ISSN: 2658-8455
Volume 6, Issue 10 (2025), pp. 150-162.

IJAFAME
International Journal of Accounting, Finance, Auditing, Management & Economics

Blockchain and Innovation Ecosystems 4.0: Toward a Conceptual Framework

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Disclosure Statement :	The authors declare that they have not received any financial support that could have influenced the objectivity of this study. They take full responsibility for any potential plagiarism, the use of artificial intelligence in the writing process, as well as for the results presented in this article.
Conflict of Interest :	The authors report no conflicts of interest.
Cite this article :	TOMAL, A., & HAMIDI, L. S. (2025). Blockchain and Innovation Ecosystems 4.0: Toward a Conceptual Framework. *International Journal of Accounting, Finance, Auditing, Management and Economics*, *6*(10), 150–162.
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Received: 13/07/2025 *Accepted: 15/09/2025*

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Abstract:

This article provides a theoretical analysis of how Blockchain technology can enhance innovation ecosystems 4.0. In these modern ecosystems, the complexity of interactions is intensified by the diversity and interdependence of actors, including companies, public institutions, researchers, and citizens. These collaborative networks require robust methods to ensure transparency, shared governance, and fair distribution of benefits, especially in the face of accelerated innovation cycles.

Blockchain offers groundbreaking functionalities to address these challenges: it ensures immutable and secure traceability of contributions, thereby enhancing intellectual property protection through a decentralized and transparent ledger. By automating collaborative processes with smart contracts, blockchain reduces coordination costs and guarantees reliable execution of agreements. Finally, it enables decentralized governance, granting each participant equal and transparent involvement in decision-making. These features position blockchain as a promising pillar for more inclusive, efficient, and resilient innovation ecosystems 4.0.

Keywords: Open Innovation, Innovation Ecosystem 4.0, Decentralized Governance, Transparency
Classification JEL: O33
Paper type : Theoretical Research

Résumé:

Cet article propose une analyse théorique sur les contributions potentielles de la blockchain aux écosystèmes d'innovation 4.0. Dans ces écosystèmes modernes, la complexité des interactions est accrue par la diversité et l'interdépendance des acteurs, incluant entreprises, institutions publiques, chercheurs, et citoyens. Ces réseaux collaboratifs requièrent des méthodes robustes pour assurer transparence, gouvernance partagée et répartition équitable des bénéfices, face à l'accélération des cycles d'innovation.

La blockchain offre des fonctionnalités révolutionnaires pour répondre à ces défis : elle garantit une traçabilité immuable et sécurisée des contributions, offrant ainsi une protection accrue des idées dans un registre décentralisé et transparent. En automatisant les processus de collaboration à travers des contrats intelligents, elle réduit également les coûts de coordination et assure l'exécution fidèle des engagements. Enfin, la blockchain permet une gouvernance décentralisée, donnant à chaque acteur une participation égale et transparente dans la prise de décision. Ces caractéristiques font de la blockchain un pilier prometteur pour des écosystèmes d'innovation 4.0 plus inclusifs, efficaces et résilients.

Mots-clés: : innovation ouverte, écosystème d'innovation, Blockchain, gouvernance décentralisée, transparence
JEL Classification : O33
Type de papier:Recherche théorique

ISSN: 2658-8455
Volume 6, Issue 10 (2025), pp. 150-162.

IJAFAME
International Journal of Accounting, Finance, Auditing, Management & Economics

1. Introduction

Innovation has consistently established itself as one of the main drivers of economic growth and competitiveness, shaping not only the trajectory of firms but also the development of nations. The World Intellectual Property Organization (WIPO, 2023) stresses that innovation performance is today a critical determinant of resilience and adaptability in increasingly turbulent markets. According to the Organisation for Economic Co-operation and Development -OECD- (2022), investments in innovation-related activities account for more than 2.7% of global GDP (Gross Domestic Product), illustrating the central role of knowledge and technology in contemporary economies. This confirms that innovation is not only an economic necessity but also a social and political imperative in the context of globalization, digitalization, and ecological transition.

Historically, the theorization of innovation can be traced back to Joseph Schumpeter (1928), who conceptualized it as a linear and sequential process, largely dependent on the entrepreneur as a solitary agent of creative destruction. While this vision provided a solid foundation, it progressively revealed its limits, especially in the wake of the economic and energy crises of the 1970s. Empirical studies (Kline & Rosenberg, 1986) demonstrated that innovation is rarely linear or predictable; instead, it is systemic, interactive, and dependent on feedback loops among diverse actors. This systemic approach gave rise to the concept of innovation systems, highlighting the roles of institutions, firms, universities, and governments in fostering collective dynamics.

In the 2000s, this understanding evolved into the paradigm of open innovation (Chesbrough, 2003), which emphasizes permeability between organizations and their environments. Companies are no longer considered isolated entities but rather nodes within broader ecosystems, where value creation depends on collaborations with startups, research laboratories, suppliers, and even customers. This model has gained significant traction in both academic literature and managerial practice. Ecosystems of innovation, particularly in sectors such as healthcare, fintech, and clean energy, are increasingly recognized as laboratories for societal transformation (Pecqueur & Klein, 2020; Bogers, Chesbrough, & Moedas, 2018).

However, the open innovation model is accompanied by new and complex challenges. Expanding the circle of stakeholders exacerbates tensions over intellectual property, complicates trust-building, and raises governance issues. Similarly, the management of shared knowledge, accountability, and equitable distribution of value are recurrent obstacles in open ecosystems (Bogers et al., 2018). These shortcomings demonstrate that while the concept of open innovation is theoretically appealing, its practical implementation often remains fragile and uncertain.

Against this backdrop, blockchain technology has emerged as a promising instrument to address some of these challenges. Defined by its features of decentralization, immutability, and transparency, blockchain offers new mechanisms for ensuring trust, traceability, and secure collaboration without the need for a central authority. In the field of innovation, blockchain has the potential to:

- Facilitate secure knowledge sharing between partners;
- Ensure transparent allocation of intellectual property rights;
- Create incentive systems (e.g., tokenization) that reward contributions fairly;
- Strengthen governance in ecosystems by providing auditable and decentralized decision-making tools.

Despite this potential, the integration of blockchain into innovation ecosystems remains underexplored at the theoretical level. Current research often focuses on blockchain applications in finance (cryptocurrencies, decentralized finance) or supply chain management, while its role in fostering and structuring innovation ecosystems is still in its infancy

(Treiblmaier, 2019). Moreover, the literature lacks conceptual frameworks that articulate how blockchain features can effectively support the mechanisms of open innovation, especially in terms of governance, trust, and collective learning.
This gap motivates the present study. By conducting a systematic literature review, this article seeks to identify the main challenges of open innovation ecosystems and analyze how blockchain can provide solutions to these challenges. The objective is to propose a conceptual framework that integrates blockchain into the architecture of innovation ecosystems, thereby offering both theoretical contributions and practical insights for organizations and policymakers. In doing so, the article aspires to enrich the debate on the digital transformation of innovation processes and to highlight blockchain's role as a potential catalyst for Innovation Ecosystems 4.0.

2. Theoretical framework

2.1. Open Innovation

Although open innovation was formalized and popularized by Henry Chesbrough (2003) with the publication of his book *Open Innovation: The New Imperative for Creating and Profiting from Technology*, its roots actually go much further back. The open-source movement, which emerged in the 1990s, laid the foundation for this revolution. This collaborative model, centered on the collective creation of software and the public availability of source codes, profoundly changed how innovation could be conceived and disseminated (West & Gallagher, 2006). Indeed, open-source relies on a fundamental principle: the openness of knowledge, where every user has the right to copy, modify, and redistribute a software code, while adhering to the principles of copyleft, which protects the openness of derivative works.
This philosophy served as a basis for broader thinking about innovation in industrial and commercial terms. It allowed for the imagining of a model in which companies no longer held a monopoly on value creation but actively collaborated with external partners, whether universities, suppliers, or even competitors. Chesbrough (2003) thus describes open innovation as the antithesis of the traditional closed innovation model, where companies relied solely on their internal resources to develop products. In this context, open innovation is defined as "*the intentional use of inflows and outflows of knowledge to accelerate internal innovation and expand the external use of innovations*" (Chesbrough, 2003). This model promotes a combinatory approach, where internal ideas are enriched by those from external sources, opening up new horizons for collaboration.
Open innovation is primarily divided into two models:

- **Outbound open innovation**: In this framework, a company shares its internal innovations with external actors through licensing, collaborations, or the creation of spin-offs (Huizingh, 2011). This practice not only generates additional revenue but also creates a continuous flow of knowledge sharing, fostering rapid evolution in the ecosystem in which the company operates.
- **Inbound open innovation**: This model encourages companies to open up to external sources of knowledge and to integrate ideas from various partners, such as research labs, universities, or startups. The goal is to capture collective intelligence to enhance internal innovations, thereby creating a synergy between internal and external expertise.

Gassmann and Enkel (2004) identify a third process, the **"coupled process model"**, which combines these two knowledge flows bilaterally. This model is particularly relevant in co-creation contexts, where companies and their partners engage together in collaborative innovation projects. The coupled process allows for a smooth circulation of knowledge, creating a true innovation ecosystem, based on the pooling of resources, skills, and ideas. This model

ISSN: 2658-8455
Volume 6, Issue 10 (2025), pp. 150-162.

IJAFAME
International Journal of Accounting, Finance, Auditing, Management & Economics

reflects the current dynamics of many sectors, where innovation increasingly relies on strategic alliances, public-private partnerships, and collaborative R&D projects.

However, with the rise of new technologies, the multiplication of stakeholders, and the acceleration of innovation cycles, companies now operate in environments characterized by increased interdependence (Freeman, 1987; Lundvall, 1992). In this context, innovation is no longer the result of a simple bilateral collaboration between a company and its external partners, but rather unfolds within complex networks involving diverse actors, such as governments, universities, companies, startups, and civil society (Etzkowitz & Leydesdorff, 1995). These multiple interactions require a more systemic approach, integrating not only knowledge flows but also the co-evolution and coordination between interdependent actors. This is how the concept of the innovation ecosystem emerged (Moore, 1993), responding to this new reality where innovation is built collaboratively within a broader and more integrated set of actors, each playing a crucial role in creating collective value.

2.2. Toward an Innovation Ecosystem 4.0

The concept of the innovation ecosystem was introduced in 1993 by James F. Moore in his article "*Predators and Prey: A New Ecology of Competition*", published in the Harvard Business Review. Moore used a biological metaphor to describe the complex interactions between economic actors in a competitive environment, comparing these relationships to those of living organisms in a natural ecosystem. Just as in a biological ecosystem, where organisms interact, cooperate, and compete to survive while maintaining balance, companies, institutions, and other actors in an innovation ecosystem collaborate to develop and evolve new ideas and technologies.

Historically, the study of dynamics involving external actors in the extra-organizational innovation process is undoubtedly much older. Alfred Marshall (1890) described the economic advantages created by agglomerations, which can be seen as a "1.0" version of innovation ecosystems, based on local proximity and interdependence effects. After World War II, the expansion of extended supplier networks and the development of industrial networks can be considered a "2.0" version of these innovation ecosystems. Subsequently, several researchers (Lundvall, 1992; Moore, 1993; Freeman, 1995) emphasized the importance of national innovation systems in creating an environment conducive to innovation, marking the advent of "3.0" innovation ecosystems. Then, with the technological advances of the past 25 years, particularly in communication and digital collaboration, innovation ecosystems have reached version 4.0. This evolution is based on increased connectivity among actors and the ability to integrate new participants, such as consumers and civil society, into the innovation process.

Innovation ecosystems 4.0 can take several forms. They may be structured around businesses (business ecosystems), universities (university ecosystems), or adopt more open and virtual forms like open innovation platforms (Lima & Seulliet, 2019). Organizationally, they can be formal, such as competitiveness clusters and clusters, or informal, such as consortia.

At the territorial level, innovation ecosystems can expand into more complex models, integrating a diversity of public and private actors. One of the most influential models is the triple helix, which relies on partnerships between the public sector, private sector, and academic institutions to stimulate innovation at the local and regional levels (Etzkowitz & Leydesdorff, 2000). This model later evolved into a quadruple helix, adding a participatory and democratic dimension by involving citizens and civil society in the innovation process (Carayannis & Campbell, 2009). Finally, the quintuple helix model introduces a fifth helix, that of the "natural environment of society," recognizing the importance of environmental sustainability in modern innovation processes (Carayannis et al., 2012).

In summary, innovation ecosystems act as protective cocoons for innovation. They stimulate complex dynamics of collaboration among diverse actors to encourage innovation and create

value. However, in recent decades, with the widespread dissemination of information systems, the concept of the innovation ecosystem has become considerably mainstreamed, sometimes losing specificity and structured conceptual frameworks. To address this conceptual gap, Lima & Seulliet (2019) proposed seven prescriptive dimensions to better define and guide the development of innovation ecosystems:

- **Territorial anchoring**: An innovation ecosystem 4.0 is distinguished by its deep roots in a specific territory, allowing its members to gather, interact, and co-create in both physical and virtual environments. An ecosystem is anchored through a set of elements that shape its identity, such as history, culture, traditions, and local know-how.
- **Transversality and multidimensionality**: A 4.0 ecosystem is based on co-creation facilitated by a flexible and adaptable structure, encouraging the participation of a wide range of stakeholders: entrepreneurs, government, academic institutions, or citizens. The richness of such an ecosystem stems from its transversality and its ability to encourage interdisciplinary interactions. In this sense, Metcalfe's Law (Shapiro & Varian, 1999) emphasizes that the value of a network grows proportionally with the number of possible interactions, thus reinforcing the importance of a multidimensional approach in ecosystem design.
- **Openness and connectivity**: An innovation ecosystem 4.0 does not operate in isolation but is in constant interaction with other ecosystems. Its productivity and capacity to innovate are enhanced when it fosters open connections with other innovation networks, fully integrating the concept of open innovation in an expanded and collaborative dimension. These interconnections between ecosystems multiply knowledge exchanges and co-creation opportunities.
- **Participative governance**: In a 4.0 ecosystem, governance is based on principles of decentralization and equitable participation. It is organized around user communities and prioritizes horizontal peer-to-peer relationships, promoting inter-organizational cooperation and collaborative innovation. This decentralized approach increases participant engagement in co-creation while encouraging mutual learning.
- **Use of formal tools and methods**: While an innovation ecosystem 4.0 should encourage spontaneous and informal interactions, often driven by serendipity, it must also rely on formalized methods and tools to maximize its efficiency. Essential methods include collective intelligence tools, ideation, design thinking, rapid prototyping, prospective monitoring, as well as innovation platform management systems that structure and facilitate exchanges among ecosystem actors.
- **Ethics in value sharing**: The value created within an innovation ecosystem 4.0 is based on an ethic of sharing. Each contributor is recognized and valued for their input, and the added value is distributed equitably among stakeholders. This balance is essential to ensure a fair distribution of the benefits of innovation and to reinforce cohesion within the ecosystem.
- **Direction, meaning, and values**: An innovation ecosystem 4.0 thrives when it is driven by a common mission and shared values, which unite members around a collective goal. These values must be clearly identified and communicated to create a strong inter-organizational culture, fostering engagement and collaboration among the actors.

Finally, although innovation ecosystems are significant catalysts for creativity and collaboration, they face many challenges that hinder their effectiveness. One major issue is the opportunism of participants, where some actors seek to maximize their personal interests at the expense of collective goals (Williamson, 1985). This opportunistic behavior risks eroding mutual trust between partners, limiting information exchange and hindering transparency (Das & Teng, 1998). Moreover, imbalanced governance, where large companies dominate decision-making processes, marginalizes smaller actors (Nambisan & Sawhney, 2011), and the unequal sharing of gains from innovation creates tensions, discouraging long-term engagement (Pisano & Verganti, 2008). Added to this are challenges related to the traceability of contributions and

ISSN: 2658-8455
Volume 6, Issue 10 (2025), pp. 150-162.

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the protection of intellectual property rights, where shared ideas may be misattributed or exploited without authorization (Leminen et al., 2012; Gawer & Cusumano, 2014). Additionally, complex and slow decision-making processes due to the diversity of stakeholders complicate governance, while the lack of adequate economic incentives hampers the active participation of smaller actors (Buterin, 2013; Davidson et al., 2018). These challenges highlight the need to introduce more advanced mechanisms capable of addressing these issues while ensuring transparency, traceability, and more decentralized and equitable governance.

2.3. Blockchain: A Revolutionary Technology with Great Potential

Blockchain is an innovative digital technology that is radically transforming the way transactions and information are managed. Initially developed in 2008 by an individual or group under the pseudonym Satoshi Nakamoto, it was publicly introduced as open-source technology in 2009, alongside the cryptocurrency Bitcoin (Nakamoto, 2008; Lachene, 2018).

Blockchain is generally defined as a technology for storing and transmitting information, which is transparent, secure, and operates without a central control authority (Blockchain France, 2016). It is often compared to a large decentralized ledger or a public database that immutably records transactions since its inception. Its operation is based on cryptography to ensure the security of transactions and relies on the increasing computing power of machines connected to the internet to validate and secure these exchanges (Lachene, 2018). Each transaction is grouped into a block, protected by cryptographic algorithms, and once validated, this block is added to the previous chain of blocks, making any subsequent modification or deletion impossible. This immutability makes transparency one of the essential characteristics of blockchain.

Although originally associated with the cryptocurrency Bitcoin, blockchain quickly expanded its range of applications. Sectors such as banking, businesses, and even governments have adopted this technology to take advantage of its distinctive benefits: transaction traceability, elimination of intermediaries, and secure collaboration between stakeholders (Tapscott & Tapscott, 2016). Additionally, blockchain can reduce transaction costs and improve system efficiency, especially in financial and logistics sectors.

Blockchain is built on a fundamental principle of decentralization and transparency. Unlike traditional centralized systems, where a single authority controls and verifies transactions, blockchain is a distributed ledger shared among multiple participants called nodes. Each node holds a complete and up-to-date copy of all transactions made on the blockchain. When a new transaction is initiated, it is grouped with others in a block. This block is then subjected to a validation process by the nodes through a consensus mechanism, the most commonly used being Proof of Work, which requires solving complex mathematical algorithms (Nakamoto, 2008). Once validated, the block is chronologically added to the existing chain of blocks, forming an immutable archive that is accessible to all.

Furthermore, the security and integrity of transactions are guaranteed by the use of cryptography. Each block contains a unique cryptographic hash linked to the previous block, creating an unbroken chain. Any attempt to modify a block would result in a break in the chain, immediately detectable by all nodes in the network. This process makes blockchain nearly tamper-proof and ensures total transparency, as every transaction is publicly visible but remains secure and protected from alterations (Lachene, 2018). This mechanism also ensures reliability without the need for an intermediary, eliminating the need for central authorities, making it a particularly suitable technology for systems requiring autonomous and secure verification (finance, logistics, smart contracts, etc.).

Beyond its traditional applications, blockchain can also play a central role in the governance of innovation ecosystems. Its ability to offer a secure, transparent, and decentralized infrastructure makes it particularly well-suited to managing the complexity of collaborative environments

involving a wide array of stakeholders. According to Lima and Seulliet (2019), blockchain paves the way for a more responsible, ethical, and scalable innovation paradigm, thanks to its ability to support the following core functions:

- ***Immutable Traceability and Securing Contributions:***

In open innovation ecosystems, protecting intellectual property and ideas remains a major challenge. This lack of protection often hampers idea sharing and stifles innovation. In a study conducted by Ylitalo with 35 participants in a Design Thinking workshop, it was observed that employees were hesitant to share their ideas during plenary ideation sessions, often preferring to do so afterward. This behavior is largely attributed to the absence of traceability of contributions, as it is difficult to accurately determine the origin of an idea in a collective context (Ylitalo, 2016 as cited in Schoenhals et al., 2018).

Blockchain, with its decentralized and immutable architecture, offers a promising solution to this problem by ensuring optimal traceability and protection of contributions. As Lima and Seulliet (2019) state, "blockchain establishes a common foundation where data is shared, and then each party can exploit it for their own specific advantage." This technology allows each user to upload creations, models, or ideas onto a timestamped ledger, providing indisputable proof of their origin and ownership. Once on the blockchain, this information becomes immutable, preventing any subsequent modification or deletion. In doing so, blockchain opens new possibilities for intellectual property protection. Indeed, the Dennemeyer Group and the Bahead Research Institute recommend in their report *The Future of Intellectual Property* the creation of "an alternative to conventional intellectual property rights, based on blockchain, which would be faster, more transparent, tamper-proof, and operate without intermediaries" (Schoenhals et al., 2018).

Through these functionalities, blockchain creates a trusted environment that encourages greater participation and sustained engagement from actors, as every contribution is valued and securely protected while facilitating the secure sharing of ideas and creations. Based on these assumptions, we formulate the following hypothesis:

H1: Blockchain adoption positively contributes to the effectiveness of open innovation ecosystems by strengthening trust among actors.

- **H1-1**: Blockchain adoption has a positive effect on trust among actors in the open innovation ecosystem.
- **H1-2**: Trust positively affects the effectiveness of innovation ecosystems.

- ***Process Automation via Smart Contracts:***

Blockchain enables the automation of complex processes through smart contracts, which are self-executing computer programs triggered automatically when predefined conditions are met. Unlike traditional contracts, which require human intervention or intermediaries to be executed, smart contracts operate autonomously once implemented on the blockchain, ensuring reliable, transparent, and tamper-proof execution (Buterin, 2013).

In innovation ecosystems, smart contracts simplify project management by automating various tasks, such as validating collaboration milestones or distributing resources among actors. For instance, when a project reaches a certain milestone or a contribution is verified, the smart contract can automatically release funds or assign intellectual property rights to the relevant stakeholders. This significantly reduces coordination costs by eliminating the need for centralized control or intermediaries, while also speeding up execution times (Tapscott & Tapscott, 2016).

Smart contracts also offer greater security and transparency. Once programmed, the contract's content and conditions cannot be altered without the consent of all parties. This limits potential conflicts, improves the quality of interactions, and facilitates collaboration, as everything is predefined and immutable. Additionally, the automatic execution ensures that no actor can

ISSN: 2658-8455
Volume 6, Issue 10 (2025), pp. 150-162.

IJAFAME
International Journal of Accounting, Finance, Auditing, Management & Economics

delay or prevent the contract's execution once conditions are met. This is particularly beneficial in innovation ecosystems where multiple stakeholders (companies, universities, startups, etc.) must collaborate on complex projects that require smooth and fast task management.
Moreover, smart contracts can be used in various applications, such as intellectual property management, tracking contributions in open innovation projects, or distributing the gains from collaboration. This ensures a fair and transparent distribution of results, fluidity of interactions, and reduced potential tensions, guaranteeing the quality of interactions and sustained engagement from actors in the innovation process (Catalini & Gans, 2016).
From this analysis, we formulate the following hypothesis:
H2*: *Blockchain adoption positively contributes to the effectiveness of innovation ecosystems by improving the quality of collaboration among actors.

- **H2-1**: Blockchain adoption has a positive effect on collaboration among actors in the innovation ecosystem.
- **H2-2**: Higher-quality collaboration positively contributes to the effectiveness of innovation ecosystems.

- ***Decentralized Governance:***

Unlike traditional models where a central authority or intermediaries' control and oversee decisions, blockchain promotes the distribution of governance through a network of participants. This distributed and democratic governance model gives each actor an active role in decision-making and project management by offering everyone equal access to information and processes (IBM, 2022).
The elimination of intermediaries in decision-making not only reduces administrative costs but also allows for faster and more transparent management of operations. In a blockchain-based decentralized governance system, every transaction or data modification is automatically recorded in an immutable and transparent ledger, accessible to all stakeholders. This strengthens trust among participants, as no single entity controls the process, and every action can be verified by the network. Blockchain enables reliable and continuous tracking of all transactions, promoting more inclusive and participatory governance.
Furthermore, this decentralized governance model is particularly suited to innovation ecosystems, which bring together a wide variety of actors (companies, academic institutions, startups, citizens, etc.). In these complex environments, blockchain allows decision-making to be distributed horizontally, ensuring that every stakeholder has an equal voice and power in the process. Governance rules can be embedded in smart contracts, which automate certain decisions and guarantee faithful execution of the defined terms without human interference (Buterin, 2013). This enhances transparency and the effectiveness of innovation ecosystems while encouraging broader and more engaged participation.
In addition, blockchain-based decentralized governance is often used in DAO (Decentralized Autonomous Organization) projects, where decisions are collectively made by network members through token-based voting mechanisms, ensuring an equitable distribution of decision-making power (Catalini & Gans, 2016).

- ***Transparent Distribution of Gains:***

Blockchain offers an innovative solution to ensure the fair distribution of benefits within an innovation ecosystem by guaranteeing that each contribution is recognized and fairly rewarded. This transparency is made possible by the decentralized nature of blockchain, which eliminates the need for a central intermediary to manage the distribution of gains. Each transaction and contribution is immutably and traceably recorded in the distributed ledger, ensuring that actors receive their share based on their actual contributions (Gawer & Cusumano, 2014) and guaranteeing fairness among ecosystem members (Lima & Seulliet, 2019).

H3: Blockchain adoption positively contributes to the effectiveness of innovation ecosystems through decentralized governance.

- **H3-1**: Blockchain adoption has a positive effect on decentralized governance.
- **H3-2**: Better decentralized governance positively affects the effectiveness of innovation ecosystems.

3. Conclusion

In conclusion, blockchain emerges as a transformative infrastructure with the potential to redefine the dynamics of innovation ecosystems, particularly within the paradigm of open innovation 4.0. Its core attributes (immutable traceability, decentralized governance, automation via smart contracts, and transparent value distribution) respond to some of the most persistent structural challenges facing innovation ecosystems today. These include the protection of intellectual contributions, the reduction of coordination and transaction costs, the reinforcement of trust among heterogeneous actors, and the fair allocation of collectively created value.

By eliminating reliance on centralized authorities and enabling secure, peer-to-peer collaboration, blockchain fosters a more inclusive, transparent, and participatory innovation environment. This empowers all actors (whether firms, researchers, startups, or civil society stakeholders) to engage meaningfully in co-creation processes, with equitable access to information, governance, and recognition.

Moreover, blockchain does not merely act as a technical facilitator. It also introduces a new institutional logic grounded in transparency, automation, and distributed trust, which aligns with the increasingly complex, fluid, and multidisciplinary nature of innovation ecosystems 4.0. Its ability to encode governance rules and value flows directly into tamper-proof protocols offers significant potential for overcoming power asymmetries and reinforcing long-term collaboration.

At the same time, the widespread adoption of blockchain in open innovation contexts still faces major limitations. Scalability remains a concern in ecosystems characterized by frequent interactions (Croman et al., 2016), while interoperability between different blockchain platforms is still limited, hindering seamless integration across networks (Belchior et al., 2020). Privacy and regulatory compliance also raise challenges, since the immutability of blockchain can conflict with data protection frameworks. Furthermore, governance models like decentralized autonomous organizations (DAOs) may suffer from power concentration and inflexibility in adapting to evolving collaboration needs (Hassan & De Filippi, 2021).

As the technology matures and regulatory frameworks evolve, future research should investigate empirical applications of blockchain within diverse innovation contexts. This includes exploring its integration with complementary technologies such as artificial intelligence, the Internet of Things, or digital identity systems, as well as assessing its impact on innovation performance, resilience, and sustainability at the ecosystem level.

Ultimately, blockchain's contribution goes beyond efficiency gains; it may serve as a catalyst for more ethical, democratic, and sustainable innovation ecosystems, capable of addressing contemporary societal and environmental challenges.

ISSN: 2658-8455
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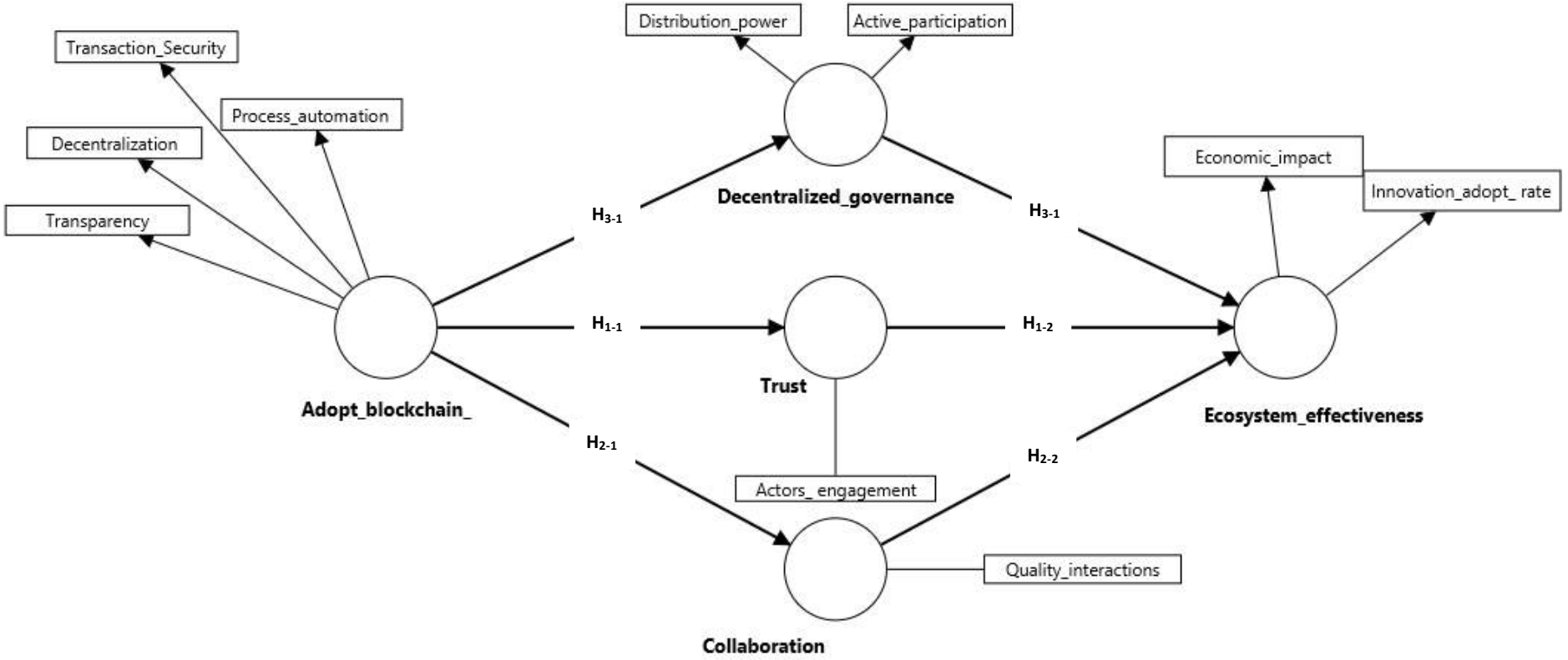
Figure N°1 : *Conceptual Modeling of the contribution of Blockchain on the Efficiency of Innovation Ecosystems 4.0*



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