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The economics of blockchain : a focus on skills demand

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A background image showing a graduation cap (mortarboard) resting on a stack of books, with a rolled-up diploma to the right.

THÈSE DE DOCTORAT

L'économie de la blockchain : un regard sur la demande de compétences

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Laboratoire GREDEG
Groupe de Recherche en Droit, Économie et Gestion

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du grade de docteur en Économie
d'Université Côte d'Azur**

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L'économie de la blockchain : un regard sur la demande de compétences

Résumé

Cette thèse étudie la dynamique industrielle de la technologie blockchain à l'ère de l'industrie 4.0. À travers trois chapitres, il s'agit de comprendre les implications en termes d'évolution, de demande de compétences et de performance de diffusion de cette technologie numérique.

Le premier chapitre de la thèse correspond à une revue de littérature visant une synthèse de la littérature sur la blockchain, afin de rendre accessibles les principaux concepts de cette technologie. Nous examinons les implications que les différentes générations de blockchain peuvent avoir sur l'analyse des modes de coordination décentralisés des agents. Nous soulignons également que l'état actuel des connaissances ne permet pas de saisir pleinement la complexité de la blockchain, en termes d'implications plus larges pour l'activité économique et la société. Ce chapitre fournit un socle sur lequel la thèse peut s'appuyer pour se concentrer sur les compétences liées à la blockchain, à la fois en termes

de demande des entreprises et de leurs implications en termes de performance de diffusion. Le deuxième chapitre cherche à déterminer si la technologie blockchain correspond à la dynamique industrielle de Schumpeter Mark 1 ou Schumpeter Mark 2, sur la base de la demande de nouvelles compétences émanant des entreprises. En utilisant une base de données originale de 385 offres d'emploi dans trois domaines différents, à savoir la blockchain, la biotechnologie et la tenue de magasin, publiées par 285 entreprises en France et en Allemagne au début de 2019, ce chapitre explore si les attributs habituels de Schumpeter Mark 1 et 2 s'appliquent à la blockchain.

Le troisième chapitre examine les implications de la technologie blockchain à travers une perspective des coûts de transaction dynamique pour caractériser les compétences requises pour une diffusion réussie des applications décentralisées. En utilisant une base de données originale comprenant les profils de 266 équipes contractantes d'applications décentralisées basées sur différentes blockchains, en 2021, nous explorons si la performance distincte des transactions réalisées par le biais de cette technologie peut être expliquée par les capacités idiosyncrasiques intégrées par les individus.

En somme, la thèse vise à mieux comprendre ce qu'est réellement l'économie de la blockchain et quelles sont les voies de recherche encore à venir au niveau des entreprises, des emplois et des compétences, à l'ère de l'industrie 4.0.

Mots-clés : blockchain, Schumpeter Mark 1 et Mark 2, innovation, technologie, industrie 4.0, entreprises, emplois et compétences, cryptographie, gouvernance, coûts de transaction.

The economics of blockchain: a focus on skills demand

Abstract

This thesis investigates the industrial dynamics of blockchain technology in the era of Industry 4.0. Across three chapters, the aim is to understand the implications in terms of evolution, skills demand and diffusion performance of this digital technology.

The first chapter of the thesis corresponds to a literature review aiming at a synthesis of the literature on blockchain, in order to make the main concepts of this technology accessible. We examine the implications that different generations of blockchain may have on the analysis of agents' decentralized modes of coordination. We also emphasize that the current state of the art does not fully capture the complexity of blockchain, in terms of broader implications for economic activity and society. This chapter provides a baseline on which the thesis can start focusing on blockchain-related skills, both in terms of demand from firms and their implications in terms of diffusion performance.

The second chapter investigates whether blockchain technology corresponds to Schumpeter Mark 1 or Schumpeter Mark 2 industrial dynamics, based on the demand for new skills emanating from firms. Using an original database of 385 job advertisements in three different fields, namely blockchain, biotechnology and storekeeping, published by

285 companies in France and Germany in early 2019, this chapter explores whether the usual Schumpeter Mark 1 and 2 attributes apply to blockchain.

The third chapter examines the implications of blockchain technology through a dynamic transaction cost perspective to characterize the capabilities required for successful diffusion of decentralized applications. Using an original database comprising the profiles of 266 contracting teams of decentralized applications based on different blockchains, in 2021, we explore whether the distinct performance of transactions realized through this technology can be explained by the idiosyncratic capabilities embedded by individuals.

In sum, the thesis aims at better understanding what the economics of blockchain really is and what research avenues are still ahead at the level of firms, jobs and skills, in the age of Industry 4.0.

Keywords: blockchains, Schumpeter Mark 1 and Mark 2, innovation, technology, industry 4.0, firms, jobs and skills, cryptography, governance, transaction costs.

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General Introduction

General Introduction

The wonders of blockchain technology

Blockchain is a pervasive digital technology revolutionizing the way information is being stored and exchanged, setting aside the requirement for a central monitoring authority. As such, blockchain technology is a disruptive innovation that has the potential to reshape the economy and society, as advocated by many commentators (Cong & He, 2019; Davidson et al., 2018; Yermack, 2017). Within the context of Industry 4.0, this thesis explores how the emergence of blockchain-related innovations is shaping the economy and society, with a specific focus on industrial dynamics by identifying why and how firms (large firms, multinational, but also start-ups and entrepreneurial projects) and industries (manufacturing and non-manufacturing) are developing this technology, and with what pre-requisites as well as implications on the demand for skills. As pointed out in a recent study (Nielson, 2023): *“Blockchain, the technology underlying cryptocurrency, is the new focus of many industries. [...] The blockchain talent shortages are making the blockchain skills highly looked for in the global job market.”*

But what is blockchain technology really?

Blockchain represents a form of Distributed Ledger Technology (DLT) that has profoundly transformed the way information exchanges occur. In the past, especially since the Middle Ages in prominent Italian city-states like Venice, Florence, and Genoa, the reliance on a central intermediary was essential, often facilitated through the practice of double-entry bookkeeping. The fundamental principles of double-entry bookkeeping remained merely unchanged until the advent of blockchain. This is why some refer to blockchain as the 'trust machine,' as it operates without the need for any central authority to guarantee the integrity of data. From a more technical standpoint, user-generated data is chronologically verified and organized into secure blocks linked by cryptography, creating an immutable chain of transactions. Consequently, blockchain serves as a dynamic and tamper-resistant database protected by storage nodes against unauthorized modifications. It functions as a secure ledger that records all executed transactions since the inception of the distributed system. This robust technology promises enhanced security, transparency, and trust in an increasingly interconnected world.

While blockchain is often associated with fintech, the thesis argues that it has a broader scope of applications. Referring to [Dosi \(1982\)](#), the thesis considers blockchain as displaying its own technological paradigm, consistent with the Schumpeterian views of creative destruction. This research aims to better investigate the characteristics of blockchain technology, its impact on firms' strategies including the demand for skills, and an improved qualification of what blockchain performance can be in practical use.

Research objectives and challenges

The objective of this dissertation is to better understand what the economics of blockchain might be, investigating the extent to which blockchain technology disrupts interactions among individuals, industries, and institutions. This quest, however, copes with the four following challenges. First, investigating blockchain presents a challenge, as blockchain has intrinsic complex features. This technology incorporates various digital mechanisms that rely on economic incentives, and its overall functioning depends on the collaboration of multiple actors and the interplay of numerous technical factors. Although some terms may initially appear technical, this work is an attempt to present the technology in an accessible manner, while remaining in line with the statement emphasized in a pioneering economics article on blockchain (Böhme et al., 2015), p. 233: *"many questions remain open, especially for researchers who possess a deep understanding of Bitcoin, technical data collection skills, and a strong background in social science."* This dissertation aims to provide a more structured literature review that clarifies the different definitions of the blockchain and the corresponding research agendas.

Second, there exists a gap in our understanding of the intricate relationship between the adoption of Industry 4.0 technologies, the demand for the corresponding skills, and their impact on industrial development. Indeed, bearing in mind the productivity paradox concerning Information Communication Technology (ICT), recent research posits intangible assets as determinant for the successful deployment of General-Purpose Technology (GPT) (Brynjolfsson et al., 2021). More precisely, the deployment of ICT process seems to correspond to a J-curve pattern where initial investments may take time to fully manifest their effects. Despite the complexities in attributing output gains to ICT investments,

the role of intangibles assets in shaping novel opportunities is considered as a driver of a substantial and sustained increase in labour productivity. Therefore, it appears necessary to bring a deeper understanding of the competences driving industrial progress in the era of Industry 4.0, blockchain technology being one key aspect of it.

Third, it is essential to recognize that the effects of digitalization are not uniform across countries, especially within the European Union. Some studies comparing different countries present a pessimistic picture, showing that low and mid-skilled jobs are more vulnerable ([Aghion et al., 2019](#); [Reljic et al., 2021](#)). For instance, the United States workforce appears to be more exposed to robotization than the German one due to their different industrial structures ([Acemoglu & Restrepo, 2020](#)). On the other hand, [Domini, Grazzi, Moschella, and Treibich \(2021\)](#) show that automation accompanying the digital transformation within firms has a positive impact in terms of net employment, with no significant changes in the composition of the workforce in France. A similar conclusion is reached by [Aghion, Antonin, Bunel, and Jaravel \(2020\)](#), who emphasize that firms engaged in international trade tend to benefit more from digital innovation. These contrasting effects raise fundamental questions about the policymaking decisions required to ensure that society benefits from digitalization. Consequently, understanding these changes and the skills requirements – also in a geographical context – becomes a crucial objective for governments, aiming to achieve productivity gains but also to mitigate their destructive impacts on labour ([Frank et al., 2019](#)).

Think of the labour market for digital skills. One of the salient challenges currently faced by industries across the EU members is the shortage of digital skills¹. EU firms encounter challenges when it comes to recruiting information and communication technology (ICT) experts (Eurostat, 2023). To be more specific, a significantly larger percentage of large enterprises (72.2%) encountered difficulties when attempting to recruit or re-recruit new employees. Medium-sized enterprises (63.7%) and small enterprises (59.9%) also experienced notably high proportions of difficulties in their recruitment efforts. The reference area covers EU-Member States, Iceland and Norway, candidate countries and potential candidate countries. The data is available for manufacturing and service sectors on NACE 2-digit level since 2009. In our analysis, we are more specifically looking at the information society indicator “Enterprise had hard-to-fill vacancies for jobs requiring ICT specialist skills”². We see in Figure 1 that in 2022 Germany is facing a digital skills shortage in almost 8.4% of its firms, while France reaches 6%, which corresponds to the average level among the 27 eurozone countries. The map (Figure 2) appears to reveal that firms situated within the European megalopolis region, with Scandinavian countries such as Denmark, Sweden, and Finland, are the most exposed to this shortage.

¹Sources: Eurostat - Enterprises that recruited or tried to recruit ICT specialists by NACE Rev.2 activity ISOC_SKE_ITRCRN2] last update: 29/08/2023 11 : 00

²Information society indicator: [E.ITSPVAC2]

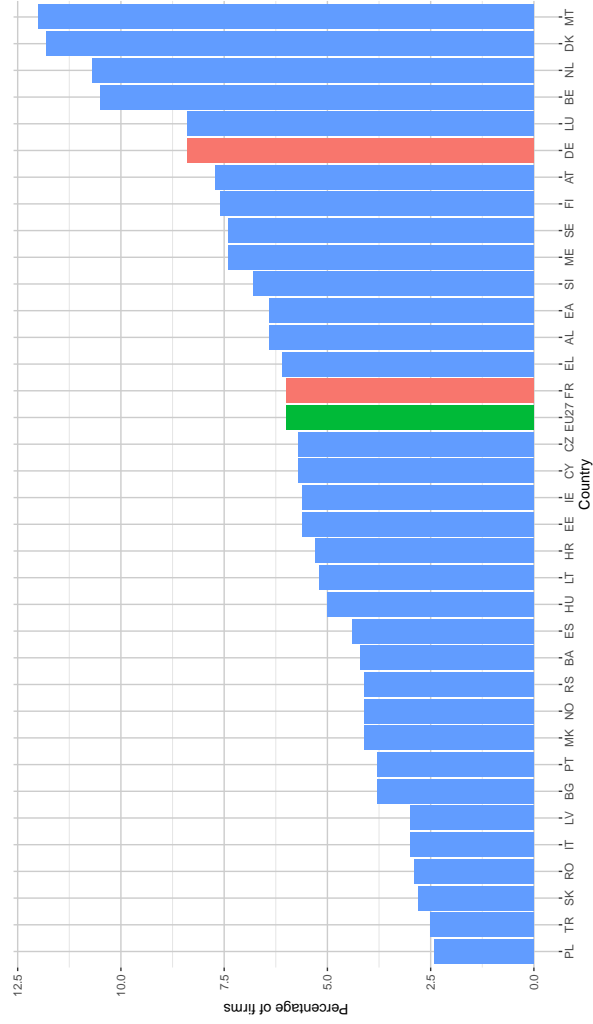


Figure 1: Digital skills shortage across European Union countries in 2022.

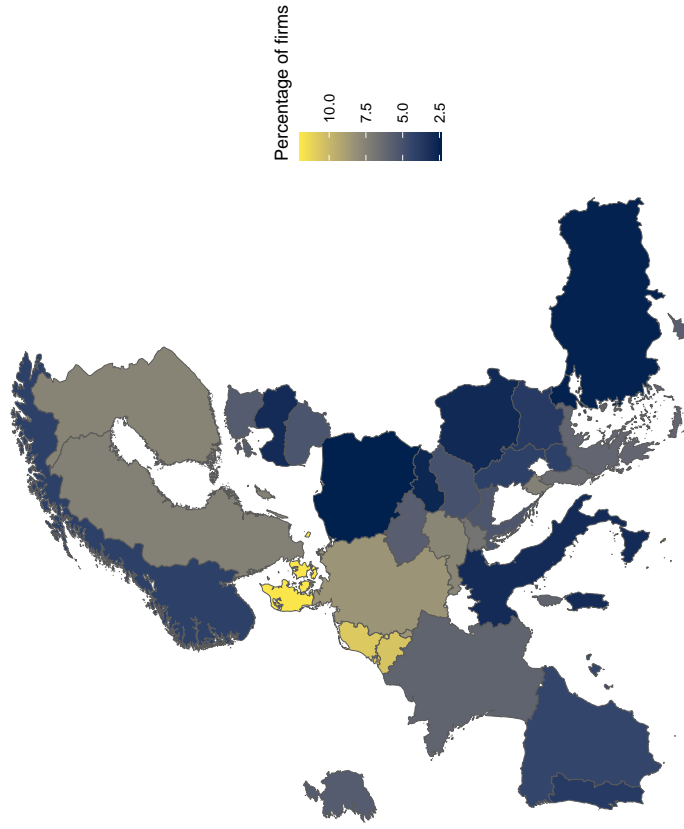


Figure 2: Map of the European countries facing digital skills shortage in 2022.

Beyond and above these cross-country disparities, demand for such skills is stubbornly on the rise over the last decade. The shortage in digital skills supply raises concerns about their potentially limiting impact on industrial development, as illustrated in Figure 3³. Indeed, the development of frontier technologies such as blockchain technology has garnered significant interest from the US and China, which are actively patenting in this field in comparison to the EU (Bergeaud & Verluise, 2022). Furthermore, the emergence of new inventions also leads to the obsolescence of human capital. This seems particularly true for what concerns non-STEM workers, who are being more affected than their STEM counterparts (Aghion et al., 2022). Given the decisive role of the digital transformation in economic growth (Falck et al., 2023), a better understanding of the match between supply and demand for digital skills is deeply needed.

³In the following analyses, the digital sectors comprise the economic sectors “Manufacture of computer, electronic and optical products” (NACE division C26), “Manufacture of electrical equipment” (NACE division C27) and “Information and communication” (NACE section J). The non-digital sectors comprise the economic sectors NACE sections D, E, F, G, H, I, K, M, N, R-S and NACE section C (excluding divisions C26-C27 and C19), see (Falck et al., 2023). To compute the number of firms, we employ an additional Eurostat database corresponding to the Annual enterprise statistics by size class for special aggregates of activities (NACE Rev. 2) [SBS_SC.SCA_R2] last update: 15/03/2023 23:00.

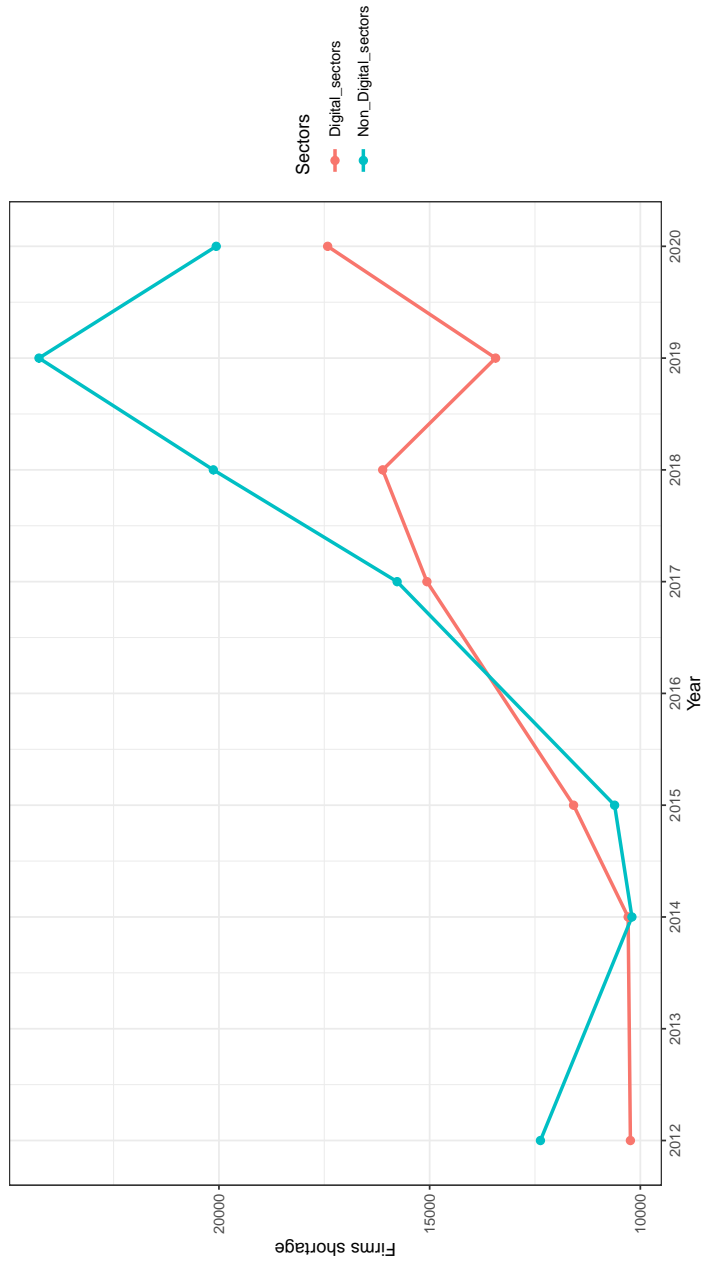


Figure 3: Number of EU firms per sectors facing ICT skills shortage 2012-2020.

Fourth, as any new technology, the economics of the blockchain is lacking exhaustive data. One of the challenges in this thesis has been the constant search for reliable data to analyse the industrial dynamics of this technology. To address this issue, this research implements two complementary methods. First, hand-collected job offers published online, obtaining a representative sample of blockchain's industrial dynamics. Second, web scraping techniques to gather information on blockchain-related application characteristics and blockchain entrepreneurs' profiles. This careful collection of data allows for the development of econometric models in view of generating robust results on which more general implications could be derived. The effort of data gathering is not exempt from usual caveats, and this work remains to be seen as investigating one possible line of research in the vast literature that now develops in the field of the economics of blockchain.

Structure of the dissertation

The rest of this dissertation is structured in three chapters. In Chapter 1, I review the literature to present the different generations of blockchain, starting from the famous Bitcoin to extend it to the context of industry 4.0, delineating different research agendas over time. I then go a step further in the examination of some simple heuristics to better appreciate the potential of blockchain technology. Chapter 2 explores the emergence of blockchain technology and its associated demand across industries through an empirical analysis of job offers from firms based in France and Germany. Chapter 3 provides a complementary understanding of the industrial dynamics of the technology by investigating the practical use of blockchain platforms by entrepreneurs through an empirical analysis of what determines their performance. In an overarching conclusion, I summarize the main findings of the thesis and discuss potential further developments.

Chapter 1 starts with a literature review the objective of which is to trace the evolutionary path of blockchain technology, starting from its conceptual foundations (Bitcoin) to its current frontier of development (the context of Industry 4.0). This exploration goes through the consideration of three generations of blockchains, each representing significant pillars in the technology's evolution. The first generation, characterized by the advent of cryptocurrency applications like Bitcoin ([Nakamoto, 2008](#)), revolutionized digital transactions in a decentralized manner. This disruptive effect makes central authorities redundant, raising research questions about optimal design and the coexistence of multiple equilibria within the blockchain's algorithm. Moving forward, the second generation leads to the widespread utilization of smart contracts, facilitated by platforms like Ethereum ([Buterin et al., 2014](#)). This implies the emergence of flatter organizations and rendered intermediaries obsolete. Finally, the third generation reach a powerful combination of blockchain technology with other Industry 4.0 technologies, such as the Internet of Things (IoT) and Artificial Intelligence (AI). This complementarity promises the automation of routine tasks and even strategic ones, creating new opportunities and challenges for various sectors. While research is progressing, much theoretical groundwork and empirical evidence still lie ahead, and different avenues of research are possible.

Chapter 1 then pursues the objective to disentangle simple heuristics that seem to prevail in the ongoing debate surrounding blockchain's implications. By delving into the controversies and challenges posed by this technology, this contribution aims to shed light on its potential to address contemporary societal and economic issues. The first prior concerns Bitcoin which was created as a tool to challenge government monetary sovereignty, potentially posing a threat to democratic values, I explore how blockchain community can

deal with those ethical concerns (Agerskov et al., 2023). Consistent with the book of Acemoglu and Robinson (2019), blockchain can be considered a digital ‘shackled leviathan’. In contrast to the concentrated power of Big Tech companies, this technology offers the advantage of providing democratic governance features that can benefit society as a whole. However, realizing this promise requires the formulation of adequate rules by regulators. The second prior pertains to one of the most controversial aspects regarding blockchain technology: its impact on climate change. The Bitcoin protocol raises concerns due to the significant energy consumption required for its operation. However, the contribution shows that blockchain technology also offers new and innovative solutions to prevent waste and to fit in with sustainability practices. For instance, I explore some of the possibilities that can be implemented for the supply of renewable energy. The last a priori concerns cybersecurity and the reliance on blockchain properties in the mind of many. Indeed, while the most capitalized blockchains are recognized for their resilience in terms of security using cryptographic techniques, the progress of quantum computing poses a threat to all systems built on cryptography. Of course, blockchain technology does not represent the most important system if we think about the whole internet network or the banking system. Nonetheless, it appears crucial to underly the consequences of advancements in quantum computing and how blockchain technology can mitigate a scenario of obsolescence arising from it.

Overall, this literature review thesis chapter enriches our comprehension of blockchain technology’s past, present, and future challenges, emphasizing an original perspective on its multifaceted implications for society and the economy. Chapter 2 and Chapter 3 explore more in depth the industrial dynamics of blockchain technology, with a specific focus

on the dynamics of skills and their shortage, both in the perspective of firm performance and technology performance.

In Chapter 2 I investigate the rise of blockchain technology across industries and how firms try to integrate it. This analysis focuses on blockchain job offers from companies based in France and Germany. Due to the emergence of this technology, there is a lack of a reliable database, which led me to manually collect online job offers from firms seeking to recruit blockchain-skilled individuals. I categorized these job offers into four different groups: internship, entry-level, experienced, and managerial positions. The counterfactual is constructed with the same emphasis, allowing me to compare different skill profiles, including low skills and high skills. The objective is to understand the Schumpeterian paradigm inherent in this technology and how firms attempt to recruit individuals with blockchain skills. The approach permits to comprehend the technological regimes of blockchain and the potential economic consequences of innovations associated with it (Fontana et al., 2021). Indeed, the European Union emphasizes the significance of blockchain as a Key Enabling Technology (KET), recognizing its synergies with other technological advancements such as AI and IoT. Although the literature recognizes blockchain as a radical innovation integrating existing technologies, there is still some lack of clarity regarding the characteristics of firms and sectors leading to its diffusion. Particularly, as a digital technology, the impacts on the production activities and labour market require identifying the main trends of the diffusion of blockchain. Therefore, the thesis develops an empirical investigation of the specific demand for blockchain-skilled individuals to emphasize the potential disruption of established routines (Acemoglu et al., 2022; Nelson & Winter, 1985). My main result suggests, first, that blockchain profiles

sought to be recruited by firms appear to be highly skilled individuals without any experience. Second, firms interested in recruiting blockchain individuals are mostly incumbents instead of young start-ups. Third, while we could expect banks to be the main recruiters, there is not a dominant industrial sector.

Several implications can be developed from this basis. For instance, blockchain is a disruptive technology in which experienced workers may have few comparative advantages in terms of knowledge over inexperienced workers. It implies questioning to what extent hierarchies must rethink their organizational structure if they want to benefit from the potential of this technology. Indeed, some intermediaries might become possibly obsolete, resulting in more direct interactions and flatter organizations. Last, due to its widespread impact across different industrial sectors and the interests of established and leading firms, it appears that blockchain should be considered a GPT with pervasive implications. In sum, this chapter contributes to a more nuanced comprehension of the adoption of blockchain technology and its disruptive implications across different industrial sectors.

While Chapter 2 seeks to provide an understanding of the industrial dynamics stemming from the integration of blockchain technology, Chapter 3 enlarges the scope by investigating the emergence of blockchain platforms and its implications in terms of innovation from related startups. It is considered that these new peer-to-peer platforms have the potential to generate value added and to introduce new services ([Bacache-Beauvallet & Cagé, 2016](#)).

Chapter 3 is an empirical analysis that explores the practical utilization of complex smart contracts corresponding to Decentralized Applications (DApps). This contribution aims to take part of the existing debates in the literature concerning the complementarity between pillar evolutionary and neo-institutionalist theories ([Williamson, 1999](#); [Winter, 1988](#)) to elucidate the diversity of blockchain-based applications in terms of their diffusion performance ([Ahluwalia et al., 2020](#); [Howell et al., 2020](#)). Data is sourced through web scraping techniques. This data includes information related to smart contracts, such as the intensity of algorithm modifications. Additionally, some information is obtained from blockchain platforms, capturing metrics such as the number of transactions, token values, and smart contract deployment dates. Entrepreneurs' skills and characteristics, educational backgrounds (STEM or non-STEM) and work experience, are obtained from LinkedIn profiles. This merger of datasets allows to harmonize the competences and contractual perspectives thanks to those different variables. The findings of the study suggest that there is a significant influence of entrepreneurs' dynamic capabilities ([Teece, 2007](#); [2012](#)) measured through the development activities, on the successful diffusion of DApp based on blockchain platforms, as indicated by the total volume of transactions executed. Notably, DApps that belong to the open-source category appear to display the most transactions. However, the decision to opt for this open-source characteristic implies costs such as being potentially challenged by competitors, thereby elevating the risk of jeopardizing the entire project's value. Furthermore, it is important to consider that stakeholders are in a better position to monitor the effectiveness of development activity ([Onjewu et al., 2023](#)). This visibility enables a more informed evaluation of investment prospects. Hence, this implies that entrepreneurs need to invest sufficient effort in algorithmic improvements and adapt to platform changes to achieve evolution-

ary fitness. Indeed, this approach seems essential for maintaining and maximizing their Schumpeterian rents (Petit & Teece, 2021). Overall, the implications of dynamic capabilities underline that competition within blockchain ecosystems should be recognized at both platform and application levels. Compared to the current state of the platform industry, blockchain holds the potential to bring redistributive welfare to end-users (Pike, 2020).

Recognizing the potential of blockchain technology, governments can develop effective policies to provide a skilled workforce capable of designing and implementing ethical and intelligent automation in the factories of the future. Assessing this digital evolution is not only essential to harnessing the benefits of Industry 4.0 technologies, but also to ensuring sustainable economic growth and widespread prosperity. The findings of the thesis highlight a particular demand for, and significant impact of, blockchain skills, including widespread adoption of the technology across various sectors. By and large, blockchain technology is a driving force for growth and it is clear as crystal rock.

Chapter 1 - Blockchain:

Literature reviews

1.1 Blockchain as a New Digital Paradigm

Abstract ⁴

This chapter provides a synthesis of the blockchain literature in view of making accessible the main concepts of this technology that are still obscure to many. We study in a pedagogical way the main implications that the different generations of blockchain can have on the analysis of the decentralised coordination modes of agents. We advance that if blockchain has been seen as a disruptive technology since the start, it appears now a general purpose technology as well, which strongly shapes economic implications both in terms of transactions, organizations, and occupations.

Key words : blockchain, cryptography, governance, industry 4.0, innovation, technology

⁴This chapter has been published in Elgar Encyclopedia on the Economics of Knowledge and Innovation (pp. 22-30). Edward Elgar Publishing, 2022.

1.2 Blockchain: antecedents and future challenges

Abstract⁶

Studying the antecedents and future challenges of blockchain is the major goal of this chapter. The contribution examines some of the heuristics that seem to persist in the collective consciousness, especially the ones commonly associated with blockchain as a cryptocurrency, as a potential source of energy/environmental imbalances, and as a tool for cybersecurity. The goal of the chapter is to highlight that these heuristics do not fully capture the complex implications of blockchain, and the technology should be viewed as having a much broader spectrum of implications for economic activity and society. While the disruption of financial institutions by cryptocurrencies and the decentralization of transactions remain prominent in the minds of many observers and commentators, the potential of blockchain technology goes far beyond these features, along with consequences that may be counterintuitive at first glance. This chapter explores the limitations and challenges of blockchain technology, providing a more complete understanding of its potential impact.

Key words : blockchain, cryptography, governance, industry 4.0, innovation, technology

⁶This chapter has been published in Bergé, J.-S. (Ed.), *The A Priori Method in the Social Sciences: A Multidisciplinary Approach* (pp. 131-141). Springer International, 2023.

Chapter 2

Chapter 2 : Blockchain as Schumpeter Mark 1 or Mark 2?

An empirical analysis of blockchain job offers in France and Germany

Abstract¹⁷

This paper investigates whether blockchain technology corresponds to Schumpeter Mark 1 or Schumpeter Mark 2 industrial dynamics. Using an original database of 385 job offers in three different domains, namely, blockchain, biotechnology and storekeeping, posted by 285 companies in France and Germany in early 2019, we explore whether the usual Schumpeter Mark 1 and 2 attributes apply to blockchains. We use ordered multinomial probit models to explain the level of work experience demanded by companies. To our knowledge, this contribution is one among very few attempts to identify the main features of blockchain industrial dynamics.

Key words: blockchain, Schumpeter Mark 1 and Mark 2, innovation, technology, firms, jobs and skills

¹⁷This chapter has been published under the following reference: Cimiterra, M., Krafft, J., & Nesta, L. (2021). Blockchain as Schumpeter Mark 1 or Mark 2? An empirical analysis of blockchain job offers in France and Germany. *Industrial and Corporate Change*, 30(6), 1388-1402.

Chapter 3

Chapter 3 - Decentralized Applications on Blockchain: Exploring Transaction Performance and the Role of Individual Capabilities

Abstract¹⁸

This chapter attempts to understand the implications of blockchain technology through a dynamic transaction cost perspective in view of characterizing the capabilities required for successful diffusion of Decentralized Applications. Using an original database of the profiles of 266 contracting teams of Decentralized Applications based on different blockchains, in 2021, we explore whether the distinct performances of transactions realized through this technology can be explained by the idiosyncratic capabilities embedded by individuals. We use an OLS model to explain the performance in terms of transactions of DApps developed across different blockchains.

Key words: transaction costs; capabilities, blockchains

¹⁸This chapter is an ongoing project co-authored with Professor Arianna Martinelli.

3.1 Introduction

What makes blockchain-based Decentralized Applications (DApps) successful? This question is particularly relevant concerning the 4th industrial revolution, along which blockchain technology has the potential to become the digital backbone of information technology for infrastructure projects and operations. So far, the social sciences literature focuses mainly on the supply and the demand of the technology through a financial perspective ([Halaburda et al., 2022](#)). Bitcoin represents the first blockchain ever established, corresponding to a cryptocurrency. From this basis, several related applications were developed and most of the studies investigate the opportunities and consequences of their emergence corresponding to Tokenomics ([Cong et al., 2021](#)). Indeed, blockchain technology enhances Fintech innovation corresponding to DeFi through cryptocurrencies, initial coin offerings (ICOs) and more broadly tokens ([Cong & Xiao, 2021](#); [Howell et al., 2020](#); [Yermack, 2017](#)). In line with this approach, [Lyandres, Palazzo, and Rabetti \(2022\)](#) adopt a duopolistic model to investigate utility tokens and their impact on price competition. Utility tokens are specific tokens which represent a claim for a service or a product. Their research focuses on comparing the pricing adjustments made by incumbents and entrants in different scenarios at two stage levels, where incumbents can offer their products/services in exchange for either fiat currency or tokens, while entrants compete by entering the market with a utility token.

The field of institutional cryptoeconomics, adopting a neo-institutionalist approach, has been developed to analyze the institutional aspects of blockchain technology ([Ahluwalia et al., 2020](#); [Berg et al., 2019](#); [Davidson et al., 2018](#)), including a dynamic model of institutional innovation ([Allen et al., 2020](#)). However, research on the demand side of

blockchain technology, viewed through the lens of industrial dynamics, remains limited (Cimiterra & Krafft, 2022; Cimiterra et al., 2021). Building upon this existing research, our study aims to investigate the emergence of DApps and the factors influencing their success. Specifically, we examine the entrepreneurial capabilities of DApps founders and their relationship with the observed success of DApps, measured by the number of transactions realized.

While economic research has predominantly focused on the characteristics, features, and potential of blockchain technology itself, the dynamics specific to start-ups utilizing blockchain technology are still nascent and understudied. Furthermore, there is a need to explore the distinctive performance of these start-ups and the factors that drive it (Ahluwalia et al., 2020; Howell et al., 2020). To address this gap, this chapter analyzes how the idiosyncratic characteristics of entrepreneurs influence the success of DApps projects. Given that transactions on a blockchain involve costs, a higher number of observed transactions signifies better performance for the involved entrepreneurs (Donmez & Karaivanov, 2022). Thus, this study focuses on the capabilities of decentralized blockchain-based application founders, assuming that the success of DApps, as reflected in realized transactions, depends on the entrepreneurs' dynamic capabilities in designing algorithms that effectively leverage both the consensus protocol and the incentives of a blockchain, thereby achieving "evolutionary fitness" (Teece, 2007). Furthermore, we posit that successful entrepreneurs possess significant bargaining power in shaping the institutional evolution of blockchain technology, extending their influence beyond individual DApps to impact the broader development and governance of blockchain systems (Allen et al., 2020).

The chapter is structured as follows. Section 2 provides a literature review concerning blockchain and DApps literature, and the dynamic neo-institutionalist framework. Section 3 presents the data and empirical methodology. Section 4 discusses the results and Section 5 concludes the chapter.

3.2 Review of the literature

3.2.1 Blockchain and Decentralized Application

Blockchain technology can be defined as a distributed ledger technology in which the exchanges of information take place without the intervention of a central authority. In this new system, information is stored and sequentially grouped into blocks, distributed among all users, using cryptographic techniques. These characteristics make this technology particularly secure, immutable, transparent. Therefore, digital scarcity (Brekke & Fischer, 2023) is achieved for the first time because the information that can be obtained from this technology is timestamped and unique, which leads some to consider the blockchain as the "trust machine"¹⁹.

Even though blockchain technology has emerged recently, there are already three generations of blockchain. Bitcoin and other related crypto assets can be considered the first generation of blockchain, based on the decentralization of transactions. The second generation corresponds to blockchain platforms (e.g. Ethereum among many others) that enable large scale smart-contracts²⁰ development and use. Finally, the last generation

¹⁹Cf. article from The Economist <https://www.economist.com/leaders/2015/10/31/the-trust-machine>

²⁰A smart-contract can be defined as lines of code putted on and executed by a blockchain, resulting by the decentralization of organization.

enables interoperability between blockchain technology and other industry 4.0 technologies such as the internet of things and artificial intelligence (Cimiterra & Krafft, 2022; 2023).

A decentralized application can be defined as software that is run by a network of peer-to-peer computers instead of a single computer (Wu et al., 2021). While decentralized application per se already existed before blockchain, such as Bittorent, those applications were facing difficulties to provide uniqueness of information especially when thinking about intellectual property rights (Raval, 2016). The second generation of blockchain incorporates a decentralized virtual machine²¹ in its core design. By providing decentralized computing capacity, the second generation of blockchain enables the development of software that runs thanks to these new platforms through smart contract, corresponding to Decentralized Application (DApp for short).

Therefore, for the rest of the chapter, the acronym DApp refers to a complex blockchain-based smart contract, i.e., a software application that operates on a blockchain network to provide decentralized and transparent functionality. Because blockchain technology permits to achieve digital scarcity, each file stored on a blockchain can be considered as unique and capable of fitting into a legal framework. An example of a DApp could be Opensea that represents a marketplace for Non Fungible Tokens²² (NFT for short).

²¹A virtual machine is the dematerialization of a computer system. Virtual machines are based on computer architectures and provide the functionality of a physical computer.

²²An NFT can be defined as a record on a blockchain that is associated with a particular digital or physical asset. While its legal aspect remains unclear at the time of writing, its application to intellectual property rights is of interest to legal institutions (Evans, 2019).

Blockchain-based smart-contracts are often considered as a new form of entrepreneurial financing through Initial Coin Offerings (ICO) that results to growth and higher future employment for start-ups using it (Catalini & Gans, 2018; Howell et al., 2020). However, economic analysis should not focus only on the financial aspect through crypto-assets and ICO that have emerged with blockchain technology, researchers should also look at all other data structures that can be put on a blockchain (Davidson et al., 2018). Indeed, blockchain enables new forms of coordination between agents, as this technology represents an infrastructure that has the potential to be scalable, iterative, replicable, and highly adaptable.

In comparison with applications developed on centralized platform like big techs, several benefits make DApp an attractive option for developers. Firstly, once a smart contract is deployed on the blockchain, it remains available to clients without the risk of censorship. Additionally, the privacy aspect allows users to interact with DApps without revealing their real-world identities, enhancing anonymity. The complete data integrity provided by the blockchain's immutability and cryptographic security ensures that transactions and data cannot be modified by malicious actors. Lastly, the trustless computation and verifiable behaviour of smart contracts eliminate the need to rely on a central authority, allowing for transparent and predictable execution. However, there are drawbacks to DApp development, including maintenance challenges, performance overhead, network congestion, user experience complexities, and the risk of unintentional centralization, which may compromise the advantages of blockchain technology.

Base layer blockchains are more beneficial for users, where network effects do not increase market power through a single intermediary (Frolov, 2021). Notwithstanding, it seems important to stress that the complexity of this technology creates informational asymmetry which implies that end users will rely on different backward layers and developers that could represent gatekeepers in the long run (Makarov & Schoar, 2022). The actual difficulty to regulate the technology can lead to financial instability and fraudulent behaviour is already impacting the industry where malevolent actors abuse the credulity of investors (Cong et al., 2022). Still, the disruption of the platform industry is likely to be important bringing new forms of collaborative interaction (Onjewu et al., 2023; Pazaitis et al., 2017). From a technological perspective, blockchain technology can be associated with different technologies like Internet of Things (Bakos & Halaburda, 2021) and can help in the development of more democratized AI (Montes & Goertzel, 2019). It also has the potential to bring competition to the digital sector that seems difficult to regulate although desirable (Catalini & Kominers, 2022; Lyandres et al., 2022; Petit & Teece, 2021; Pike, 2020). Thus, blockchain technology leads to the disruption of the intermediation relationship with Big Techs avoiding the excess of controlling authority, enabling higher organizational performance coming from the balance between decentralized coordination and centralized authority (Berg et al., 2019; Catalini & Gans, 2020; Cong & He, 2019; Dosi & Marengo, 2015; Reijers et al., 2016).

Since blockchain technology is still in its infancy, there are a wide variety of blockchains platforms competing and due to its dynamic nature, there is not yet a dominant design that prevails (Arthur, 1989). For instance, the Ethereum blockchain changed its governance protocol recently even though it corresponds to the second most capitalised

blockchain. Yet we observe a new wave of digital applications developing because of the emergence of this new technology, corresponding to the entry phase of the DApps industry life cycle (Klepper, 1997).

3.2.2 Dynamic neo-institutionalist theory

Numerous surveys explore the contractual and competences perspectives as theoretical approaches to understanding the economics of organizations (Dosi & Marengo, 2000; Foss, 1993; Hodgson, 1998; Langlois, 1992; Montresor, 2004; Nooteboom, 2004; Williamson, 1999; Winter, 1988). While transaction cost economics and evolutionary economics share the assumption of bounded rationality, they differ in focus, with the former emphasizing transactions and the latter emphasizing production (1988). Transaction cost economics models examine notion of equilibrium, while evolutionary economics considers dynamic coordination through routines, capabilities, tacit knowledge, and path dependence (Dosi et al., 2019).

The competences perspective highlights the role of learning and path dependency in understanding firm boundaries in the long run, as routines become established and adjustments become smaller (Winter, 1988). Transaction costs shape economic organizations by facilitating organizational innovations and overcoming previous transactional difficulties, while the specificity of human assets remains crucial (Winter, (1988)); (Hodgson, 1998). Firm boundaries are determined by the trade-off between internal competences embedded in individuals and external capabilities available through contracts. If the firm

has the right capabilities at the right time, vertical integration can occur, but its expansion is limited by the cognitive scarcity regarding his intrinsic problem-solving activities (Langlois, 1992).

Blockchain technology, belonging to the domain of complete contracts, introduces a spontaneous governance structure but relies on highly skilled developers for technical decisions (Davidson et al., 2018; De Filippi & Loveluck, 2016; Makarov & Schoar, 2022). While blockchain protocols are open source that can be interpreted as “recipes” (Dosi & Grazzi, 2010) accessible to all, their mastery remains limited to a few experts (Walch, 2019).

The governance by the infrastructure (i.e. via the blockchain protocol), is well in line with the contractual perspectives. But to understand the industrial dynamics of blockchain, it is important to consider the governance of the infrastructure and the divergent distributions of knowledge among stakeholders which is characterized by perpetual improvements, consensus among stakeholders, and frequent crises (Walch, (2019)).

The emergence of blockchain technology, accompanied by the advancement of smart contracts, has captured the attention of researchers investigating this technological transformation and its impact on agent interaction (Berg et al., 2019; Brzustowski et al., 2023; Onjewu et al., 2023). Smart contracts reduce the need for intermediaries, lower transaction costs, and align with an optimal contracts approach (Allen et al., 2020). However, the reliance on optimality in transaction cost economics or in equilibrium may limit the ability to explain empirical variance in corporate performance (Dosi & Marengo, 2000).

For instance, [Lyandres, Palazzo, and Rabetti \(2022\)](#) simplify their model concerning utility token by assuming constant marginal costs of production, while [Allen, Berg, Markey-Towler, Novak, and Potts \(2020\)](#) assume constant transaction costs for all contracts on a specific blockchain base-layer. However, these assumptions contradict the nature of our case study, which aims to evaluate Dapp performance based on the skills of their developers. Therefore, it appears crucial to consider the heterogeneity of costs of production and transactions in order to understand how the capabilities of the developer team impact performance.

In sum, by looking at the characteristics of the user-base of smart contracts platforms it highlights the externality of the network effect due to their participation. Figure 5 shows our main assumptions about the capabilities requirements for performance of blockchain based Decentralized Application. We assume that the success of DApps depends on the dynamic capabilities of entrepreneurs to design in a timely manner an algorithm ([Teece, 2007](#)). The idiosyncratic skills of founders of blockchain-based smart-contracts allow them to leverage this new form of evolutive platform ([De Filippi & Loveluck, 2016](#); [Dosi & Marengo, 2015](#); [Six et al., 2022](#)). We therefore consider that to better address the global scope of the implications of blockchain technology on economic organizations, the "dynamic neo-institutionalist" theoretical framework represents an adequate perspective ([Foss, 1993](#)).

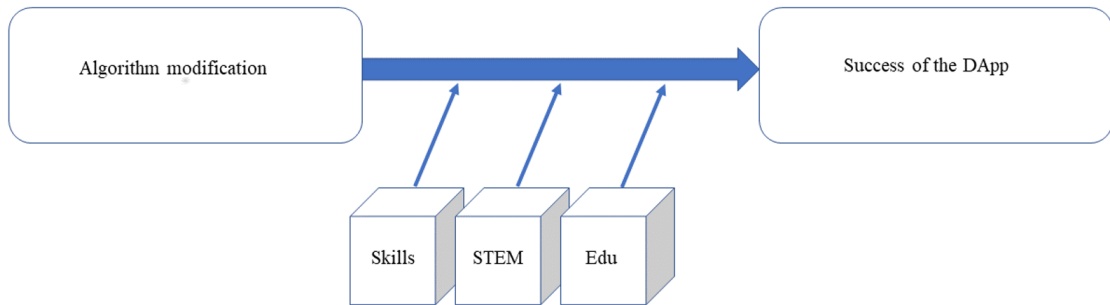


Figure 5 Capabilities requirement for performance of blockchain based decentralized Applications.

3.3 Data and Methodology

3.3.1 Context of the analysis and data collection

The Ethereum blockchain is the primary platform for developing decentralized applications (DApps). It falls under the category of permissionless blockchains, similar to Bitcoin. At the time of data collection, Ethereum’s protocol used Proof-of-Work, just like Bitcoin. This means that miners, who act as validators in the system, need to solve complex equations that require significant computational capacity and energy consumption to validate and record transactions in new blocks. To incentivize validators to perform this task, each block added to the Ethereum blockchain rewards them with a fixed amount of ether, the native cryptocurrency of this blockchain. Unlike Bitcoin, ether is not primarily intended as an alternative to fiat currencies. Instead, it can be used to purchase computing power on the Ethereum network. To make a transaction on the

Ethereum blockchain, users need to pay a certain amount of gas, which corresponds to the transaction fee. Gas can be purchased using ether. If there is a high level of network activity and limited capacity for transactions, users may choose to pay a higher fee to prioritize their transactions. As a result, transaction costs can vary based on network activity and user preferences. The incentive structure in Ethereum follows an auction model, where users have an incentive to pay higher fees to transact, and validators select blocks with the most rewards. Ethereum uses a coding language called Solidity, which is specific to the platform and facilitates the development of smart contracts and DApps. It's worth noting that while other blockchains may have similar and different characteristics compared to Ethereum, they have been less successful as of the time of writing, and therefore, we won't go into detail about them in this description. Overall, [Allen, Berg, Markey-Towler, Novak, and Potts \(2020\)](#) resume the pool of blockchains as “*a population of diverse institutional systems I*”.

To investigate how entrepreneurs' capabilities affects the success of DApps projects developed in Ethereum and other blockchain based layer competitors, we construct an original database using different sources. First, we retrieve data on DApps project and performance that were collected using web-scraping techniques from the two main websites²³ referencing this new ecosystem ([Wu et al., 2021](#)). After combining the two data sources we obtain a sample of 614 unique DApps. We retrieve data about the DApps founders scraping LinkedIn²⁴ which allows collecting personal data about their education

²³Data were collected from www.statesofthedapps.com and www.dappt.io during 08/2021.

²⁴After identification of the founders, data were collected from LinkedIn during 01/2022.

and past work experience among other things. The final dataset includes a total of 266 DApps²⁵.

3.3.2 Econometric models and dependent variables

As we aim to examine how DApps founders' capabilities affects DApps success, our dependent variable is the `TOTAL_TRANSACTION`²⁶ realised by a blockchain-based decentralized application. To be more precise, it corresponds to the invocation of the smart contract(s) related to the DApp.

To tackle our research question, we estimate the following model:

$$TOTAL_TRANSACTION_i = \alpha + \beta_1 ALGORITHM_MODIFICATION_i + \beta_2 OPEN_SOURCE_i + \beta_E \mathbf{E}_i + \beta_X \mathbf{X}_i + \epsilon_i$$

Where i indicates the DApp, `TOTAL_TRANSACTION` is the dependent variable measuring the DApp diffusion performance, `ALGORITHM_MODIFICATION` is the variable of interest capturing dynamic capabilities, `OPEN_SOURCE` is a dummy variable equal to one if the DApp algorithm is visible and zero otherwise. Vector \mathbf{E}_i includes the variables related to the teams' capabilities. \mathbf{X}_i is the vector of controls at DApp level. Explanatory variables are described in detail in the next section.

²⁵The final dataset includes less DApps because for some DApps we were unable to clearly identify the founders, whether they voluntarily anonymized their identity or the project was not sufficiently described.

²⁶As precised by www.dappt.io, "*The amount of transaction represents the numbers of actions between users and dapps that involved smart contract interactions.*"

To analyze the relationship between our dependent variable, `TOTAL_TRANSACTION`, and the explanatory variables, we employ a logarithmic transformation in our regression analysis. This transformation helps to address the issue of non-linearity and skewness of our sample.

Figure 6 illustrates the distribution of our transformed variable, which exhibits a strong resemblance to a normal distribution. Nevertheless, we do observe a slight inflation of zero values. This inflation arises because we assign a value of zero to the true zeros that initially approached negative infinity following the log transformation. By making this adjustment, we are able to consider the unique characteristics of our dataset. However, from a theoretical standpoint, it is worth considering whether DApps that exhibit zero transaction truly hold significance in our study since we are interested about transaction costs at the DApp level, not coordination cost which belong to the institutional system ([Allen et al., 2020](#)).

To determine the coefficients, we employ ordinary least squares (OLS) regression, which offers efficient and unbiased estimates of the relationship between the dependent and explanatory variables. By utilizing OLS, we can identify the factors that impact the value of `TOTAL_TRANSACTION`, allowing us to draw conclusions about the underlying economic dynamics. Furthermore, we opt to utilize OLS with zero truncated data as part of our methodology.

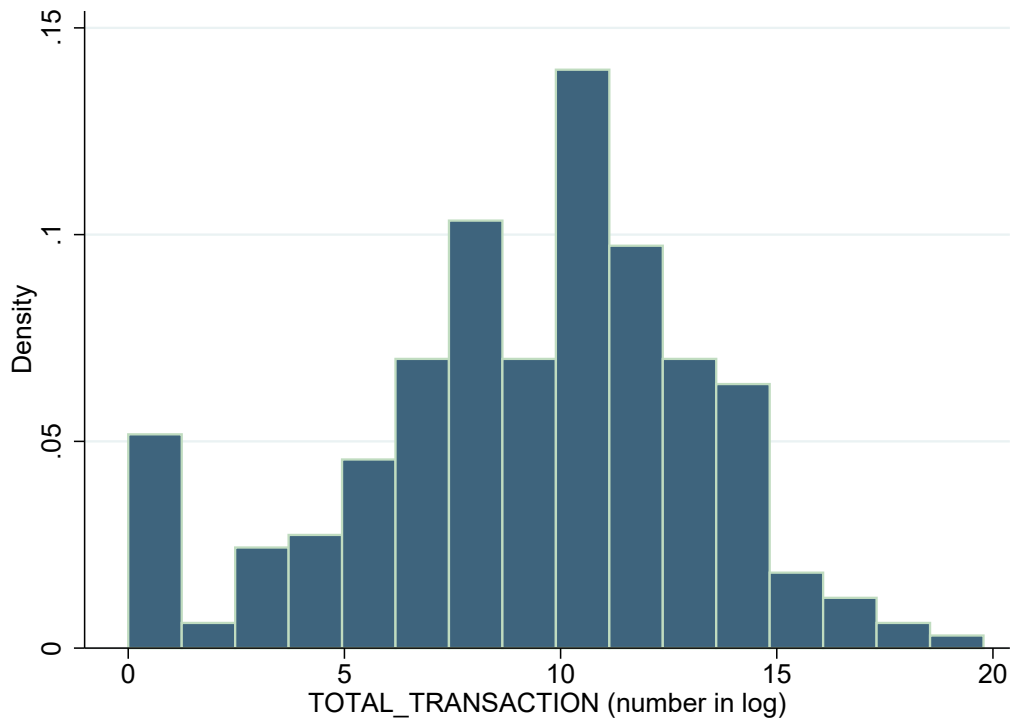


Figure 6 Histogram of the dependent variable.

3.3.3 Explanatory variables

Table 10 presents the list of the dependent variables and how they are operationalized. Table 11 reports summary statistics for the variables; while the correlations are presented in the Appendix (see Table 16).

The variables of interest correspond to the capabilities of the team of founders. The variable ALGORITHM_MODIFICATION is a continuous variable of development activity observation that occurred in the last three months. In the context of software

development, "code pushes" refer to the act of uploading or "pushing" new or modified code to a code repository, such as a Git repository. A code repository is a place where software developers can store, share, and collaborate on code. "Issues" are typically used to track tasks, enhancements, and bugs related to a software project. An issue can be created by any member of the development team, and it typically includes a description of the problem or task, as well as any relevant details or comments. "Pull requests" are a way for developers to request that their code changes be merged into the main codebase of a project. A pull request typically includes a description of the changes being proposed, as well as any relevant comments or discussion. Other members of the development team can review the pull request, make comments, and ultimately decide whether or not to accept the changes. Overall, development activity refers to various actions and processes that are commonly used in software development to manage and collaborate on code. As defined by Teece (2012), dynamic capabilities represent the ability to make critical decisions that are made by a few decisive individuals early in a project in a rapidly changing environment. Algorithm changes are accompanied by critical decisions representing the essence of dynamic capabilities. Therefore, we assume that this variable captures a decisive interaction between top managers in a dynamic context since the changes were made recently (during last 3 months) at the time of the database collection.

The variable OPEN_SOURCE is a dummy variable equal to one if the code of the DApps is accessible through code repository website such like github. As emphasized by Howell, Niessner, and Yermack (2020), the fact that the code of the algorithm is transparent has a positive effect in terms of recruitment and success of an ICO. Here we consider that it implies both confidence and more competition for the teams that display

Table 10: Summary of variables of interest and their sources.

	Measure	Concept	Source
Dependent variable: <i>TOTAL_TRANSACTION</i>	Number of transactions	DApp success; occurrence of the transformation of the state of a blockchain (Allen et al., 2020).	Dappt.io
Explanatory and control variables: ALGORITHM_MODIFICATION	The intensity of observable algorithm modifications of the Dapp	Presence of dynamic capabilities (Teece, 2007; 2012); optimizing the transaction costs (Allen et al., 2020).	Stateofthedapps
OPEN_SOURCE	Dummy equal to 1 if the code is transparent and accessible to anyone	The effect of showing the code to users and competitors (Goldfarb & Tucker, 2019; Howell et al., 2020; Makarov & Schoar, 2022).	Stateofthedapps
TEAM_EXP	Experience of the team	Work experience of the team for the development of a blockchain project (Cimiterra et al., 2021).	Crunchbase, LinkedIn
STEM_CAP	Dummy equal to 1 if the field of study of at least one of the team members corresponds to STEM and zero for other fields	Measure of a peculiar knowledge (Winter, 1988).	Crunchbase, LinkedIn
AGE	Time in month after the deployment of the smart contract	The effect of time (Langlois, 1992).	Dappt.io
MARKET_CAP	Dummy equal to 1 if the DApp is based on a utility token	Effect of tokenizing the service (Ahluwalia et al., 2020; Cong et al., 2021; Lyandres et al., 2022).	Dappt.io
INSTITUTION	Dummy equal to 1 if the DApp is develop on a specific blockchain, and zero for other blockchains	The institutional system of governance subject to the contracting behaviour between users and developers (Allen et al., 2020).	Stateofthedapps, Dappt.io
INDUSTRY	Dummy equal to 1 if the DApp belongs to an industry, and zero for other industries	Effect of developing a DApp in a specific sector (Teece et al., 1994).	Dappt.io

Table 11: Summary statistics of the variables used in the econometric exercise.

	Obs	Mean	S-D	Min	Max
<i>TOTAL_TRANSACTION</i>	266	2353121	2.43e+07	0	3.90e+08
ALGORITHM_MODIFICATION	266	440.5865	2075.659	0	26396
OPEN_SOURCE	266	0.33	0.47	0	1
STEM_CAP	266	0.74	0.44	0	1
TEAM_EXP	266	2.75	0.65	0.41	4.37
AGE	266	30.16	12.88	1.32	72.60
MARKET_CAP	266	0.18	0.38	0	1

Obs: number of Decentralized Applications; S-D: Standard Deviation; Min: Minimum; Max: Maximum; M: Million; B: Billion.

Note: These 266 DApps are for 12 blockchains. 205 DApps come from Ethereum blockchain and 61 DApps come from other blockchains: EOSIO, Hive, ICON, Klaytn, Loom, Neo, POA, Polygon, Steem, TRON, Zilliqa.

and make accessible their codes. Indeed, it represents a way to signal themselves to other firms that may be interested to recruit high skilled profiles ([Goldfarb & Tucker, 2019](#)). It also represents competition because of the ease of access to the core code of the algorithm that might be used against the own creators as explained by [Makarov and Schoar \(2022\)](#) with the case of Uniswap against SushiSwap.

Vector E_i includes variables related to founders' capabilities captured by his/her education. First, we have a dummy variable capturing the field of education. STEM_CAP is a dummy variable equal to one if at least one founder has a diploma in Science, Technology, Engineering and Mathematics (STEM) and zero otherwise. Second, the variable TEAM_EXP capture the average job experience of the team and it is calculated as the number of years after the degree of each team divided it by the total number of members.

We linearize the variable using the logarithm to remove collinearity with the variable LN_TEAM_SIZE.

Finally, vector \mathbf{X}_i includes some control variables related to the DApp. First, we control for the AGE of the DApp to check whether the effect of time is an important factor to consider in terms of success. We include the variable MARKET_CAP, a dummy variable concerning whether the use of the DApp implies owning some crypto-assets. This type of crypto asset refers to utility token. It is important to note that not all DApps use utility tokens, and some DApps may use other types of tokens or may not use tokens at all. For example, a DApp that is built on top of a blockchain might use a cryptocurrency that is designed to be used as a medium of exchange, such as bitcoin or ether, rather than a utility token. Finally, we include a complete vector at the INSTITUTION level and an INDUSTRY vector to control the effect of institutional governance and the industry characteristics. To account for the different institutional systems and their specific protocol use, which result in distinct transaction costs, we incorporate INSTITUTION fixed effects.

3.4 Econometric results

3.4.1 Descriptive results

Table 12 presents the DApps industrial applications where we observe heterogeneity across sectors and institutions. Ethereum has the larger share (77%) of DApps covering different sectors. The larger number of DApps are developed in the game sector (83), followed by Finance (39) and Social (36). The average age of DApps across the sample is 2.50 years (30 months), indicating rather young projects. Concerning the total number of

transactions across the sectors, we observe that Games (5.7 million), Social (2.5 million) and Exchanges (1 million) are the most successful. Concerning the average size of teams (1.92), we observe that DApps are led by small groups of decisive individuals.

Table 13 shows the number of DApps developed by the different institutional systems indicating that Ethereum is the most successful blockchain (206). This blockchain is also the one where there are the most complex DApps with those that are open source (73) and those that have an utility token design (44).

In terms of founder capabilities, Table 14 reveals that STEM (196) emerges as the predominant profile. When it comes to educational qualifications, bachelor's (165) and master's (100) degrees appear to be more widespread compared to PhD (16), which aligns with societal trends. In relation to the entrepreneurs' experience, Ethereum stands out as the blockchain where they possess the highest average experience (33.24 years), while the overall sample's average experience corresponds to 32.95 years.

Table 12: Sectoral decomposition of key variables

Sector	N	Ethereum	INSTITUTION	Age	Tx	S.
Exch.	24	19	5	36	1050356	2.26
Finance	39	35	4	22	329232	2.17
Games	83	65	22	29	5698355	1.87
Market pl.	24	23	2	28	327524	2
Social	36	17	19	33	2466608	1.88
Others	60	46	16	34	304330	1.80
Mean (total)	(266)	(206)	(68)	30	2353121	1.92
F-test		5.78	4.90	5.94	0.50	2.47
R^2		0.10	0.09	0.10	0.01	0.05

N: number of Decentralized Applications, some of these DApps are cross-chain meaning that the project is developed on different blockchains; Ethereum: share of DApps developed through Ethereum; INSTITUTIONS: share of DApps developed through other blockchains; Age: average age of DApps; Tx: total transactions of each sectors; S.: average size of teams.
 Exch.: Exchanges
 Market pl.: Market places
 Others: Other industries namely Development, Energy, Gambling, Governance, Health, Identity, Insurance, Marlet place, Media, Property, Security, Storage and Wallet.
 INSTITUTION: Other blockchains namely EOSIO, Hive, ICON, Klaytn, Loom, Neo, POA, Polygon, Steem, TRON, Zilliqa.

Table 13: Blockchain decomposition of related variables

INSTITUTION	DApp	Tx	Algorithm Modification	Utility token	Cross-chain
Ethereum	206	$6.36e + 07$	73	44	7
Others	38	$5.62e + 08$	15	3	2

Others: other blockchains namely: EOSIO, Hive, ICON, Klaytn, Loom, Neo, OST, POA, Steem, TRON, xDai.
 Tx: total transactions.

Table 14: Cross tabulation of blockchain with entrepreneurs' characteristics

INSTITUTION	STEM	BACHELOR	MASTER	PhD	Average Experience
Ethereum	154	126	83	9	33.24
Others	42	39	17	7	32.04
TOTAL (mean)	196	165	100	16	(32.95)

Others: other INSTITUTION namely: EOSIO, Hive, ICON, Klaytn, Loom, Neo, OST, POA, Steem, TRON, xDai.

3.4.2 Econometric results

Table 15 reports the results of the OLS models. The variable LN_AM²⁷, that we assume is corresponding to the dynamic capabilities of the team, is positive and significant at the 1% level. Here the interpretation is that a 1% increase of the observed number of modification of the DApp algorithm would lead to 0.50% increase of transactions. The LN_AM variable appears to fit well with the notion of dynamic capabilities, this tends to show that individuals with those characteristics are the most likely to adapt and shape a changing environment (Teece, 2007). The variable OPEN_SOURCE is negative and significant at the 10% level. When the core code of the decentralized application is visible and accessible by anyone, the total number of transactions is 302% lower in comparison with other applications.

²⁷LN_AM corresponds to observed frequency of algorithm modification.

Figure 7 illustrates how the performance of OPEN_SOURCE DApps is linked to the extent of dynamic capabilities integrated by their teams via LN_AM. This analysis enables us to understand the factors driving the adoption of open source DApps. The graph suggests that DApp teams that engage in algorithm modifications with an intensity surpassing a threshold ranging from 2 to 4 tend to attain greater transaction volumes in comparison to their counterparts.

This suggests that there is a cost associated with having an open source DApp, likely due to the risk of competitors capitalizing on their work (Makarov & Schoar, 2022), as well as the increased monitoring from users and investors (Onjewu et al., 2023). If these stakeholders are not satisfied with the team's performance, they are less inclined to engage and utilize the service. Conversely, teams that prioritize extensive implications in their algorithm design appear to maximize their Schumpeterian rents (Petit & Teece, 2021).

The variable TEAM_EXP is negative at the 1% level of significance. When the experience in terms of months increases by 1%, the expected total of transactions decreases of 0.68%. While the negative impact of this variable may seem surprising at a first glance, these results are in line with the findings of Cimiterra, Krafft, and Nesta (2021), who show that leading firms seeking to recruit blockchain skill profiles tend to be looking for inexperienced but highly qualified profiles. Finding that experienced teams have less transactions than inexperienced ones seems to corroborate the fact that blockchain is a radical technology where new routines need to be developed for successful projects (Six et al., 2022).

The variable STEM_CAP is positive and significant at 1% level. DApp projects that are developed with at least one team member with a degree in STEM have an expected number of transactions which is 214% higher than for other DApps. The variable AGE is positive and significant at 1% level. When the level of month increases by one, it is associated with 0.04% increase in the expected total number of transactions. It seems logical with our approach that the first movers display more transactions.

The variable MARKET_CAP shows a positive value at the 1% significance level. Consequently, DApps utilizing utility tokens in their design exhibit a higher number of transactions compared to other DApps, indicating an increase of 883% in transaction volume. This aligns with [Cong, Tang, Wang, and Zhao \(2023\)](#) findings, demonstrating the growing share of token transactions on the Ethereum blockchain. Although the technical requirements to design a utility token is not considered significant, this result suggests that the greater the complementarity between a DApp and the market, as reflected in the price adjustments facilitated by tokenizing the service, the more transactions occur. This observation appears consistent with the model proposed by [Lyandres, Palazzo, and Rabetti \(2022\)](#).

To check the sensitivity of our analysis to the econometric model choice, we perform the same analysis using a Tobit. All the main results hold.

3.5 Discussion and conclusions

In conclusion, blockchain technology is currently undergoing an intense evolution phase at both the platform and application levels. This evolution brings potential for interoperability with other industry 4.0 technologies. However, the absence of a standardized framework for entrepreneurs to build algorithms with certainty creates a need for dynamic capabilities in this crucial stage. The second generation of blockchain, where smart contracts are widely used, highlights the significance of the complementarity between suppliers and complementors.

This study on blockchain-based decentralized applications aims to identify the capabilities necessary for success in this emerging industry. While many assume that autonomous decision-making is inherent at both the institutional system and DApp levels, our findings suggest that human intervention plays a crucial role. We specifically explore the extent to which dynamic capabilities contribute to the diffusion of blockchain technology.

From a theoretical perspective, our approach has significant implications as it empirically reconciles contractual and competences perspectives. To our knowledge this study represents one of the few attempts to empirically underly the complementarity between these two theories. The transparency provided by blockchain technology facilitates our findings. Additionally, while [Allen, Berg, Markey-Towler, Novak, and Potts \(2020\)](#) are focusing theoretically on the institutional evolution of blockchain, our study aims to understand the idiosyncratic characteristics of those shaping the technology's evolution.

Blockchain technology presents challenges, including concerns about collusive behaviour among service providers and potential disruptions to antitrust policies (Cong & He, 2019; Schrepel, 2021). However, it also brings benefits to society through the welfare redistribution achieved by adopting open-source feature (Goldfarb & Tucker, 2019) and by tokenizing the service (Lyandres et al., 2022). The dynamic capabilities approach can provide further insights into competition within the blockchain industry, particularly for firms seeking Schumpeterian rents (Petit & Teece, 2021).

The adoption of a new consensus protocol by Ethereum introduces turbulence but also an opportunity for scalability and reduced energy consumption (De Vries, 2022; Saleh, 2021). Replicating the approach used in this chapter could shed light on the potential increase in competition within institutional technologies resulting from this change.

We humbly acknowledge that this study has its limitations, particularly in terms of its cross-sectional nature, which restricts a comprehensive understanding of the dynamic changes and evolution in the blockchain industry over time. However, by examining the interactions between different actors, capabilities, and technologies, we can gain some understanding of the industrial dynamics of blockchain technology. While our study may not capture the complete picture, it is our hope that these findings can contribute to future research and assist entrepreneurs, policymakers, and industry participants in their exploration of blockchain technology.

Table 15: Regression results

Variables	OLS	OLS Zero-truncated	Tobit
	DV: LN_TOTAL_TRANSACTION		
LN_ALGORITHM_MODIFICATION	0.527*** (0.050)	0.503*** (0.059)	0.531*** (0.049)
OPEN_SOURCE	-1.949** (0.630)	-1.585* (0.621)	-1.998*** (0.629)
STEM_CAP	1.383** (0.476)	1.150*** (0.111)	1.403*** (0.507)
TEAM_EXP	-0.859** (0.212)	-0.682** (0.158)	-0.897*** (0.231)
AGE	0.0498*** (0.006)	0.0358*** (0.004)	0.0524*** (0.007)
MARKET_CAP	2.477*** (0.481)	2.290*** (0.091)	2.531*** (0.494)
Observations	266	251	266
R^2	0.337	0.402	
INSTITUTION FE	YES	YES	YES

Note: Errors clustered at INSTITUTION level in parentheses.
The set of unreported control variables pertains to INSTITUTION and INDUSTRY.
Significance levels: *** $P < 0.01$, ** $P < 0.05$, * $P < 0.1$.

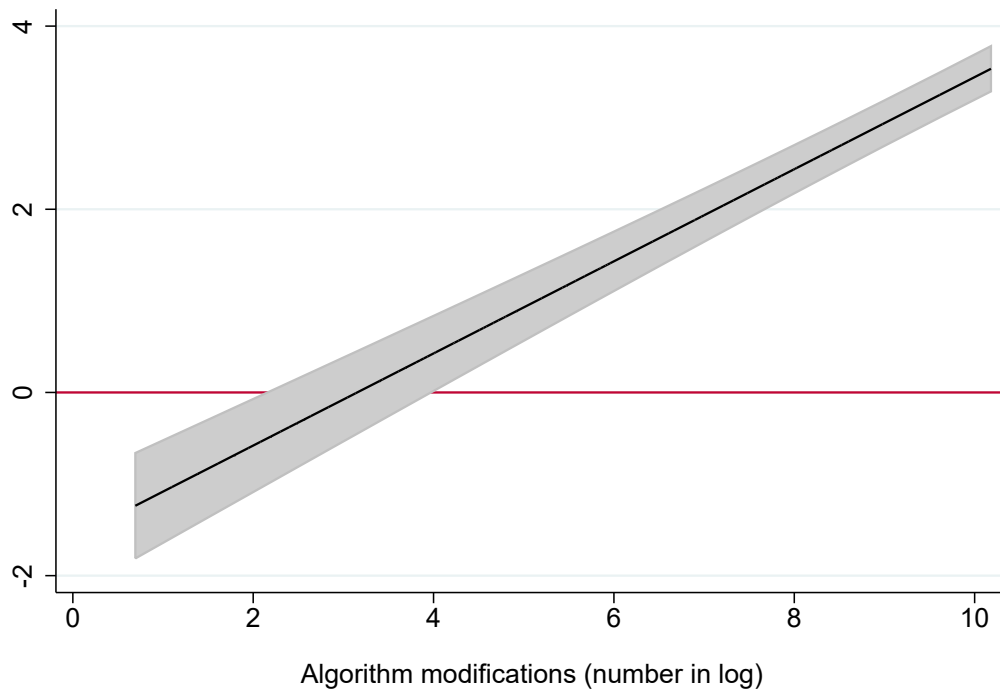


Figure 7 Linear prediction on the number of transaction (log) of algorithm modification (log) including the negative effect of the dummy variable open-source set to 1 if there is observable modification of the algorithm, 0 otherwise.

3.6 Appendix

Table 16: Matrix of correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
TOTAL_TRANSACTION	1.000								
ALGORITHM_MODIFICATION	-0.009	1.000							
OPEN_SOURCE	0.111	0.302	1.000						
STEM_CAP	0.044	-0.046	-0.033	1.000					
TEAM_EXP	-0.033	-0.059	-0.072	0.021	1.000				
AGE	0.020	0.218	0.200	-0.015	0.079	1.000			
MARKET_CAP	-0.026	0.329	0.345	-0.081	-0.081	0.067	1.000		
INSTITUTION	0.078	-0.011	-0.065	-0.106	-0.106	-0.022	-0.105	1.000	
INDUSTRY	-0.039	0.110	0.016	0.008	0.0008	0.177	-0.061	0.076	1.000

General Conclusion

General Conclusion

Review of the research findings

This thesis investigates the economics of blockchain technology through three chapters, with a focus on industrial dynamics and skills requirements in the age of Industry 4.0. It begins by conducting a comprehensive literature review for academics in social sciences on the topic of blockchain, in view of establishing an accessible understanding, covering its evolution and main challenges. Subsequently, I examine the industrial dynamics surrounding blockchain technology through an empirical analysis of blockchain job offers in France and Germany, aiming to gain deeper insights into the profiles that firms are seeking. Finally, I empirically analyse the success of blockchain technology applications in terms of their diffusion, with an emphasis on the impact of entrepreneurs' skills in explaining distinct performance outcomes.

Evolution and challenges of Blockchain Technology

In Chapter 1, I conduct a literature review of blockchain technology to enhance the understanding of its socio-economic implications. I investigate in a first step the evolution of blockchain technology through three generations. The first generation of blockchain corresponds to the decentralization of transaction and the disruption of traditional financial institutions. The technology provides a digital infrastructure allowing secure and transparent peer-to-peer transactions without the need for intermediaries. It occurs with the advent of cryptocurrencies, with Bitcoin leading the way. The second generation of blockchain technology relates to the emergence of blockchain platforms such as Ethereum. The deployment of smart contracts at a large scale represents the core feature of this evolution where self-executing conditions implies the potential to automate various processes reshaping organizations into flatter and more efficient structures. These new digital platforms compete with big techs and foster innovation across industries. The third generation of blockchain technology integrates Industry 4.0 technologies. This last generation emphasizes the synergy between blockchain, artificial intelligence, the Internet of Things (IoT), and other breakthrough technologies. It envisions blockchain as a General-Purpose Technology, potentially removing routines tasks but also more strategic ones.

While blockchain technology evolves rapidly, it presents different challenges. In a second step, I shed light on three significant issues demanding policymakers' attention.

Firstly, the disruptive potential of cryptocurrencies in relation to monetary sovereignty has prompted central banks to explore the development of Central Bank Digital Curren-

cies (CBDCs). However, this objective must be balanced with concerns about democratic values and individual privacy, ensuring that technological innovation does not come at the expense of fundamental rights. Secondly, the energy-intensive nature of the proof-of-work (PoW) consensus protocol, as designed in blockchains like Bitcoin, has raised sustainability concerns. This necessitates a shift towards more environmentally friendly consensus mechanisms, such as proof-of-stake (PoS), and an increased focus on transparency within supply chains, aligning with Sustainable Development Goals. Finally, the assumed robustness of blockchain technology in terms of cybersecurity faces a potential threat from quantum computing advancements. To ensure long-term security, the integration of post-quantum cryptography into blockchain protocols is determinant. Policymakers have a role in supporting research, education, and standardization efforts to address these complex challenges effectively.

Industrial Dynamics of Blockchain

In chapter 2, I apply the Schumpeter Mark 1 and Mark 2 analytical framework to investigate the industrial dynamics of blockchain technology, examining the demand for skills among firms based in France and Germany.

In this study, on the basis of a unique database, I compare the recruitment characteristics and skill requirements of different sectors: blockchain technology, biotechnology (high-tech), and storekeeping (low-tech). The empirical findings suggest that while blockchain shares some characteristics with a Schumpeter Mark 1 model, it cannot be strictly categorized within this framework. A peculiar aspect of blockchain recruitment is the preference for highly skilled individuals with limited professional experience. This

preference implies that blockchain skills differ from those required in other domains, whether high-tech or low-tech. But the firms who are seeking blockchain experts tend to be incumbents rather than startups, aligning more closely with the Schumpeter Mark 2 model in this specific dimension. Furthermore, I show that blockchain recruitment extends beyond the financial sector, encompassing a broader scope of industries than the fintech innovation commonly attributed to the technology. Finally, this analysis shows differences between France and Germany in terms of industries seeking blockchain skills, along with distinct spatial distributions that appear to be coherent with the industrial structure of each country. More precisely, France demonstrates a higher degree of concentration in blockchain recruitments that are mostly located in Paris, compared to Germany, which is more decentralized.

The main results of this study indicate that blockchain is not a niche innovation and should, therefore, be rather considered both as a General-Purpose Technology and a Key Enabling Technology with pervasive effects. The peculiar demand of firms for blockchain technology suggests the need to develop new training programs and provide continuous learning opportunities that can support the adaptation of the labour, encompassing both STEM and non-STEM individuals. These initiatives are crucial to effectively address the potential obsolescence of skills in a rapidly evolving technological environment. Furthermore, the chapter suggests the importance of organizational adaptability. Firms need to rethink their hierarchical structures, moving towards flatter organizations that promote openness to creativity and disruptive changes effectively. This ability seems determinant to benefit from the potential of blockchain technology and ensuring that organizations remain competitive and innovative in the age of industry 4.0.

Dynamic Capabilities and Implications

In Chapter 3, I investigate the determinants of the success of blockchain technology's applications diffusion. This chapter emphasizes the impact on competition and the potential for welfare redistribution within the blockchain platform ecosystem.

In this empirical analysis, I investigate an original database of Decentralized Applications (DApps) developed on a blockchain, incorporating operational data with the skills and competences of the entrepreneurs behind each application. I find a positive correlation between the success of a DApp and two main factors: the presence of an open-source feature and the extent to which developers modify the algorithm. This latter factor, which I interpret as an indicator of dynamic capabilities, highlights the significance of adaptability in the DApp's performance. This suggests that blockchain technology introduces a novel form of corporate governance, allowing investors to more effectively monitor and evaluate the projects led by entrepreneurs based on the development activities. However, it's important to note that minimal modifications may expose the project to competition and potentially reduce investment. I also observe that experience does not positively correlate with higher transaction volumes in DApps, and this is consistent with the findings on limited professional experience presented in Chapter 2 as a characteristic of blockchain recruitment. While blockchain technology does provide automation that can improve efficiency, transparency, and trust in various processes, this research highlights the determinant role of human intervention. The active involvement of entrepreneurs emphasizes the significance of their competences in ensuring the successful adoption and diffusion of this technology.

These findings acknowledge the complementarity of both contractual and competences perspectives to explain industrial organizations. To the best of my knowledge, this study represents one of the first attempts to empirically reconcile these foundational theories. By establishing this theoretical ground, I show who are the individuals shaping the evolution of blockchain technology. Interestingly, concerns related to collusive behaviours and potential disruptions to antitrust policies appear to be mitigated by the intrinsic presence of dynamic capabilities within each project, which are challenging to replicate. The introduction of service tokenization holds the potential to benefit society by fostering competition and redistributing welfare within the digital platform industry. Policymakers must consider how these features can be leveraged to create a more equitable and competitive business environment.

Limitations

This thesis contributes to the economics of blockchain by providing insights with a specific focus on the industrial dynamics' framework, and the related demand for skills. Each chapter brings their own comprehension while trying to overcome the technical complexity aspects inherent to the technology. Nonetheless, I acknowledge that the dissertation has limitations that prevent a full comprehensive overview of its implications.

By reviewing the mechanisms underpinning the three generations of blockchain technology, there remains a need for more profound microeconomic foundations to assess their overall impact. In particular, the dissertation lacks a financial perspective by omitting in depth investigations on the consequences of the cryptocurrency age and the monetary policy implications. One reason is the thesis's primary emphasis on the demand side of

blockchain technology, with less attention devoted to its supply-side dynamics. While I highlight the peculiar demand of firms concerning intangible assets that appears specific to this technology, the thesis does not develop a theoretical model to examine how blockchain influences economic growth, especially in light of the productivity paradox in Information and Communication Technology (ICT).

Regarding the methodological limitations, this thesis employs applied microeconometrics in chapters 2 and 3 to conduct a cross-sectional analysis using original datasets. In Chapter 2, the dataset consists of job offers from firms based in France and Germany. To gain a broader perspective on the adoption of blockchain technology across industries within the European Union, it is essential to expand the investigation by comparing more countries. This expansion would enable to obtain a more accurate estimate of the demand for digital skills related to blockchain technology and the corresponding training programs. In Chapter 3, the dataset is obtained through web scraping techniques and represents a snapshot of DApps (Decentralized Applications) and related entrepreneurs. However, for a more comprehensive and temporal analysis, it implies to incorporate a panel data model or time series analysis. This approach would better capture the trends and corresponding opportunities within this evolving industry.

Prospects for future investigation

The contributions of this thesis emphasize the need for a holistic understanding of blockchain's impact, and I hope that further research and exploration will follow. Blockchain technology represents a paradigm shift with the potential to revolutionize numerous aspects of our lives. As a GPT, it highlights the need for the development of theoretical models capable of capturing its broad implications. It is clear that we are still in the early stages of exploring its full potential.

For instance, I demonstrate that one of blockchain's promises lies in its capacity to contribute to addressing the urgent challenge of climate change. Through the development of regenerative financial mechanisms, blockchain can enable innovative solutions to fight environmental degradation. For example, blockchain-based carbon credit platforms can offer transparent and traceable mechanisms for incentivizing carbon reduction efforts, encouraging sustainable practices across industries. These mechanisms can promote sustainability and represent an avenue for further research exploration, both at a theoretical and applied level.

I emphasize the need to foster an ecosystem that enhances creativity, where entrepreneurs are encouraged to explore new applications and push the boundaries of what is currently possible. Embracing decentralization necessitates that both firms and governments adapt to the changing landscape and remain open to disruptive forces. At the same time, governments must take proactive measures to mitigate potential risks associated with automation's impact on the job market and the broader economy. The need to develop regulations that clarify the standards that must be respected with limitations

and boundaries aligning with the respect of human rights is a call for multidisciplinary investigation.

To gain new insights into the industrial dynamics of blockchain technology, one promising avenue for research is the analysis of patent data. By examining patterns and trends in blockchain-related patents, researchers can uncover valuable information about the technology's growth trajectory and its impact on various industries. Patent analysis provides a window into the innovative activity surrounding blockchain, offering a clearer picture of which aspects of the technology are generating the most interest and investment. Moreover, the inherent transparency of information within public blockchains offers an opportunity for researchers to compile original databases and conduct in-depth analyses. Time series and panel data models can reveal how blockchain ecosystems evolve over time, shedding light on adoption rates, consensus mechanisms, and network scalability. These analyses are critical for understanding the real-world dynamics of blockchain technology and can inform both policymakers and industry leaders about emerging perspectives.

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