mowery et al., 2004; Cohen et al., 2002); providing patent support services tailored to SMEs and start-ups, which often lack resources for sophisticated patent strategy (European Commission, 2015; WIPO, 2020); and developing regional open innovation infrastructure, including patent pools and collaborative research facilities (Chesbrough et al., 2006; West, Bogers, 2014).

Given the global nature of digital innovation and the territorial limitations of patent systems, international coordination is becoming increasingly important (Maskus, 2012; Drahos, Braithwaite, 2002). This includes patent harmonisation through strengthened PCT mechanisms, coordinated standards-essential patent governance ensuring consistent FRAND interpretation across jurisdictions, and internationally coordinated approaches to AI patentability and data governance (Reichman, 1995; Geradin, Rato, 2007).

The relationship between patent protection and regional innovation also depends on the specific characteristics of regional economies. Regions with strong university research capabilities may benefit from patent policies that facilitate university-industry technology transfer, while regions with innovation systems based more on user innovation or incremental improvement may require different policy approaches. This heterogeneity suggests that optimal patent policy may vary across regions, depending on local innovation system characteristics.

3.3. The future of patentology: towards integrated frameworks

The transformations analysed throughout this article have profound implications for patentology as an academic discipline and policy framework (Granstrand, Holgersson, 2019; Hall et al., 2014). Patentology must evolve towards genuinely interdisciplinary frameworks, integrating economics, law, management studies, technology studies and innovation policy. The digital economy reveals the limitations of disciplinary silos: economics provides incentive analysis but abstracts from institutional detail; law offers doctrinal frameworks but may lack empirical grounding; management studies illuminate firm strategies but sometimes neglect broader policy contexts; and technology studies provide a rich understanding of innovation processes but may underemphasise economic and legal constraints (Fagerberg et al., 2005; Hall, Rosenberg, 2010).

Patentology must also move beyond static, universal models, towards dynamic, context-sensitive analysis, recognising substantial variation across technologies, industries and institutional settings (Burk, Lemley, 2003; Pavitt, 1984). Context-sensitive analysis requires moving beyond a one-size-fits-all patent policy, towards differentiated approaches tailored to specific innovation contexts, potentially including technology-specific patent standards, industry-tailored governance mechanisms, and adaptive policy frameworks evolving with technological and market changes.

Strengthening empirical foundations is equally essential, moving beyond theoretical models towards evidence-based understanding of how patent systems actually function and affect innovation outcomes (Cohen, 2010; Hall, 2007). The digital economy provides rich opportunities: large-scale patent data analysis, firm-level innovation studies combining patent data with surveys and case studies, policy experiments exploiting jurisdictional variations, and technology-specific studies of patent system operation in software, AI and platform domains (Jaffe, Trajtenberg, 2002; Williams, 2013).

Patentology therefore stands at a critical juncture, where its continued relevance depends on embracing interdisciplinary integration, methodological pluralism, and context-sensitive analysis. Future research must prioritise empirically grounded insights that capture the complex interactions between technological change, institutional structures and innovation practices in digital environments. Ultimately, a more adaptive and evidence-based patentology will be essential for designing intellectual property systems that effectively balance innovation incentives with societal and economic needs in the digital age.

Conclusion

The historical evolution of patentology reflects changing technological landscapes and economic structures, from early patent privileges through the emergence of patent economics as a distinct field, to contemporary interdisciplinary approaches, integrating economics, law, management and technology studies. Classic patent theory, based on trade-offs between innovation incentives and access to knowledge, provides important insights, but offers an incomplete framework for understanding patents in digital contexts. The digital economy has transformed patent functions from simple exclusion rights to strategic assets in complex licensing networks, with patents serving multiple roles, including facilitating cross-licensing, signalling technological capabilities, and enabling participation in standard-setting processes.

Software patents represent a particularly contentious area, with ongoing debates about appropriate scope and eligibility criteria. The 2014 Alice decision's narrowing of software patent scope has had significant impacts, with evidence suggesting that reduced patent protection may facilitate open-source engagement and more focused innovation strategies, rather than deterring innovation. Standard-essential patents create new complexities in digital markets, requiring careful balance between patent holders' interests and implementers' access to essential technologies. Patent thickets and anti-commons problems in ICT markets create transaction costs and potential barriers to innovation, prompting responses, including cross-licensing arrangements and patent pool formation.

Artificial intelligence and machine learning technologies raise novel questions about inventorship, the patentability of algorithmic innovations, and the relationship between patent protection and access to training data. The rise of non-traditional innovation assets, including data, platforms and network effects, challenges patent-centric approaches to innovation policy, suggesting the need for broader frameworks, addressing diverse forms of intellectual property and innovation assets. Open-source and alternative innovation models demonstrate that substantial innovation can occur outside traditional patent-based appropriability mechanisms, raising questions about how patent policy should accommodate diverse innovation approaches.

Implications: For innovation management, this analysis suggests that effective patent strategy in digital firms requires sophisticated approaches that integrate patent management with broader business strategy, address multiple objectives beyond simple exclusion, and balance patent protection with participation in open and collaborative innovation. For regional and national innovation policy, patent policy should be considered as part of integrated frameworks, addressing multiple dimensions of innovation ecosystems, including financing, human capital, infrastructure and institutional complementarities. The relationship between patent protection and regional innovation depends on local innovation system characteristics, suggesting that optimal patent policy may vary across contexts.

Limitations: This study has several limitations. First, while 74 scholarly sources spanning multiple disciplines and time periods were analysed, the rapidly evolving nature of digital technologies means that new developments may emerge that alter the landscape analysed here. Second, the analysis focuses primarily on developed economy contexts, particularly the United States and Europe, with less attention to patent systems and digital innovation in developing economies. Third, empirical evidence on many key questions, particularly regarding AI patents, data governance and long-term impacts of recent policy changes, remains limited, requiring cautious interpretation of findings.

Future research: Several directions emerge. First, continued empirical investigation of how patent policy changes affect innovation outcomes in digital technologies is needed, particularly regarding software patents and AI innovations. Second, comparative analysis of different jurisdictions' approaches to digital patent policy can provide insights into effective policy design. Third, research on the relationship between patent systems and alternative innovation mechanisms, including open source, user innovation and collaborative platforms, can inform policies accommodating diverse innovation models. Fourth, analysis of patent systems' roles in addressing societal challenges, including climate change, public health and digital inclusion, can connect patentology to broader debates about innovation policy and sustainable development.

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PATENTOLOGIJOS EVOLIUCIJA IR TRANSFORMACIJA SKAITMENINĖJE EKONOMIKOJE: AKTUALUMO IR FUNKCIJŲ POKYČIŲ ANALIZĖ

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Santrauka

Skaitmeninė ekonomika iš esmės pakeitė intelektinės nuosavybės apsaugą, metė iššūkį tradicinėms patentologijos paradigmoms ir sukūrė kritinį žinių trūkumą dėl patentų sistemų išliekančio aktualumo ir funkcinės evoliucijos skaitmeniškai tarpininkaujamose inovacijų ekosistemose. Šiame straipsnyje nagrinėjama istorinė patentologijos raida ir analizuojama, kaip skaitmeninimas pakeitė patentų funkcijas, apimtį ir ekonominę reikšmę.

Taikant sisteminės literatūros apžvalgos metodologiją (*n* = 74 šaltiniai, 1962–2024 m.), lyginamąją institucinę analizę ir teminę sintezę, šis tyrimas atskleidžia patentologijos raidą nuo klasikinės ekonomikos teorijos iki šiuolaikinių skaitmeninių inovacijų ekosistemų. Tyrimas nagrinėja keturis tarpusavyje susijusius klausimus: (1) kaip istorinė raida formavo dabartines teorines sistemas; (2) kokias fundamentalias transformacijas skaitmeninės technologijos įvedė į patentų funkcijas; (3) kokios naujos problemos ir galimybės atsiranda skaitmeninėse inovacijų ekosistemose ir (4) kokios šių pokyčių pasekmės inovacijų valdymui ir politikai.

Atlikta analizė atskleidžia kritinius pokyčius: programinės įrangos patentai perkelia patentuojamos medžiagos ribas, standartams būtini patentai sukuria naujas licencijavimo sudėtingumo ir blokavimo rizikas, o atvirojo kodo modeliai meta iššūkį fundamentalioms išskirtinumo prielaidoms. Patentų funkcijos evoliucionavo nuo elementarių išskyrimo teisių iki strateginių aktyvų, įterptų į sudėtingus licencijavimo tinklus, platformų ekosistemas ir bendradarbiavimo inovacijų susitarimus.

Tyrimo unikalus indėlis yra fragmentuotų skaitmeninės ekonomikos perspektyvų sintezė į nuoseklią analitinę sistemą, integruojančią technologinius, institucinius ir strateginius patentų sistemos transformacijos matmenis. Svarbu buvo nustatyti konkrečias pasekmes inovacijų valdymo praktikai, regioninės ekonominės plėtros strategijoms ir politikos reformų prioritetams, darant išvadą, kad patentologija turi evoliucionuoti tarpdisciplininių sistemų, integruojančių ekonomiką, valdymą, technologijų studijas ir teisę, link, kad išliktų aktuali skaitmeninėse inovacijų ekosistemose.

RAKTAŽODŽIAI: *patentologija*, *skaitmeninė ekonomika*, *intelektinė nuosavybė*, *inovacijų valdymas*, *patentų transformacija*, *patentų aktualumas*, *patentų funkcijos*.

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