MECHANICAL ENGINEERING | PHYSICS | PRESERVATION OF THE ARCHITECTURAL HERITAGE | STRUCTURAL, SEISMIC AND GEOTECHNICAL ENGINEERING | URBAN PLANNING, DESIGN AND POLICY | AEROSPACE ENGINEERING | ARCHITECTURE, BUILT ENVIRONMENT AND CONSTRUCTION ENGINEERING | ARCHITECTURAL, URBAN AND INTERIOR DESIGN | BIOENGINEERING | DATA ANALYTICS AND DECISION SCIENCES | DESIGN | ELECTRICAL ENGINEERING | ENERGY AND NUCLEAR SCIENCE AND TECHNOLOGY | ENVIRONMENTAL AND INFRASTRUCTURE ENGINEERING | INDUSTRIAL CHEMISTRY AND CHEMICAL ENGINEERING | INFORMATION TECHNOLOGY | MANAGEMENT ENGINEERING | MATERIALS ENGINEERING | MATHEMATICAL MODELS AND METHODS IN ENGINEERING

PhD Yearbook | 2025

Head:
Prof. Michela Arnaboldi

DOCTORAL PROGRAM IN MANAGEMENT ENGINEERING

INTRODUCTION

The Doctoral Program in Management Engineering (DRIG) offers students advanced training and preparation to conduct research in the field of management, economics and industrial engineering. It aims at training professionals who are able to carry out high-quality research in the fields of management, economics and industrial engineering at universities or other research institutions. Ph.D. graduates from DRIG are also well equipped with distinctive skills and advanced knowledge to pursue a professional career in manufacturing and service companies, regulatory authorities and other public bodies. The program allows the student to develop a sound methodological background and multidisciplinary knowledge by attending courses designed to provide a multiplicity of visions, theories and approaches, a broad cultural panorama. The program emphasizes the benefit of studying problems in an innovative manner, combining various analytical approaches and research methodologies.

The commitment of the Department of Management, Economics and Industrial Engineering (DIG) to research and scientific cooperation with other academic institutions, major industrial companies and other organisations results into an ideal environment in which for students to acquire leading-edge knowledge and cultivate their own research interests in a broad range of research subjects.

PH.D. PROGRAM STRUCTURE AND CONTENTS

The Full-Time doctoral program covers three years, whereas the Executive Program lasts four years. They are entirely taught in English.

The Faculty of DRIG includes, in addition to professors of the Department of Management, Economics and Industrial Engineering, several international scholars: Rodney Turner, Editor of the International Journal of Project Management; Mike Wright, Imperial College London, UK; Irvine Lapsley, University of Edinburgh, UK; Hans De Bruijn, Delft University of Technology, The Netherlands; Abraham B. Rami Shani, California Polytechnic University, USA; Christopher Worley, University of Southern California, USA; David Coghlan, Trinity College Dublin, Ireland; Donald Huisingh, University of Tennessee, USA; Tobias Kretschmer, Ludwig-Maximilians-Universität München, Germany, Davide Ravasi, Director of UCL School of Management, London.

The program covers three main types of training activities.

Main courses

- Methodological courses, addressing specific research methodologies and related skills relevant to research in management, economics and industrial engineering, such as Academic Publishing, Advanced topics in Econometrics, Literature Review in Social Sciences and Engineering, Case study and action research, Experimental and behavioral methods, Theorizing from qualitative data, Survey research methodology, Modelling and Data Analysis of Complex Systems, Driving Change in Human-Computer Interaction, and A psychology perspective on humans and technologies.
- Thematic courses, aiming at introducing students to the reference theoretical background and the cutting-edge research in specific disciplines, such as Platform ThinkingForms of Theorizing in Management, Integrating qualitative and quantitative insights, and Entrepreneurship and entrepreneurial finance.

Elective courses and training on specific themes

Elective training activities are customised according to the specific needs and research interests of students. The aim is to strengthen the scientific knowledge of students in very specific topics and to introduce them to the international research community through their active participation to international scientific conferences and PhD schools.

Thesis

The aim of the Ph.D. programs at Politecnico di Milano is to instill in candidates a research-oriented mind-set, along with expertise and skills relating to a specific research topic. To develop a research-oriented mentality, candidates must acquire the ability to solve complex problems, including a thorough analysis of the problem, identification of an original solution and the ability to evaluate the solution and its applicability in given contexts. Ph.D. s who possess these abilities will have greater opportunities for advancement in research positions, both in the academic environment as well as in public and private organisations.
The main goal is the development of an original research contribution. The Ph.D. thesis should help increase knowledge in the applicant's research field. It also needs to be consistent with the research topics studied at the Department. The final thesis can be submitted in the form of either a monograph or an edited compilation of papers. The research projects presented in the following section are typical examples of the research work carried out by DRIG students.

SCIENTIFIC AND INDUSTRIAL COLLABORATIONS

Students are required to spend at least one semester in a foreign research institution. In addition, students are encouraged to attend doctoral schools and workshops organized by other institutions and to participate in international scientific conferences. The presentation of an original research work in an international conference is mandatory for admission to the final exam. To his end, students are granted of a personal research budget, covering a three years research period, and have access to mobility support measures aimed at promoting international collaborations between the doctoral programs in Europe and overseas.

In addition, Double Degree agreements are in place at the Ph.D. level:

- Double Degree Programme with the Pontificia Universidad Católica de Valparaíso (Chile), Escuela de Ingeniería Industrial, Doctorado en Ingeniería Industrial.
- Double Degree Programme with the Copenhagen Business School (CBS, Denmark), PhD School in Economics and Management.
- Double Degree Programme with the University of

Reading, Henley Business School
- (United Kingdom), PhD in Management.
- Double Degree Programme with the National Research University Higher School of Economics in Moscow (Russia).
- Double Degree Programme with TuDelft (The Netherlands).
- Double Degree Programme with Universidad Politécnica de Madrid – UPM (Spain).
- Double Degree Programme with Gent Universiteit (Belgium).
- Double Degree Programme with Skema Business School (France).
- Double Degree Programme with UNIANDES (Colombia).
- Double Degree Programme with Tampere University (Finland).
- Double Degree Programme with LUT University (Finland).
- Double Degree Programme with Qatar University (Qatar).
- Double Degree Programme with USP – Universidade de São Paulo (Brazil).
- Memorandum of understanding with TUM (Technical University of Munich).

DRIG has also developed several research collaborations with private manufacturing and service firms, regulatory bodies, and other public research institutions to fund PhD oriented research. In recent years, the following organisations supported DRIG Scholarships: Value Partners, TXT e-solutions, IBM, Siemens, Telecom Italia, Windesheim University of Applied Scencies, INAIL, INPS, Regione Lomabrdia.

PROFESSIONAL OPPORTUNITIES AND THE JOB MARKET

Typical career opportunities opened up by the doctoral program include:

- Post Docs, research fellows and young lecturers at Italian and foreign universities;
- Researchers and scholars in Management Engineering at public and private organisations;
- Highly qualified personnel at research and training institutions, or at technology transfer centers in Italy and abroad;
- Professionals at leading management and strategic consulting firms who can provide deep and advanced insights into companies' business areas;
- High-level professional roles at national and international public institutions;
- Managerial roles at multinational companies with a strong focus on innovation; Entrepreneurs in contexts characterised by a high level of innovation.

Support actions for placement are provided with the purpose of sharing experiences, services and information through a number of initiatives fitting the different types of career opportunities. Particular emphasis is given to career development in the Management Engineering area.

TOWARDS A DIGITAL THREAD ARCHITECTURE FOR CIRCULAR MANUFACTURING

Tasnim Mahmoud Mohamed Ahmed - Supervisor: Elisa Negri

The circular economy model is widely recognized by academics, industry, and governments as a solution to the 'take-make-waste' approach to consumption and production. In manufacturing, Circular Manufacturing (CM) and Circular Manufacturing Systems (CMS) are promoted over traditional linear systems. CM aims to minimize waste and efficiently use resources through closed-loop systems, maintaining materials, components, and products in continuous cycles. Effective information sharing, crucial for supply chain efficiency and coordination, is equally vital for CM implementation. Recent EU legislation, such as digital product passports, further underscores the need for comprehensive data collection and information sharing infrastructures. Despite extensive research on data management for CM, gaps remain in technologies and architectures for information sharing. Digital Thread is a technology that orchestrates the integration of information and data along the entire product lifecycle, spanning from initial design and engineering through production, maintenance, use, and eventual end of life, aligning with CM objectives.

Consequently, digital threads can be utilized to create data collection and information sharing architectures for CMSs. The objective of this PhD work is to design a product digital thread architecture that allows manufacturers to collect the needed data and information, from within and outside of their company, supporting CMSs' implementation. The methodology followed for the PhD work is the Design Science Research (DSR) methodology, focusing on the design and validation of digital thread architecture for CM as an artifact.

The PhD thesis comprises a collection of five research papers, each contributing to addressing the research questions and adhering to the DSR methodology. In the knowledge gathering stage, a mixed-method approach was employed, incorporating theoretical literature reviews and empirical studies to ensure the work's foundation in current theory and its practical relevance to the industry.

During the artifact design stage, a digital thread architecture for CM information sharing was developed, utilising Asset Administration Shell (AAS). This architecture consists of five modules: production, tracking system, data collection, circularity optimization, and the information-sharing module. It leverages the AAS as the primary tool for representing the product data model to ensure interoperability and standardisation, and low-cost digital technologies for the traceability module.

The architecture was implemented and tested at the Industry 4.0 Laboratory of Politecnico Di Milano and the Variable Organisation and Operation Management Demonstrator at the Institute for Manufacturing, University of Cambridge. Additionally, the architecture was deployed in a remanufacturing case study to validate its effectiveness in CM processes. This PhD work adds to the body of knowledge through interdisciplinary insights by intersecting manufacturing operations, supply chain management, and information technology research, highlighting the importance of traceability, stakeholder collaboration, and digital technologies for CM. It addresses notable gaps in existing literature, particularly concerning information sharing technologies and architectures for CM, thereby adding depth to the understanding of how digital technologies can facilitate CM processes. Furthermore, with the emergence of EU legislations mandating product data reporting this research provides timely and relevant insights into how industries can comply with these regulations through effective data management and information sharing frameworks.

ESSAYS ON CIRCULARITY AND DIGITALIZATION IN SUPPLY CHAINS

Clarissa Amico – Supervisor: Roberto Cigolini

In recent decades, the consumption of natural resources has surged beyond their availability, with escalating waste generation projected to require the resources of three Earths by 2050. This scarcity is compounded by global warming, with human activities raising temperatures by 1.1°C since the pre-industrial era and projections of reaching 1.5°C within 20 years. The traditional linear economic model exacerbates these issues, necessitating more sustainable practices. The circular economy paradigm in supply chain management has emerged as a vital solution to mitigate environmental impact.
Alongside circular economy principles, technology plays an increasingly crucial role in supply chain management. Technologies such as blockchain, artificial intelligence, cloud computing, and additive manufacturing are revolutionizing the industry, and reshaping the supply chains.
This dissertation aims to enhance the understanding of the circular economy paradigm and digitalization within supply chain management, bridging gaps in both theoretical and practical domains. Comprising a cover essay and three appended papers, namely Paper 1, 2, and 3, this thesis provides a comprehensive understanding of how circular economy and emerging digital technologies, namely blockchain and artificial intelligence can be leveraged to create more sustainable and efficient supply chains, offering valuable insights for both academia and industry.
Paper 1 investigates the environmental and economic sustainability of transitioning from a global linear supply chain to a circular one, quantitatively assessing three circular strategies – Reuse, Remanufacturing, and Recycling – through a simulation model based on a real-world case from the fashion industry. The findings reveal that a circular supply chain outperforms a linear one across multiple dimensions, including economic viability, emission reductions, and resource efficiency. It offers the apparel industry a comprehensive analysis of the economic and environmental advantages of circular economy practices, emphasizing the importance of customer engagement to enhance product returns and profitability.
Paper 2 discusses how blockchain technology can enhance port logistics by improving transparency, security, and efficiency. Using simulation model methodology and interviews with port terminal managers, the study validates the practical implications of blockchain technology, demonstrating its potential to streamline operations. Paper 2 aids managers in understanding the significance and challenges of bills of lading in port logistics. It highlights how blockchain-based bills of lading can improve visibility, security, and trust among stakeholders, enabling managers to streamline operations and reduce inefficiencies.
Finally, Paper 3 examines the impact of artificial intelligence on the automotive industry supply chain. Through semi-structured interviews with experts in artificial intelligence in the automotive sector, the study gathers qualitative insights into how artificial intelligence is transforming supply chain dynamics. The findings indicate that artificial intelligence offers numerous benefits to automotive companies and their supply chains including improvements in efficiency, operational performance, and environmental impact. Paper 3 offers the automotive sector detailed insights into the benefits, strategies, and challenges of implementing artificial intelligence, helping companies optimize their supply chain operations.

CLIMATE ENGINEERING: REGIONAL AND DISTRIBUTIONAL IMPLICATIONS IN CLIMATE-ECONOMIC MODELLING

Pietro Andreoni - Supervisor: Massimo Tavoni

This thesis explores the intersection of climate policy, economic inequality, and governance, focusing on two major climate engineering strategies: Carbon Dioxide Removal (CDR) and Stratospheric Aerosol Injection (SAI). Through theoretical analysis, numerical modeling, and policy evaluation, it examines how these technologies, while essential or potentially beneficial for mitigating climate change, may also exacerbate income and wealth disparities both within and between countries. The research highlights the need for regulatory interventions and robust governance to prevent unintended socio-economic consequences and ensure a fairer distribution of climate mitigation benefits.

The first two chapters analyze the economic and distributive consequences of financing large-scale CDR, a critical component of global decarbonization strategies. A fundamental challenge emerges as CDR firms might accumulate excessive profits under carbon pricing mechanisms, potentially worsening income inequality. Within individual countries, carbon pricing shifts costs onto consumers while CDR revenues concentrate among private firms, leading to an increase in wealth disparities. On a global scale, the geographical distribution of CDR potential plays a decisive role in determining whether high-removal capacity benefits wealthier or poorer nations. Using an integrated assessment model (RICE50+), the study quantifies these effects, showing that inequality spikes around net-zero emissions, making regulatory responses necessary. The second chapter further develops this argument by conceptualizing excessive CDR profits as a market failure driven by scarcity rents and convex cost curves. It proposes market regulations, particularly price caps or separation of emission and removal markets, to limit profit-driven inequality while maintaining economic efficiency.

The third chapter shifts focus to SAI, a form of solar geoengineering, exploring its economic and geopolitical implications. While SAI has the potential to provide rapid cooling, its regional effects vary significantly, creating winners and losers. The study challenges conventional geoengineering models that assume globally optimal deployment, arguing that unilateral SAI implementation by powerful nations could maintain or deepen existing climate inequalities. Using an enhanced RICE50+ model, the research simulates different governance scenarios, revealing that cooperative deployment can effectively stabilize temperatures with significant economic benefits. However, unilateral deployment by wealthier northern countries risks failing to provide adequate cooling for equatorial and tropical regions, shifting precipitation patterns and disproportionately harming vulnerable nations. Poorer equatorial regions, despite benefiting from SAI, lack decision-making power and face greater risks from its misuse.

By examining the unintended economic consequences of climate engineering, this thesis underscores the need for market regulation in the case of CDR and robust international governance for SAI to prevent further exacerbation of global inequalities. It argues that climate policy should not only focus on reducing emissions or temperature but also ensure equitable outcomes. The work highlights the tension between efficiency and equity in climate mitigation and emphasizes the necessity of integrating socio-economic considerations into the models that evaluate climate engineering strategies.

SUSTAINABILITY AND CLIMATE CHANGE: UNRAVELING FIRMS' INTERNATIONALIZATION AND FINANCIAL STRATEGIES IN THE FACE OF ENVIRONMENTAL CHALLENGES

Martina Barbaglia - Supervisor: Giancarlo Giudici
Co-Supervisor: Stefano Elia

The world is facing an accelerating climate crisis, compelling firms to scale up their efforts to reduce carbon emissions and align with global sustainability goals. Investors, regulators, and consumers are increasingly holding companies accountable for their environmental impact, making sustainability a critical factor in competitiveness and corporate reputation. Among the key players in this transition, multinational enterprises (MNEs) are uniquely positioned to drive meaningful change due to their extensive global networks, diverse institutional contexts, and broad stakeholder engagement. At the same time, financial decisions – such as capital structure and investment in green initiatives – play a crucial role in determining whether firms can effectively transition to a low-carbon economy. While some businesses proactively embrace sustainability as a strategic advantage, others face financial constraints that limit their ability to implement green strategies. Understanding these dynamics is essential for shaping policies and business practices that balance financial and environmental priorities.
This dissertation, comprising a collection of three papers, examines the intersection of environmental sustainability, international business, and corporate finance, taking a dual perspective to analyze how firms respond to environmental pressures and how their decision-making processes impact the environment. It explores whether firms integrate sustainability into their internationalization and relocation strategies, the role of regulatory frameworks in shaping such decisions, and how financial constraints influence environmental performance. By addressing these pivotal issues, this research provides insights into an evolving corporate landscape where financial and environmental imperatives are increasingly interconnected.
The first paper addresses the relocation decisions of MNEs in response to environmental sustainability pressures. It investigates whether MNEs prioritize reshoring previously offshored operations or relocating to another host country, based on their sustainability commitments and the environmental regulatory framework of their country of origin. The study reveals that firms committed to sustainability do not necessarily favor reshoring and the environmental benefits of shorter value chains (e.g., reduced carbon emissions due to lower transportation needs, minimization of overproduction and waste, adoption of innovative and cleaner technologies, enhanced alignment between strategic and operational policies) unless their home country enforces stringent environmental regulations.
By integrating insights from stakeholder and signaling theory, the study suggests that regulatory incentives are essential to increase the likelihood of environmentally conscious firms committing to reshoring. This challenges the pollution-haven hypothesis, demonstrating that strict environmental policies can act as a pull factor for sustainability-oriented companies.
Shifting to the financial realm, the second paper delves into the nuanced relationship between a firm's capital structure and its carbon performance. Excessive debt can limit a firm's capacity to invest in sustainability initiatives and curtail managerial discretion, preventing overinvestment in green projects driven solely by personal interests, which may result in higher carbon intensity. However, debt can also act as a governance and monitoring mechanism, fostering disciplined investments, a focus on long-term objectives, and socially responsible practices, ultimately leading to reduced carbon intensity. The findings suggest that firms with a higher proportion of debt relative to equity in their capital structure tend to underperform in carbon management and exhibit greater carbon intensity, particularly when nearing financial distress. Building on this, the third paper specifically examines the impact of financial distress on firms' implementation of environmental practices.
Using a regression discontinuity design, the paper reveals that financially constrained firms are less likely to engage in green initiatives and exhibit weaker carbon performance compared to financially stable ones. This highlights a risk-shifting behavior, where companies prioritize financial survival over long-term sustainability during periods of financial instability. Managers facing financial constraints may cut discretionary environmental expenditures, reinforcing the trade-off between short-term liquidity and long-term sustainability. The findings align with stakeholder-agency theory, illustrating how financial distress exacerbates misalignment between corporate actions and broader stakeholder interests.
Overall, this thesis makes significant contributions to two major strands of literature: international business and corporate finance. Firstly, it enhances the understanding of relocation and post-offshoring strategies, which have gained importance amid the growing pressures of deglobalization. Additionally, it brings attention to the often-overlooked environmental impact of MNEs' international activities. From the perspective of institutional theory, it underscores how variations in the stringency of environmental policies can influence MNEs' decisions to reconsider and potentially redesign their internationalization strategies. Furthermore, the thesis sheds light on the financial mechanisms driving corporate environmental performance, emphasizing the potential adverse effects of debt on carbon performance, particularly when approaching financial distress. Managers and policymakers can draw key lessons from the conclusions of this dissertation. For instance, managers of global firms must be prepared to reassess and potentially restructure their international operations to account for the environmental externalities of their global footprint. In a rapidly changing regulatory environment, where fluctuations in environmental policies are on the agenda, it is crucial not to overlook differences in countries' regulatory frameworks and their impact on firms' decision-making processes. For managers of firms facing financial constraints or instability, focusing solely on short-term survival may seem prudent. However, neglecting the longer-term implications of insufficient attention to sustainability can impair a firm's ability to recover and access capital markets in the future, especially as regulatory scrutiny and investment decisions increasingly favor sustainable practices. From a policymaker's perspective, crafting well-designed environmental regulations can serve as a powerful lever to encourage firms to adopt greener business practices. Additionally, financial support mechanisms are crucial to prevent firms from deprioritizing sustainability during times of financial distress. Green financing mechanisms, tax incentives for sustainable investments, and conditional subsidies for distressed firms that maintain green initiatives can help mitigate the adverse effects of financial strain on sustainability commitments. Harmonizing international environmental policies can also reduce regulatory arbitrage, discouraging firms from relocating to jurisdictions with weaker environmental standards. These policy insights highlight the importance of coordinated efforts to align corporate sustainability with broader climate goals.
In conclusion, this dissertation highlights the intricate relationship between sustainability, internationalization, and corporate finance, laying a solid foundation for advancing academic research aiming to address the pressing environmental challenges of our time. As climate risks escalate, understanding how firms navigate the complexities of internationalization and financial strategy vis-à-vis climate issues becomes an essential focus for both academic research and practical intervention.

NASCENT INDUSTRIES: AN INQUIRY INTO INDUSTRIAL AND INSTITUTIONAL DYNAMICS

Fabio Busicchia - Supervisor: Cristina Rossi-Lamastra

Co-Supervisor: Alessandro Lucini-Paioni

Nascent industries are industries at the earliest stage of development, characterized by substantial uncertainty. What occurs during the nascent period has implications for the later stages, when industries achieve robust commercial activity. To this aim, diverse studies spanning economics, management, and institutional fields have examined how and why industries emerge. Studies in economics and management mainly investigate firms' product-market entry as a key element for industrial dynamics, *i.e.*, entry and exit patterns, and contribute to formalize the industry lifecycle model. Institutional theorists consider the institutional dynamics, *i.e.*, changes of an entity's alignment with the institutional environment, paramount for industry emergence. A central theme of institutional dynamics is that an entity achieves and maintains legitimacy. In this realm, organizational ecologists explain how density (number of firms) influences legitimization and competition forces. Other institutional theorists focus on identifying firms' resources or strategies to gain legitimacy. Past studies mainly focus on commercializing firms, their characteristics, and strategies post-commercialization to explain nascent industries' industrial and institutional dynamics. Despite scholarly contributions, a more comprehensive analysis of technological investments and the core technologies underlying a nascent industry can provide more nuanced explanations of their inherent dynamics. First, focusing on product-market entry has precluded a more in-depth investigation of firms' technological entry, *i.e.*, patenting and innovation efforts in a new domain, as a key decision to identify investing firms (*i.e.*, technological entrants). Technological entry is the first technological investment undertaken by firms, regardless of any subsequent value capture mechanism in the product-market. Firms that engage in technological entry are *de facto* firms that commit resources during the nascent period of industries and should be consistently more integrated into the entry dynamics. As technological entry precedes market entry, firms' subsequent decisions and survival can be affected by pre-commercialization choices and deserve further investigation. Second, I delve into the individual and environmental antecedents of individual judgment formation. Individual judgments are the core of institutional dynamics and are crucial for legitimizing technologies underlying nascent industries. Moving from these premises, this thesis is a collection of five papers investigating firms' technological investments and technology legitimacy judgments by individuals, specifically the general public.

The setting of the empirical papers is the commercial drone industry. Drones are characterized by uncertainty and several market opportunities to the extent that they attract several firms' interests to capture value from their technological investments. This makes the context suitable for analyzing technological investments before commercialization. The pervasiveness of the technology on the general public also makes the context appropriate for studying legitimacy judgment. To this aim, I develop two datasets. In the US drone context, I track technological entrants, their commercialization decisions, and firm exit modes from 2000 to 2023. In the Italian context, I integrate survey data on citizens' public perception of drones with information on the number of drone firms and news on drone deployments in different local areas.

In Paper 1, I develop a conceptual model to examine investment decision-making and its implications for firm and industry development. I illustrate that a technological investment strategy unfolds into a sequence of events and decisions over time. I distinguish (i) technological entry and (ii) subsequent technological investments. I frame technological investment strategy as the results of the interdependencies of five dimensions: (i) whether/who – whether to invest and who invests; (ii) when – the contextual timing of investments; (iii) where – the area to invest; (iv) what – the types of investments; (v) how – the technological entry and investments mode to develop the competencies and resources needed. Extant knowledge allows to derive factors that influence firms' technological investments (*i.e.*, pre-investment experience), such as individuals' and firms' beliefs and competencies and assets.

In Paper 2, I establish guidelines for effectively collecting data on entrants, moving from the premise that limited research is the difficulty in accessing and collecting novel data on firms in a nascent context. I propose a question-driven checklist for structuring industry emergence research, discussing issues on the selection of the industrial context and the definition of the data collection method (*e.g.*, setting industry boundaries, sampling). As sampling is crucial for theoretical advancements and minimizes methodological concerns, I also provide a taxonomy of indicators to identify relevant firms. I implement these guidelines to collect data on technological and market entrants in the US commercial drone industry. A combination of patents classified through machine learning techniques and keyword analysis, drone projects, funding rounds, cases of business diversifications, and alliances/acquisitions was used as a proxy of technological commitment.

In Paper 3, I investigate how the technological entry-timing shapes product-market entrants' subsequent exit patterns (*i.e.*, failure vs. M&A) in nascent industries. Drawing arguments from the first-mover advantage theory, I stylize four entry-timing choices considering the technology and product-market dimensions: being a pioneer in both technology and product-market, being a pioneer in technology and a follower in the product market, being a follower in technology but a pioneer in the product market, or being a follower in both technology and product-market. Findings indicate that technology pioneers exhibit lower chances of failure and higher chances of M&A than technology followers, regardless of being market pioneers or followers. Among technology followers, market pioneers exhibit a slightly higher chance of M&A than market followers, but there is no significant difference in failure rates.

In Paper 4, I investigate the antecedents of the general public's technology legitimacy judgments. Based on the recent advancements in legitimacy theory as a multi-level construct, I focus on the role of two informational inputs for individuals: the perceptions of (external) validity cues and the individual's perceptions of the technology. The extent to which they rely on their evaluations rather than on perceived external validity crucially depends on individual evaluative mode (active *vs* passive mode). Results show that the effect of the perceived (drone) benefits and risks matter and are more significant for individuals adopting an active evaluative mode than a passive one. Exposure to a greater source of validity cues (proxied by the number of drone firms and press releases on drone applications) strengthens their technology legitimation, especially when the size of these sources reaches a certain threshold and individuals are in a passive evaluative mode.

In Paper 5, I explore the effect of a set of individual and environmental factors on willingness to use a new technology, namely Advanced Air Mobility (AAM) transportation systems. Results show that individuals' job positions, flying habits, and prior experience with drones positively influence such willingness. We also find that regional features matter, with respondents living in poorly connected and less innovative regions more willing than others to use them.

This thesis advances industry emergence research with a more nuanced analysis of technological entrants and their decisions, especially entry-timing, and their implications for long-term survival and of the factors influencing citizens' technology legitimacy judgments. The findings also provide insights to firms on the interplay of technology and market entry-timing decisions. It also gives policymakers insights into how people judge technology approval to foster possible policies.

ADVANCES IN MODELLING FINANCE AMID CLIMATE CHANGE: ADEQUACY AND EXAMPLES

Matteo Calcaterra – Supervisor: Massimo Tavoni

This thesis explores the intersection of climate change, finance, and economic modelling, addressing the pressing challenge of integrating financial considerations into climate-economy models. Climate change poses significant threats to global welfare, requiring substantial investments in both mitigation and adaptation. While Integrated Assessment Models (IAMs) have been instrumental in analyzing climate-economy interactions, they face criticism for inadequately representing financial dynamics.

Theoretical Foundation

The research argues that IAMs are "adequate-for-purpose" for analyzing financial aspects of climate change, despite their limitations. The thesis employs three distinct methodological approaches to exemplify this adequacy. The first approach involves model enhancement, augmenting existing models with new parameters or dynamics. The second method utilizes one-way coupling, where IAM outputs serve as inputs for specialized financial models. The third approach entails model restructuring, altering the core economic structure of IAMs to incorporate more refined macro-financial dynamics. These methodologies are applied to address three key challenges identified by the IPCC: perceived investment risk-return profiles, policy misalignment, and political economy constraints.

Reducing the Cost of Capital to Finance the Energy Transition in Developing Countries

The first paper examines how reducing the cost of capital for energy financing in developing countries could advance both mitigation efforts and energy justice. Using five detailed-process IAMs, the research calibrates region-specific and technology-specific cost of capital values, also implementing a "learning-by-financing" mechanism to model realistic future development.

The analysis reveals that international convergence in financing costs would significantly benefit developing nations. Renewable electricity generation increases by 10% under Nationally Determined Contributions (NDCs) scenarios and 5% under 1.5°C scenarios. The renewable electricity gap between current policies and 1.5°C compliance is reduced by approximately 30%. Electricity costs in developing countries decrease by approximately 10%, while energy expenditures as a percentage of GDP drop by 5% in Africa and Latin America and 2.5% in India. Furthermore, inequality in per-capita renewable energy generation decreases by 4% under NDC scenarios and 2% under 1.5°C scenarios.

The paper demonstrates that a convergence in financing costs not only promotes renewable energy deployment but also advances energy justice by making clean energy more accessible and affordable. This illustrates how financial mechanisms can be powerful tools for accelerating the energy transition while addressing equity concerns.

Sovereign Debt Sustainability Under Climate Change

The second paper investigates how climate change impacts sovereign debt sustainability. Using a one-way coupling approach, it combines projections from the RICE50+ IAM with a stochastic Debt Sustainability Analysis (DSA) model to analyze different socioeconomic, climate, and impact scenarios.

The study reveals several critical insights regarding the complex relationship between climate change and public finances. Under high-impact climate change scenarios, sovereign debt trajectories become unsustainable for many countries, threatening their fiscal stability and capacity to provide essential services. Even low-impact scenarios could be challenging for debt sustainability, particularly for nations already facing fiscal constraints or high climate vulnerability.

The research examines adaptation as a potential solution, finding that it can help mitigate these challenges, but only if properly balanced with public financing considerations considerations. If governments bear too much of the adaptation cost directly, the fiscal benefits may be outweighed by the additional expenditure. Exploring traditional fiscal consolidation approaches, large increases in primary surpluses (1-3.6% of GDP) would be required to maintain debt sustainability. Lastly, maintaining pre-climate-change levels of government spending would lead to unsustainable debt accumulation across virtually all scenarios.

The paper concludes that governments will face increasingly difficult trade-offs between debt sustainability and maintaining public services, making climate mitigation essential for long-term fiscal health. Without substantial emissions reductions, sovereigns will find themselves "on thinning ice," with diminishing fiscal space and growing vulnerability to economic shocks.

Climate Policy Design and Inequality

The third paper in the dissertation explores the relationship between climate change and inequality, positioning them as deeply intertwined phenomena. The article describes a newly developed model on Realistic Inequality Subnational Outcomes, Tax and Transfers Optimization in a Regional Integrated Climate-Economy (RISOTTO RICE), which extends previous climate-economy frameworks by incorporating decile-level dynamics rather than static distributional mappings. This model uniquely integrates climate, second-best economic settings, and inequality within a single analytical framework. Building on the transparency of the seminal RICE model, the research constructs an economic framework with meaningful heterogeneity that interacts endogenously with state-of-the-art climate dynamics and mitigation calibrations. This allows for examination of how inequality awareness transforms optimal climate policy, specifically investigating how governments recalibrate carbon taxation when they explicitly account for its distributional implications.

The results demonstrate that the core behavior of the model displays interesting endogenous feedbacks between climate policy and inequality. Under inequality-averse policies, governments implement intertemporal optimization of carbon taxation, front-loading carbon taxes in early periods followed by lower rates later, creating a distinct "higher now, lower later" taxation pattern. Countries with higher projected increases in inequality implement more aggressive front-loading. The findings indicate that strategic tax scheduling offers a cost-effective approach to addressing distributional concerns within climate policy, enhancing political feasibility of ambitious climate action without compromising environmental effectiveness.

Conclusion and Implications

The thesis provides strong evidence that IAMs can meaningfully analyze financial dimensions of climate change despite their limitations. The three papers demonstrate that financial interventions like cost of capital convergence can significantly enhance mitigation efforts and energy justice; climate impacts pose severe threats to sovereign debt sustainability that cannot be easily managed through conventional fiscal approaches; and that inequality and climate change are interlinked and should be analyzed in a comprehensive framework. The research has important implications for policymakers, suggesting that financial risk-sharing, early climate action, and a higher focus on inequality should be cornerstones of climate policy and analyses. It also advances the methodological frontier by demonstrating how different approaches to IAM enhancement can address distinct aspects of the climate-finance challenge.

GOVERNING AND ORGANIZING CORPORATE INNOVATION: STRUCTURES, MECHANISMS, AND INTERACTIONS

Francesca Capella - Supervisor: Josip Kotlar

Today, the need for firms to innovate and continuously reconfigure themselves is an unavoidable strategic imperative for survival and success. Yet, managing innovation in rapidly evolving business contexts has grown increasingly complex, requiring firms to navigate not only internal processes but also a wider ecosystem of stakeholders, collaborative practices and competitive pressures. This complexity necessitates new collaborative organizational frameworks and constructs that can accommodate and support the interplay of a broad set of internal and external stakeholders creating new products, knowledge, business models, and applications often unpredictably and over extended periods.

Despite innovation represents one of the most debated topics within organizations at strategic, operational, and practical level and the amount of knowledge that has been generated to date is truly enormous, many organizations still struggle to translate theoretical insights into actionable practices. Companies need strategies, processes and structures to manage and exploit innovation within their boundaries, creating and capturing value from it. Furthermore, they need to organize themselves to manage innovation initiatives successfully. These aspects underscore the necessity of governing both the innovation processes and the related innovation initiatives.

The concept of governance, traditionally defined as a system through which companies are managed and governed by separating ownership and control and broadly understood as the system of rules, practices, and processes by which organizations are directed and controlled, plays a critical yet underexplored role in the innovation management context. Governance emerges as a critical element to be studied in the innovation management field, particularly exploring different governance mechanisms, structures and interactions and investigating how they influence innovation outcomes. While extant literature treats governance mainly as a static framework, designed to control and support innovation within predefined structures, emerging scholarship highlights its dynamic interplay with innovation, suggesting that governance mechanisms not only respond to but actively influence and shape innovation processes. This evolving perspective raises a central research question: *"How does governance shape the management of innovation within organizations?".*

From both academic and practitioner perspectives, the need for a nuanced understanding of how governance shapes innovation is paramount. For academics, the central question revolves around the theoretical underpinnings of governance and its evolving role in innovation processes. Traditional models often fail to capture the complexity of the modern innovation landscape, particularly with the rise of open innovation and digital transformation. For practitioners, the challenge lies in designing governance frameworks that support innovation initiatives while ensuring that innovation aligns with the organization's long-term strategic goals.

The collection of papers included in this thesis seeks to address the aforementioned gaps by examining the interplay between governance and innovation across different organizational contexts. A prominent context contributing to the emerging stream of innovation governance research is open innovation (OI), where governance mechanisms play a critical role in managing potential conflicts, achieving collaborative objectives among multiple actors, and ensuring the efficient exchange of knowledge and competencies. Among the various OI initiatives, those related to corporate venturing (CV)—such as CV Capital (CVC) and CV Clienting—stand out as especially compelling. These initiatives are often characterized by a natural imbalance of power among the involved parties, creating a fertile ground to study how innovation governance structures and mechanisms can mediate and optimize such dynamics to support innovation outcomes. Another organizational context where power dynamics significantly shape innovation governance is that of family businesses. In these firms, economic and business goals must be balanced with non-economic objectives, such as preserving family harmony, ensuring intergenerational succession, and maintaining family control over the business. Family firms present a unique organizational setting where the interaction between familial relationships, business management, and governance creates both opportunities and challenges for innovation. In this context, political capital—"the variety of economic, social, and cultural resources available to individuals and groups to affect organizational decisions, actions, and outcomes" emerges as a key factor in driving innovation initiatives. Furthermore, family businesses are often characterized by governance configurations that combine formal structures with informal mechanisms. These distinctive features make family firms an ideal context to explore how innovation-related decisions are made and how governance mechanisms can effectively support the implementation of innovation initiatives.

This dissertation examines innovation governance through three interconnected studies, each examining specific aspects of the phenomenon to enhance its conceptual and practical understanding. Each study explores governance mechanisms and dynamics that facilitate or hinder the strategic management of innovation within organizational contexts, employing a variety of theories, methods, and empirical settings. Guided by Mintzberg's (1979) emergent strategy framework, the research takes an exploratory approach, seeking to uncover patterns of behavior, actions, and processes across the studies. While the scope of the three papers is necessarily limited and cannot provide a definitive framework for innovation governance, the findings lay a foundation for further research in this area.

The investigation begins within the context of family firms (Paper 1), offering an opportunity to engage with the constructs of political capital and political behavior and their interplay with innovation management and governance. This foundational study allowed to deepen agency and stewardship theory—frameworks extensively utilized in family business literature but underexplored in the field of innovation management. Intrigued by the potential to extend these theoretical perspectives into the context of open innovation, the subsequent research (Paper 2) pivots to a specific emerging initiative: CV Clienting. The juxtaposition of CVC and CV Clienting exposes conceptual and practical tensions, highlighting the complexities of adopting a singular governance approach. Instead, the findings emphasize the criticality of dual governance models that harmonize stewardship and ownership perspectives for effective innovation management. The first two studies converge on a recurring and fundamental challenge: determining whether innovation models or specific initiatives drive the design and implementation of governance structures, or whether governance mechanisms shape the evolution of innovation processes. This dilemma resembled a "chicken-and-egg" paradox, sparking further inquiry. As a result, the third study (Paper 3) was designed to explore this reciprocal relationship in greater depth, focusing on how governance and innovation co-evolve and mutually influence one another within organizational settings over time.

This structure allows for an in-depth exploration of governance mechanisms in distinct settings, each chosen for its potential to shed light on different facets of the governance-innovation relationship.

These studies highlight the evolving relationship between governance and innovation and provide tools for both scholars and practitioners to manage innovation more effectively. The scope of governance addressed in this thesis spans multiple levels, from individual managers and their political behaviors to organizational structures and processes.

UNVEILING INTEGRITY IN IMPACT INVESTING – AN EMPIRICAL ANALYSIS OF THE EUROPEAN INDUSTRY

Chiara Cremasco – Supervisor: Irene Bengo

The investment community has increasingly embraced sustainable finance to address pressing social and environmental issues. Impact investing stands out for its potential to generate measurable social and environmental value alongside financial returns. Unlike socially responsible investing, impact investing deliberately allocates capital to create impact, and is defined by three characteristics: i) intentionality, which refers to the deliberate allocation of funds for social or environmental change; ii) measurability, requiring that social impact objectives are monitored and evaluated; iii) additionality, assessing the extent to which an investment contributes to a social objective beyond what would have occurred otherwise.

Impact investments have grown significantly, with global assets surpassing a trillion dollars at the end of 2021, exceeding previous forecasts. Academic literature on the subject has also expanded. However, the sector faces challenges, particularly in ensuring impact integrity – the alignment of investment actions with social and environmental goals. A key concern is impact washing, where financial firms misrepresent the true impact of their investments, undermining the credibility of impact investing. This threatens the ability of the sector to generate genuine social value. Regulators and stakeholders are increasingly calling for greater transparency and accountability to ensure that impact investment managers fulfil their promises. Despite this, there is a gap in academic literature regarding how to prevent impact washing and ensure market integrity.

This dissertation contributes to the conversation on impact investing practices by investigating their integrity. Specifically, it includes three papers that study how investment firms address the risks of impact washing and implement governance mechanisms to ensure the integrity of impact investments.

The research has three objectives: Paper 1 explores the extent of impact washing in the European financial context (Research Objective 1). Paper 2 investigates the legal implications of impact washing, identifying triggers and strategies to prevent or mitigate it (Research Objective 2). Paper 3 identifies impact governance strategies to improve transparency, accountability, and effectiveness in delivering predefined impact objectives (Research Objective 3).

The European impact investing ecosystem serves as the empirical context for the research, which is characterized by both challenges and advances. While some countries lack maturity on the issue, Europe has the most advanced regulations ensuring transparency in sustainable finance. This makes it an ideal context to explore the research objectives.

The research uses a mixed-method approach, including statistical techniques, thematic analysis, and the Gioia methodology. Paper 1, published in September 2022 in the *Journal of Sustainable Finance & Investment*, employs a quantitative methodology to assess investment funds' transparency under the EU's Sustainable Finance Disclosure Regulation (SFDR). It analyses over 52,000 investment funds from the Morningstar Direct database, finding significant fuzziness between funds claiming sustainability goals and those that do not. Many Article 9 funds, which should pursue sustainability objectives, exhibit behaviours akin to Article 6 funds, which lack explicit sustainability objectives. This suggests that the SFDR may not fully prevent impact washing and ensure adherence to declared social and environmental goals.

Paper 2, published in June 2024 in *Management Decision*, examines the rising phenomenon of impact litigation, where financial firms face legal challenges due to unmet impact objectives. With the increasing popularity of impact investing, firms face mounting pressure to demonstrate social and environmental impact. Failure to meet expectations can lead to accusations of impact washing, resulting in reputational damage, legal sanctions, market exclusion, and potential lawsuits. Based on semi-structured interviews with impact investment managers and lawyers, the inductive analysis using the Gioia methodology identifies four key themes that may trigger litigation: i) the lack of clarity around impact investing definitions; ii) the rise of impact washing; iii) the absence of shared impact measurement standards; and iv) misalignment of interests among stakeholders. The paper recommends adopting rigorous governance mechanisms, including clear contractual frameworks, to improve transparency, accountability, and prevent impact washing.

Building on Paper 2, Paper 3, currently under review in *Accounting, Auditing & Accountability Journal*, focuses on strategies to develop effective impact governance. It addresses a gap in the literature: the lack of stakeholder engagement in decision-making processes for impact investments. While these investments aim to benefit a wide range of stakeholders, particularly vulnerable communities, these groups are often excluded from the impact measurement and management (IMM) processes. The paper proposes a participatory decision-making framework that integrates stakeholder perspectives into IMM. Grounded in dialogic accounting theory, it emphasises the importance of dialogue and inclusivity to ensure that impact investments align with community needs. Through focus groups and interviews with European impact investing practitioners and academics, the paper identifies four stages where stakeholder engagement is crucial: i) defining impact objectives; ii) data collection; iii) monitoring and reporting; and iv) performance evaluation. Proactive communication and feedback throughout these stages ensure that investments move toward achieving predefined impact outcomes, thereby improving transparency and reducing the risk of impact washing.

The findings of this dissertation have theoretical and practical implications. Theoretically, it advances impact investing literature by examining the integrity of practices in the European financial market, focusing on tackling impact washing. The dissertation contributes to research by moving beyond definitional debates and assessing the effectiveness of impact investments in achieving social value. It introduces management theories such as organizational category theory, agency theory, and dialogic accounting to the field, providing depth to the traditionally practitioner-driven literature. These theories highlight the importance of governance structures, stakeholder alignment, and participatory decision-making in preventing impact washing.

Practically, the research offers recommendations for regulators and practitioners. These include: i) strengthening regulatory frameworks like the SFDR to prevent impact washing; ii) implementing stronger governance structures to mitigate impact litigation risks; and iii) adopting participatory decision-making models to engage key stakeholders in impact measurement and management processes.

The dissertation has some limitations, which can inform future research. First, the focus on the European context limits the generalisability of the results to other regions with different regulations and market dynamics. Second, the research concentrates on equity-based financial instruments, particularly investment funds. Further research could explore other financial instruments and strategies in different geographical contexts. Lastly, while the mixed-method approach enhances the research, refining the individual research designs could deepen the overall contribution.

In conclusion, while the European impact investing sector has made significant progress in promoting social and environmental value creation, challenges remain in ensuring market integrity. Regulatory frameworks like the SFDR are crucial for transparency but insufficient to prevent impact washing. Investment firms must adopt rigorous governance mechanisms to ensure their impact claims are transparent and credible.

FOSTERING HEALTHCARE INTER-PROFESSIONAL COLLABORATION AND CO-DELIVERY AMONG VOLUNTARY ORGANIZATIONS AND HEALTH PROVIDERS

Federico De Luca - Supervisor: Cristina Masella

Co-Supervisor: Daniela Sangiorgi

This thesis investigates the dynamics and strategies of collaboration between volunteers and socio-health professionals in the co-production of healthcare services within the Italian context. Healthcare systems face increasing pressure from rising costs, growing demand, and limited resources, which have amplified the need for volunteer contributions to support service delivery. Effective inter-professional collaboration between volunteers and healthcare professionals is essential for improving service efficiency and patient outcomes. However, role ambiguity, professional hierarchies, and operational misalignment often undermine these efforts. This thesis aims to identify the key factors that facilitate successful collaboration between volunteers and healthcare professionals and to explore how co-production strategies can enhance service delivery and long-term sustainability in healthcare settings.

The research addresses two core research questions: (1) What factors enable effective collaboration between voluntary organizations and health and social care professionals in implementing services? (2) How can co-production strategies be developed to enhance service delivery among volunteers and health professionals? A multidisciplinary approach combining qualitative methods is employed across four case studies, each examining a specific aspect of volunteer integration and inter-professional collaboration in healthcare (figure 1).

The first study explores the role of volunteer organizations in Italy's Community Health Centers (CHCs), which serve as hubs for primary care and health promotion. Findings reveal that successful integration of volunteers depends on well-defined roles, clear communication channels, and shared governance frameworks. Volunteers are pivotal in organizing health screening events, supporting patient navigation, and providing health education. However, challenges arise from resource allocation issues and the alignment of volunteer activities with clinical priorities, which require targeted management strategies to resolve.

The second study examines the integration of volunteers in pediatric care, focusing on relational and operational dynamics between volunteers and healthcare professionals. Trust, mutual respect, and structured training programs emerge as key facilitators of effective teamwork. Volunteers provide emotional and practical support to patients and families, enhancing the overall care experience. However, role conflicts and inconsistent recognition from healthcare professionals present challenges, highlighting the need for better-defined protocols and ongoing communication to strengthen volunteer integration.

The third study investigates the role of territorial labs in community-based mental health services. These labs serve as experimental spaces where healthcare professionals, volunteers, and service users collaborate to design and deliver mental health interventions. Key success factors include horizontal leadership structures, flexible service models, and the involvement of "experts by experience" in shaping care delivery. Findings suggest territorial labs enhance service adaptability and responsiveness by leveraging community resources and fostering shared decision-making. However, sustaining these initiatives requires stable funding and strategic governance to address stakeholder alignment issues.

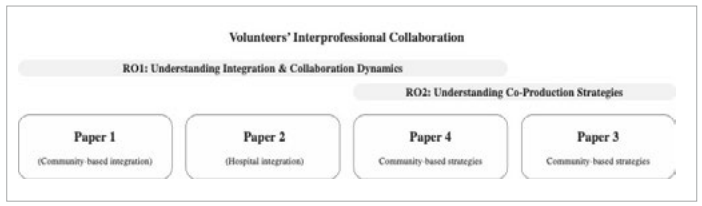

Fig. 1 - Thesis conceptual framework

The fourth study focuses on developing Family Centers in Brescia, which aim to integrate social and healthcare services through partnerships with third-sector organizations. Effective co-delivery depends on clearly differentiating professional and volunteer roles, consistent communication, and strategic alignment of service goals. Volunteers contribute to family support services such as counseling, health education, and peer mentoring. However, barriers, including professional resistance, role ambiguity, and inconsistent funding, must be addressed to improve the effectiveness and sustainability of the Family Center model. Collectively, the findings highlight the importance of structural clarity, shared governance, and cultural alignment in fostering inter-professional collaboration. Effective volunteer integration requires well-defined roles, consistent training, and mechanisms for feedback and adaptation. Cultural dynamics, including professional identity and power relations, significantly shape collaboration outcomes. Strategies that promote horizontal communication, mutual trust, and collective problem-solving enhance the resilience and effectiveness of co-produced healthcare services.

The thesis makes significant theoretical and practical contributions to healthcare management and service design. From a theoretical perspective, it advances understanding of inter-professional collaboration and co-production in healthcare, particularly concerning volunteer integration. The research extends existing frameworks by identifying the mechanisms and conditions that enable effective collaboration in hybrid healthcare models. From a practical standpoint, the thesis provides actionable insights for healthcare providers, policymakers, and volunteer organizations. Recommendations include developing standardized training programs for volunteers and healthcare professionals, establishing clear governance structures for managing volunteer integration, and creating feedback loops to monitor and adapt collaboration strategies over time.

This research contributes to the broader debate on healthcare innovation and sustainability, highlighting the role of volunteer-supported co-production in enhancing service efficiency and patient outcomes. The findings underscore the need for adaptive, inclusive, and resilient healthcare models that leverage the strengths of both professional and volunteer contributions. Future research is encouraged to explore the long-term impacts of hybrid service models and the evolving role of volunteer organizations in shaping healthcare delivery.

THE IMPACT OF IMMERSIVE TECHNOLOGIES ON CUSTOMER EXPERIENCE

Michele Di Dalmazi - Supervisors: Lucio Lamberti

The widespread commercialization of virtual reality (VR) technologies has sparked increasing interest in their ability to enhance marketing strategies and consumer engagement.
These immersive technologies offer brands innovative ways to connect with consumers throughout various stages of the marketing funnel. However, existing research on the tangible impact of immersive experiences remains fragmented and limited. While the initial enthusiasm surrounding VR was followed by skepticism, businesses continue to experiment with and integrate extended reality (XR) solutions into their marketing initiatives. Nevertheless, critical gaps persist in understanding how these technologies generate business value, particularly due to uncertainties related to return on investment. Many companies hesitate to adopt VR-driven marketing due to unclear performance indicators, low consumer adoption rates of VR devices, and the absence of standardized frameworks for designing and assessing immersive experiences effectively. Additionally, prior studies have largely concentrated on either technological advancements or consumer perceptions, with minimal empirical research investigating how immersive technologies influence decision-making across different marketing funnel stages.
This dissertation seeks to bridge these gaps by analyzing the impact of immersive technologies on customer experience and assessing their effectiveness in driving business value. Specifically, the primary research objective explores how immersive technologies influence customer experiences across various stages of the marketing funnel. To address this question, the study is structured around three key objectives. The first examines the potential of immersive experiences to create business value in areas such as product placement, branding, and tourism. The second identifies moderating factors, including consumer characteristics and elements of the immersive experience, that affect the success of these initiatives, thus informing targeted marketing strategies. The third advances methodological approaches in immersive marketing research by incorporating explicit and implicit measures—such as eye-tracking, electroencephalography, and galvanic skin response—to objectively assess consumer reactions.
This dissertation employs an experimental methodology, utilizing a multi-method approach to examine the effects of immersive technologies on consumer behavior. This approach enhances measurement precision by integrating self-reported responses with physiological and behavioral data, addressing gaps in existing literature that primarily rely on subjective assessments. The methodology aligns with recent marketing research calls for more objective, real-time consumer engagement and decision-making metrics. Three out of the four papers included in this dissertation adopt an experimental research design, which is particularly suited for establishing causal relationships between immersive technology usage and consumer behavior.
The first paper establishes a foundational analysis of the most promising marketing applications of immersive technologies. It identifies three key areas where VR can generate significant business value: product placement, where immersive environments enhance brand recall; green branding, where VR's capability to simulate realistic nature-based experiences strengthens sustainability perceptions; and tourism marketing, where virtual previews of destinations shape consumer intentions. This study also highlights key challenges, including barriers to consumer adoption and complexities in content creation, setting the stage for subsequent experimental investigations.
The second paper explores the effectiveness of product placement in immersive environments, focusing on the role of presence and attentional mechanisms. The findings indicate that exploratory tasks and heightened presence enhance brand recall, whereas goal-oriented tasks reduce attention to placed products, leading to advertising blindness. The study demonstrates that perceptual attention, measured via eye-tracking, and cognitive engagement, assessed through electroencephalography, mediate recall effectiveness through distinct pathways. These insights provide practical recommendations for marketers designing product placements in VR environments, emphasizing the need to balance immersion with attention management.
The third paper examines how VR-based environmental storytelling influences consumer perceptions of a brand's sustainability efforts. The study finds that VR enhances green brand image by fostering a sense of presence and emotional engagement in virtual nature environments. However, its effectiveness varies depending on consumer involvement levels—VR is more impactful among less environmentally engaged users but has a weaker effect on highly involved consumers. This research contributes to sustainability communication studies by illustrating how immersive experiences shape brand associations through implicit persuasion, while also raising ethical concerns regarding the potential for misleading sustainability claims in virtual environments.
The fourth paper investigates the effects of VR-based tourism previews on consumers' intention to visit and recommend a location. Results indicate that immersive experiences intensify emotional responses and increase visit intentions and word-of-mouth recommendations. Additionally, the study finds that age moderates these effects, with older consumers displaying stronger reactions to the emotional arousal induced by VR. Presence is identified as a key mediator in shaping behavioral responses, reinforcing the idea that immersive media's effectiveness depends on how convincingly users feel present in the experience. This research extends knowledge on digital tourism marketing by demonstrating that immersive previews serve as powerful promotional tools, particularly when targeting experience-driven demographics.
This dissertation contributes to the literature on immersive consumer experiences by systematically evaluating the role of presence in VR marketing. It addresses conflicting findings regarding the interplay between presence and key outcomes such as memory, green brand image, and consumers' intentions to purchase or recommend products. Furthermore, this work sheds light on the underlying mechanisms driving the effectiveness of immersive technologies in achieving awareness and conversion objectives. It responds to recent calls for further research into the cognitive processing of product placement in three-dimensional virtual environments while expanding previous findings on destination marketing, which emphasize immersive media's ability to elicit stronger emotional responses. The study also explores individual factors that have been either underexamined or have produced inconsistent results in existing literature.
From a managerial standpoint, the research offers firms guidelines for optimizing immersive marketing strategies, ensuring that VR applications align with consumer engagement patterns. It provides insights into audience segmentation, particularly how consumer demographics and involvement levels influence VR effectiveness, and outlines best practices for designing immersive experiences that balance attention management with storytelling to maximize advertising impact. Moreover, the study highlights the ethical considerations surrounding immersive marketing, particularly regarding consumer data collection and manipulation risks. As VR marketing tools become increasingly sophisticated, concerns about invasive targeting and misleading brand messaging grow. Businesses must address these ethical challenges by promoting transparency and fairness in immersive advertising practices.

DRIVING SUSTAINABILITY WITH LEAN: UNLOCKING THE POTENTIAL OF LEAN MANUFACTURING PRACTICE FOR ENVIRONMENTAL PERFORMANCE IMPROVEMENT

Matteo Ferrazzi - Supervisor: Alberto Portioli

Lean Manufacturing has emerged as a vital strategy for the optimization of industrial operations, the reduction of waste, and the enhancement of productivity. Nevertheless, its contribution to the improvement of environmental sustainability has remained relatively unexamined. The escalating global apprehension regarding climate change, resource depletion, and ecological degradation has exerted mounting pressure on manufacturing industries to synchronize their processes with sustainability objectives.
This research explores the application of Lean Manufacturing Practices (LMPs) in enhancing environmental performance within the manufacturing sector. This thesis offers a noteworthy contribution to the comprehension of how to employ Lean methodologies for the advancement of sustainability initiatives.
The primary objective of this research is to analyze the relationship between Lean Manufacturing and environmental performance, to determine how LMPs can be effectively utilized to promote sustainability improvements. The study examines both the direct and indirect effects of LMPs on sustainability outcomes, identifying those practices that exert the most significant influence. In addition, it investigates the interdependencies among various LMPs, distinguishing between technical (hard) and managerial (soft) practices to better comprehend their combined impact. Given the significant failure rate of Lean projects focused on improving sustainability, this research also aims to identify the main barriers to success and the strategies that can mitigate these obstacles by using an integrated Lean approach
The study adopts a mixed-method approach, incorporating both qualitative and quantitative methodologies. A systematic literature review was conducted to establish a foundational understanding of how Lean and environmental performance interact, identifying critical gaps in existing research. Expert-driven decision-making tools such as DEMATEL (Decision-Making Trial and Evaluation Laboratory) and IRP (Interpretive Ranking Process) were used to analyze the relationships among different LMPs and assess their relative impact on environmental performance. Furthermore, a collection of case studies offers valuable insights into implementing Lean initiatives within actual manufacturing environments, emphasizing the elements that lead to their success or failure. The integration of these methodologies guarantees that the research findings are both theoretically sound and practically applicable and relevant.
The findings of this research highlight that while Lean Manufacturing has significant potential to drive sustainability improvements, its effectiveness is contingent upon a structured and strategic implementation of LMPs. This study introduces a systematic, sequence-based approach that manufacturing companies can follow to enhance their environmental performance, ensuring that Lean initiatives are executed to maximize their sustainable impact. The proposed sequence is based on understanding the interaction between soft and hard Lean Management Practices (LMPs). It begins with managerial-oriented soft LMPs, which promote leadership commitment, strategic vision, and aligning environmental objectives with corporate goals. Subsequently, it includes employee-focused soft LMPs that are crucial for fostering an organizational culture conducive to sustainability driven by Lean principles. Employee engagement, a mindset focused on continuous improvement, and structured training programs are vital for successfully implementing Lean methodologies. Upon the establishment of these foundational conditions, the implementation advances to the integration of process technology-intensive Lean Management Practices (LMPs), with a focus on incorporating lean tools that enhance production processes and minimize waste. The concluding phase involves deploying production planning and managing robust LMPs, ensuring that sustainability is integrated into daily operations through methodical planning, monitoring, and performance assessment mechanisms.
This phase is directed by prioritization strategies based on the environmental impacts associated with each LMP, ensuring that the most effective tools are implemented initially to realize maximum benefits. A significant contribution of this research lies in identifying critical interdependencies among LMPs, underscoring that, without the foundational support of soft LMPs, the implementation of hard LMPs may not yield substantial environmental enhancements. Furthermore, the study delineates the considerable challenges that organizations face in their pursuit of sustainability through the Lean approach. By adhering to the recommended sequence, organizations can systematically address these challenges, thereby ensuring that Lean projects not only enhance operational efficiency but also contribute to substantial and lasting sustainability benefits.
The contributions of this research extend to both academic and industrial domains. From an academic perspective, this study enhances the theoretical understanding of the intersection between Lean Manufacturing and sustainability, providing empirical evidence regarding the effectiveness of various LMPs. Furthermore, it addresses a significant gap in the literature by demonstrating the importance of integrating technical and managerial Lean practices to maximize environmental benefits. The research presents invaluable practical guidance for manufacturing enterprises on effectively implementing Lean practices for sustainability. Organizations can strategically deploy LMPs to optimize their environmental impact by offering a structured implementation framework while minimizing failure rates. The findings of the thesis advocate for a holistic approach that combines technical LMPs with a robust organizational Lean culture. Furthermore, the research emphasizes the need for companies to go beyond the simplistic perspective that "Lean is Green" and to adopt a more detailed and evidence-based approach to integrating Lean sustainability.
In conclusion, although Lean Manufacturing presents significant tools for enhancing efficiency and minimizing waste, its capacity for fostering environmental sustainability can only be fully realized through a methodical and strategic implementation. By addressing critical disparities in both theoretical and practical applications, this research offers a comprehensive framework that enables manufacturing companies to exploit the environmental potential of Lean and achieve lasting sustainability success.

LEADING DIGITAL TRANSFORMATION: A STRATEGIC AND OPERATIONAL PERSPECTIVE ON THE UNDERLYING ROLE OF LEAN MANAGEMENT

Stefano Frecassetti - Supervisor: Alberto Portioli Staudacher

Companies continuously seek to find innovative approaches to improve operational efficiency and competitiveness. The rise of cutting-edge digital technologies has intensified this momentum, pushing companies to embrace digital transformation. Thus, an increasing focus has been given to how companies can adapt to digital transformation to increase their performance. Among the others, it has been seen that the extensive use of Lean Management practices seems to be pivotal in obtaining a successful digital transformation.
This research explores the centrality of Lean Management in facilitating digital transformation within manufacturing companies, considering both operational and strategic perspectives. Rather than viewing digital transformation as a purely technology-driven process, the study argues that Lean Management, traditionally focused on continuous improvement and waste reduction, serves as a key enabler.
The study's primary objective is to investigate how Lean Management facilitates digital transformation and how this influences companies' performance improvement. This overarching goal is explored from two angles: at an operational level, by examining how Lean Management practices reduce barriers to digital adoption, and at a strategic level, by analyzing how these principles influence companies' patterns of approach to digital transformation and performance improvement. The study employs a multi-method approach that integrates both qualitative and quantitative methodologies to achieve these objectives. Case studies explain the nature of the relationship between Lean Management and digital transformation, showing how it helps reduce barriers and shape more straightforward patterns of approach to digital transformation. Survey-based studies provide quantitative validation of the facilitating effect that Lean Management has on digital transformation, showing its centrality in ensuring a successful transformation.
The Interpretive Ranking Process (IRP) methodology is also applied to rank the most effective Lean Management practices for overcoming digital transformation barriers.
The findings show that Lean Management significantly reduces digital transformation barriers, allowing companies to integrate new technologies more effectively. Thanks to pivotal elements such as workflow efficiency, employee engagement, and process standardization, an environment based on Lean Management is more receptive to these technologies. Furthermore, this study shows that Lean-based companies adopt digital transformation with more structured and incremental patterns than their non-Lean counterparts. This results in a smoother process and tangible performance improvements, such as increased operational efficiency and reduced costs.
The research entails both theoretical and practical implications, contributing to the ongoing discussion. From a theoretical perspective, it advances the understanding of the relationship between Lean Management and digital transformation by shedding light on the nature and strength of this relationship. It demonstrates that Lean Management does not merely help companies adapt to technological change but actively drives them throughout the whole digital transformation journey. By introducing a dual operational-strategic perspective, this thesis offers a more nuanced analysis of Lean Management's role in addressing digital transformation. From a more practical perspective, the study delivers guidance for companies seeking to embrace digital transformation successfully. It offers insights into how firms can leverage Lean Management practices to facilitate a more efficient and effective digital transformation. Moreover, it identifies the most critical Lean Management practices that help overcome digital transformation barriers, allowing companies to conduct more informed decision-making on the best practices to focus on. Further, by outlining a structured roadmap for digital transformation, this research underscores the importance of developing structured patterns of approach to digital transformation that align technological advancements with organizational culture and operational processes. With this framework, companies can benchmark their current state in the digital transformation and take corrective actions.
In conclusion, this research challenges the conventional view that digital transformation is solely a matter of technological implementation. Instead, it asserts that Lean Management acts as a crucial enabler, shaping digital transformation through structured methodologies, cultural alignment, and continuous improvement.
The research reinforces the importance of adaptability, learning, and a people-centric approach, positioning Lean Management as a fundamental pillar in the future of digital transformation for manufacturing firms.

TRANSPORTS SYSTEMS IN URBAN AREA: INVESTIGATING THE DUAL PERSPECTIVE OF MOBILITY SERVICE PROVIDER AND LOGISTICS SERVICE PROVIDER

Giovanni Garola - Supervisor: Riccardo Mangiaracina

Co-Supervisor: Chiara Siragusa

Transport Systems represent a central topic of debate for both academia and policymakers due to their implications on society and their managerial complexity. The transport sector generates negative social externalities (i.e., incidents) for around 6.6% of Europe's GDP and, at the same time, is responsible for 24.4% of European GHG emissions. The recent policies on transport decarbonisation and vehicle reduction combined with those to improve the quality of life in urban contexts have further emphasised the pivotal role of Public Transport in achieving these goals. In contrast, less attention is given to City Logistics, i.e. the logistics activity which ensures city supply, which has faced an increase on the demand side (B2C eCommerce is expected to have a CAGR of 9.32% from 2024 to 2029), while dealing with the context evolution previously mentioned. In addition, policymakers paid less attention towards logisticians, creating more challenges for the Logistics Service Providers and uncertainty in the service for the end consumers.
The 2020 pandemic posed significant challenges to the Transport System, significantly changing users' travel and purchasing habits. Its long-term effects on transport still need to be comprehensively investigated, thus making past knowledge less relevant in the management and planning of Transport Systems. This raises attention on how the decision-makers manage Transport Systems and how models and data can support them in understanding the system and its possible evolutions. Moreover, the pandemic highlighted the relevance of both the Public Transport Service and Freight Transport Service, opening the discussion on how these can be managed and integrated to improve the efficiency and effectiveness of both services.
With these premises, the following work aims to "*Investigate how the post-pandemic context has transformed the Public Transport and Freight Transport Systems in the urban context, also exploring existing synergies between them*". To achieve this objective, the research first analyses the context in detail, highlighting the changes in Public Transport and Freight Transport Services. Subsequently, four main research questions are defined to guide the work more clearly.
More in detail, the aim of this work is twofold: On the one hand, to understand how the Policymakers' decisional process on public transport, with the support of models and mobility data, was impacted by the pandemic event. On the other hand, to understand how the pandemic affected the Logistics Services Provider and how these reshaped their strategies for long-term sustainability. In addition, given the spatial, contextual, and regulatory similarities, it aims to investigate how Logistics Services can interact with Public Transport creating collaborative solutions to improve the systems' sustainability.
To reach the objective four research questions are formulated. Specifically, RQ1 and RQ2 aim to understand how continuous data collection can support the understanding of users' mobility habits (temporal, spatial and means of transport) and thus how a policymaker can use this information to define transport policies.
Instead, RQ3 analyses how the pandemic affected Logistics Services in the urban context to understand long-term implications on their operations and policies. Finally, RQ4, supported by the evidence of RQ1, RQ2 and RQ3, contributes to the discussion on the integration between Public Transport and Freight Transport services, analysing a potential solution to meet both systems' needs. To answer the research questions, the works adopt different methodologies, both qualitative and quantitative, supporting and validating the results, where possible, with empirical data.
The following PhD thesis is developed in collaboration with the transport and infrastructure department of Regione Lombardia, a northern Italian region of approximately 10 million inhabitants. The policymaker after the pandemic event faced the challenge of understanding the new mobility behaviours in the region to develop policies for the regional railway service, which represents a crucial infrastructure (more than 1900 km of rails and more than 700 thousand passengers daily).
The following thesis is structured as a collection of 6 articles, contributing to answering the RQ and the objective of the work. This thesis contributes to the study of mobility habits, highlighting how the data are functional for developing consistent transport policies and investigating the integration of passenger and logistics transport services, highlighting the synergies and benefits for all the actors involved.
The following thesis aims to provide a practical tool for academia and practitioners to develop policies and methodologies for the Transport System. Considering the first ones, the work offers a multifaceted approach to investigating Transport Systems by combining qualitative and quantitative methodologies, combining empirical data to strengthen the results. Then, it offers extensive classifications on different subjects (i.e., Data Collection Methodologies, Demand Determinants and City Logistics), clarifying and updating the existing knowledge on these topics. With a focus on the rail system, the work contributes to develop a methodology to estimate the effects of different rail interventions, providing an actionable tool for policymakers. Furthermore, the study contributes to expanding the knowledge of logisticians' response to the pandemic period and the role of resources in overcoming this event by means of empirical evidence discussed through established theories. Additionally, the research contributes to the discussion of the integration of passenger and parcel transports, considering a reverse approach (the parcel service is prioritised) with associated shifts in the modelling approach, evidencing the system's viability.
Considering the Policymakers, the work clarifies how digital technologies can be further leveraged to investigate users' behaviour and support the decisional process. In addition, it provides a detailed conceptual map of the users' behaviour to further induce the modal shift towards public transit. Besides, it develops a tool suitable for investigating the impacts of different railway policies, thus streamlining the process and providing reference values.
Instead, considering the Logistics Service Provider, it highlights the importance of resources in managing disruptive events and the need to identify an alternative distribution system. Moreover, it provides a detailed classification of existing City Logistics solutions considering their main application barrier, highlighting how these can be potentially overcome. Finally, considering both stakeholders, it provides evidence that the integration between two transport systems within the same context can bring benefits to both and the citizen, suggesting developing regulations to support the systematic adoption of these solutions as they can play a crucial role towards the accessibility and sustainability of the transport services.

ENHANCING ENERGY EFFICIENCY THROUGH SUSTAINABLE DESIGN: DEVELOPMENT OF NOVEL HEATING SYSTEM TECHNOLOGY TO REDUCE ENERGY CONSUMPTION AND ENVIRONMENTAL IMPACT IN THE USE PHASE OF PROFESSIONAL COFFEE MACHINES

Leonardo Gigli - Supervisor: Antonio Calabrese

Introduction

This industrial PhD Project research, sponsored by Simonelli Group, addresses the critical need for enhanced sustainable product design in professional coffee machines by improving energy efficiency technologies. Driven by academic and industrial concerns, this study acknowledges the growing global emphasis on environmental sustainability, particularly within the Horeca sector. The research aims to bridge the gap between theoretical exploration and practical application by developing a patented heating system technology to improve energy consumption and environmental impact during the machine's use phase.

Goals

The study is structured into three key research questions.
Firstly (RQ1), the research focuses on identifying high-energy-absorbing components within professional coffee machines. This involves a comprehensive literature review on energy efficiency and sustainable design, coupled with in depth analyses of representative machines. Life Cycle Assessment (LCA), Life Cycle Impact Assessment (LCIA), and sensitivity analyses are employed to identify energy-intensive processes accurately.
Secondly (RQ2), the study explores existing heating technology solutions in the professional coffee machine market. This includes a qualitative review of energy efficiency technologies, a classification of machines based on their heating systems, and an investigation into sensor advancements for beverage monitoring. The objective is to establish a thorough understanding of the current state-of-the-art and identify areas for technological improvement.
Thirdly (RQ3), the research focuses on the development and validation of a novel heating system technology. This technology, featuring an electronic PID control system for the steam boiler utilizing conductivity sensor readings, aims to significantly reduce energy absorption and environmental impact. The efficacy of this innovation is rigorously evaluated through LCA, LCIA, and sensitivity analyses, with comparative performance assessments against existing systems. The culmination of this research is the patent application for the novel heating system technology, marking a significant contribution to sustainable product design within the professional coffee machine sector.

Methodology, Results and Discussion

This industrial PhD project research. investigates the enhancement of sustainable design within the professional coffee machine sector, specifically targeting the Horeca market. The research begins by contextualizing the industry's current challenges, including the variability of coffee prices, rising operational costs due to increased utility and raw material expenses, and the destabilizing effects of geopolitical events on energy supply chains. These factors underscore the critical need for innovative, sustainable solutions. In the next stage, the study examines the growing emphasis on sustainable design practices within manufacturing over the past five years, highlighting initiatives aimed at minimizing environmental impact throughout a product's lifecycle. These practices, including energy efficiency enhancements, service optimization, and circular economy principles, provide a crucial framework for the development of a novel heating system technology. After that, a thorough analysis of the professional coffee machine market reveals significant growth in sales and revenue, particularly for traditional espresso machines, with a substantial portion of sales occurring internationally. This global market analysis reinforces the potential impact of the developed technology, demonstrating its capacity to provide significant energy savings and environmental benefits. To address the identified research gaps, the dissertation conducts a comprehensive Life Cycle Assessment (LCA) and Life Cycle Impact Assessment (LCIA) of professional coffee machines. These assessments establish the operational phase as the most environmentally impactful, with the steam heating element identified as the most energy-intensive component. Next, the research systematically analyzes heating technologies employed in professional coffee machines, revealing significant gaps in academic research. To bridge these gaps, a detailed classification of heating technologies is presented, categorizing systems based on their operational principles: thermosiphonic single boiler with mechanical control, thermosiphonic single boiler with digital control, and multi-boiler with digital control. This classification, based on an extensive examination of grey literature, provides a robust foundation for evaluating and enhancing heating systems. Subsequently, a comprehensive patent review further augments the body of knowledge, identifying and analyzing patent trends in water heating systems. This analysis reveals areas of high patent density and uncovers a significant opportunity for innovation in optimizing heating for espresso machines based on beverage type, directly informing the development of the novel heating system technology. In the following step, the study also investigates advancements in sensor technology for beverage monitoring, providing a comprehensive overview of sensors applicable to electrical, thermal, and mechanical measurements in professional coffee machines. This analysis supports the development of an innovative technology that integrates a conductivity sensor and PID control. In the final step, the novel heating system technology, integrated into Simonelli coffee machines, has demonstrated significant energy and thermal performance improvements, achieving energy reductions of 35-41% compared to traditional models. This innovation benefits both coffee machine manufacturers and the Horeca sector, offering a pathway to developing cutting-edge machines with enhanced performance and reduced environmental impact.

Conclusion and Future Research

This doctoral thesis significantly advances sustainable product design within the professional coffee machine sector through a comprehensive analysis of energy consumption and the development of a patented, energy-efficient heating system. This research addresses the critical need for sustainable solutions in the Horeca market, driven by escalating energy costs and environmental concerns. The core contribution is the innovative heating technology, which integrates a conductivity sensor and PID control to optimize energy use during key operational phases. This system intelligently adapts heating parameters based on beverage type, resulting in substantial energy savings. A rigorous Life Cycle Assessment (LCA) demonstrates a 34-42% reduction in energy consumption during the use phase for both single and multi-boiler machines. This reduction directly translates to a significant decrease in CO2 emissions, enhancing the environmental impact.
Furthermore, this study provides a detailed analysis of the challenges and opportunities within the industry, emphasizing the importance of sustainable design and technological innovation.
It underscores the economic implications of rising material and energy costs, demonstrating how companies can leverage energy efficiency to deal with these implications. The quantification of benefits resulting from the new heating system provides invaluable insights for both industry practitioners and academic researchers.
This research offers a valuable resource for those who want to advance sustainable product design in professional coffee machines. It highlights the potential of targeted technological advancements to drive significant reductions in energy consumption and environmental impact.
Finally, it offers the groundwork for future research, including longitudinal studies examining market dynamics and the long-term performance of the patented technology.

THE ROLE OF ARTIFICIAL INTELLIGENCE IN SUSTAINABLE INVESTING

Zeynep Hazal Kopal Maffezzoli - Supervisor: Mario Calderini

Co-Supervisor: Leonardo Boni

The dissertation, in the form of a collection of three papers, addresses the nexus between artificial intelligence (AI) technologies and sustainable investing by examining the state of the art, the potential benefits and limitations, and the ethical and practical criticalities arising from the integration of AI-based systems and tools into areas traditionally governed by human judgement in the sustainability rating and investment paradigms. This nexus is explored in three domains of the sustainable investment ecosystem: investments, ESG (environmental, social, governance) rating agencies, and issuers (i.e., companies receiving ESG ratings).
For sustainable investments to deliver its promise of driving shift towards long-term sustainable development paradigm and go beyond a marketing success, the measurement of ESG criteria alongside financial processes is necessary. For this reason, trustworthy ESG data has become more important than in the past to make informed capital allocations. ESG rating agencies, as a response to sustainability information in great demand, offer practitioners ESG assessments and insights on companies. Investors, today, invest trillions of dollars using ESG ratings. However, ever-growing criticisms about the transparency, reliability, comparability and consistency of ESG ratings make scholars doubt the validity of ESG ratings as sustainability measurement. While financial market increasingly integrates ESG criteria into investment decisions, "in terms of organisational reality, there seems to be no real shift toward more sustainable business practices" (Busch et al., 2016). The literature highlights the complexity of organisational reactivity, where companies mobilise resources either to improve their ratings or to challenge the validity and fairness of the assessments. The real-world impacts of ESG ratings on organisations is, therefore, less known.
AI technologies have emerged as potential solutions for investors to access and navigate large amounts of ESG information on companies' in an efficient and timely manner. Recent literature highlighted the potential of AI to revolutionise the sustainable finance industry through its ability to process large datasets, identify patterns and perform predictive analysis. Some ESG rating agencies in the market are already offering AI-based sustainability ratings and insights. Given the ESG data issues, the unstructured and subjective nature of sustainability disclosures and the overwhelming volume of data, both sustainable investment research and practice appear to be at a crossroads in understanding AI technologies to enhance sustainable investment strategies. Although literature and practice suggest potential advantages of AI tools, scholars pointed out doubts around the opacity of AI-driven methodologies and ethical risks that might arise from embedding human biases into training datasets. Accordingly, we still don't know the role AI plays in sustainable investments and in assessing companies' sustainability performances. Considering these gaps, the overarching objective of this dissertation is to understand whether and how AI help preserve the integrity of sustainable investments.
The research problem is investigated in the empirical settings of ESG rating providers and listed European companies. Due to the exploratory and emergent nature of the topic, a qualitative approach based on the Gioia method and abductive thematic analysis is adopted to analyse the data.
The first paper systematically reviews the literature on the intersection between AI technologies and sustainable investing and identifies clusters of AI application areas based on the conceptual framework of investment processes. Mapping the findings to this framework helps provide a common ground for the academic and practitioner communities and foster knowledge sharing. The findings, in fact, show a strong shift from traditional, manual processes to advanced, automated models that use advanced machine learning and natural language processing to quickly navigate ESG disclosures and additional, less common data sources.
For example, AI applications in pre-investment processes (e.g. screening based on ESG information) show a greater emphasis on a forward-looking perspective (e.g. predicting ESG controversies) compared to current ESG research and data, which are backward-looking. The paper also identifies benefits and limitations of AI applications in sustainable investments, which have not yet been comprehensively addressed by previous academic work.
The second paper, which collects empirical observations through semi-structured interviews with executives from global ESG rating providers, aims to shed light on the interplay between AI and human analysts in the measurement processes of ESG ratings, and the ethical and operational issues that arise from this interaction. The findings identify four aggregate dimensions that explain the distinctive role of AI and human analysts in sustainability rating and the related ethical issues: (i) AI's catalyst role for measurement; (ii) cognitive interpretation of measurement by humans; (iii) deterministic drift of technology; (iv) contingencies as exogeneous factors. While the data extraction and processing capabilities of AI are transformative, the findings highlight the need for creative cognitive and critical thinking skills unique to human analysts to ensure nuanced interpretation of sustainability in measurement. This highlights the trade-off between the quantity and quality of sustainability assessments, where an imbalance can lead to ethical issues. This work contributes to the first empirical evidence on AI-driven ESG ratings and complements the quantitative research on ESG ratings.
The third paper widens the lens to the supply side of ESG ratings and collects empirical data through semi-structured interviews with listed European issuers. The aim is to explore why and how ESG ratings are so widespread in among the financial actors, while their negative aura is so prevalent in determining social and environmental performance. The findings suggest that ESG ratings are being institutionalised, both symbolically and substantively, under the impetus of the financial sector as the main user of these instruments. The sub-themes under these two main constructs explain that this institutional shift creates both isomorphic costs and opportunities, and that normative and cultural pressures shape the adoption of ESG ratings by issuer companies along the symbolic-substantive continuum. While ESG ratings promote greater transparency over business practices and foster relationships with both internal and external stakeholders, they also imply costs for issuer organisations in exchange for legitimacy, and investor pressures that risk de-institutionalising measurement practices.
Finally, the findings of the thesis suggest that AI systems is expected to be increasingly integrated into sustainability assessments in the financial market, accelerated by the systematic production of sustainability data under upcoming non-financial disclosure regulations and increasing pressure from stakeholders. Consequently, a deeper understanding of the equilibrium between the precision and scalability offered by AI and the ethical challenges it poses paves the way for further investigation into how the increasing reliance on AI challenges existing systems in sustainable finance, and how these systems can be understood, regulated and trusted in institutional settings. Addressing this issue necessitates a concerted effort among academics, investors, technology providers and policymakers, with the objective of ensuring that AI tools fulfil their potential to enhance sustainable investment practices through more informed, data-driven decision-making, and developing consistent, reliable datasets and ethical governance frameworks to ensure that AI technologies are used responsibly in sustainability paradigms.

PUBLIC POLICIES FOR WELL-BEING: LIGHTS AND SHADOWS OF PROMOTING CULTURAL PARTICIPATION

Romain Lerouge - Supervisor: Michela Arnaboldi

In the last decades, the promotion of well-being has become the highest goal of many governments, institutions, and public agents in general. This necessity is felt particularly in Europe, where the European Union itself has set it as a crucial mission within its constituting treaty. As a result, an increasing number of programs and initiatives have been promoted aiming at monitoring well-being. Those efforts encourage the development of public policies more comprehensive of this social metric in the incoming years.

In this institutional landscape increasingly concerned with enhancing well-being, and socio-economic benefits in general, more attention has been brought forward toward the role of culture. This interest has catalysed particularly on cultural participation, deemed to be the main trigger of socio-economic change. Cultural participation is generally defined as the voluntary engagement in a broad set of activities, which are categorised into two groups: active and passive. While passive cultural participation refers to the attendance at cultural events, such as concerts or theatre, active cultural participation evokes a direct involvement in the creation and transmission of the cultural form, including activities such as painting, dancing or playing an instrument. The engagement in those artistic expressions carries values and norms of a society, and its promotion is considered to be relevant for the enhancement of people's enrichment, democratisation and social inclusion.

Towards the development of more rounded quality of life benefits, cultural participation is thus a key factor connecting public policy and citizens' benefits. Two main academic debates related to this topic can be identified. The first one discusses the association between cultural participation and well-being, mainly expressed through life satisfaction, a subjective cognitive assessment that reflects people's highest values and goals. Overall, a positive link between cultural participation and life satisfaction emerges. However, the effect appears in some cases as weak, differs depending on the cultural activities considered and varies also across different social groups in the population, suggesting the heterogeneity of the effect.

Cultural participation is not new to dynamics of inequalities. Since the seminar work of Bourdieu, it is in fact often depicted as a means of social distinction where the social benefits are mainly absorbed by advantaged classes. This dependence of people's outcomes on their social background has been framed and discussed in Equality of Opportunity theory, which identifies family background as the main determinant of those unbalances. Based on this theory, family belonging is set as a major determinant shaping people's propensity to participate, but also their ability to extract utility from cultural participation, and to achieve higher life satisfaction in general. This dynamic is particularly relevant for policy-makers, concerned with the identification and containment of those structural inequalities.

The second debate, instead, focuses on the role of public policies in the promotion of people's cultural engagement. The primary role of cultural policy lies in the provision of arts, and incentivising cultural participation is presented as a priority to enrich people's lives, and advance democratisation and social inclusion. Instead, some authors criticise this view claiming that, rather than enhancing people's engagement in the arts, public initiatives tend to favour only limited social groups. People's propensity to participate is indeed dependent also on other factors such as their level of education and income, which deeply affect the ability of policies to reach a larger public. In this perspective, few studies investigate the extent to which cultural expenditures are associated with cultural participation focusing on a local level, where spatial dynamics of cultural agglomeration and the territorial link with local cultural participation become visible. However, the influence of socio-economic characteristics of the population is still overlooked in the evaluation of policies' effectiveness, and further investigation remains limited by the difficulty of finding granular data on local public expenditures.

Considering the gaps highlighted, this thesis explores the role of cultural participation as an instrument of public policy to promote well-being, exploring the influence of people's socio-economic characteristics in shaping both their engagement in the arts and their expected outcomes in terms of well-being distribution in the population.

On one hand, this thesis shows the limitations of relying exclusively on cultural policies for the enhancement of cultural participation without considering the influence of socio-economic barriers. At the same time, it also presents the opportunities granted once those barriers are overcome, when the disadvantaged groups can offset most of the well-being inequalities with respect to the rest of the population. To address the risk of social exclusion, broaden the audience engaging in the arts, and ultimately maximise the well-being benefits in a population, policies aiming at promoting participation need to be accompanied by complementary measures that fall beyond the strictly "cultural" domain.

In this direction, three main aspects emerge as potentially relevant as a complement to cultural policies: education; physical accessibility; and social identity.

Education is set as a crucial determinant of cultural participation, visible both at an individual and territorial level. This thesis depicted it also as an inter-generational investment, for which parents can affect people's propensity to participate and ability to fully benefit from participation, transmitting cultural profiles and identity across generations. This thesis outlines the importance of educational investments, and their interconnection with cultural ones. The higher the spending on education, the better the schooling level in a city, the stronger the link between cultural spending and local participation. In other words, while cultural participation is a lever for addressing people's well-being, education is an enabler: it enables people to engage, but also to obtain benefits from their engagement.

Another actionable aspect for policy is the reinforcement of physical accessibility to cultural facilities, explored in this thesis in a broader sense considering people's ability to commute easily towards cultural facilities, and across the city in general. Indeed, while empowering an efficient transportation network allows citizens to reach easily cultural places, in a larger view it incentivises journeys around the surrounding areas, facilitating encounters, the exploration of city's offerings, and strengthening communitarian links.

The third and last aspect that emerges in this thesis is the development of a social identity. The social aspect has certainly been pointed out as a source of distinction and exclusion, but it could also be the key to address them. On one hand, building stronger territorial links serves as a vehicle to reinforce social belonging, and reinforcing synergies and agreements among neighbouring municipalities could play a central role in this direction. On the other hand, favouring the plurality of cultural expressions available could provide tailored artistic forms closer to the excluded social groups. This thesis outlined the richness of cultural expression and most of them resulted as particularly relevant for people from disadvantaged families, with few exceptions for which they appear to miss the proper means to fully understand and thus benefit from the cultural form. In a multicultural, globalised and diverse society, each social group should have its own artistic channels to express its values and identity, enhancing its sense of belonging to a defined community.

NAVIGATING STRATEGIC CHALLENGES IN LEVERAGING AN ENABLING TECHNOLOGY: THE CASE OF 5G

Mattia Magnaghi - Supervisor: Antonio Ghezzi

Throughout its relatively short but lively history, the mobile telecommunications industry has undergone several dramatic technological shifts, which have entailed significant changes in telcos' business. Among such shifts, one that holds the deepest and most cross-cutting implications at all levels of the value network is certainly the regulated transition from one generation – or "G" – of mobile network infrastructure to another. From the first generation, or 1G, deployed in the '80s to deliver analog voice services, mobile networks have come a long way and reached their current technological apex with the rollout of 5G, which started in 2019.
According to the literature, the shift to 5G networks can be considered a "game changer," and estimates suggest that focusing on its development in key sectors such as mobility, healthcare, manufacturing, and retail could lead to a substantial boost in global GDP, with a potential increase of up to $2 trillion by 2030 (McKinsey & Company, 2022).
Therefore, 5G cannot be simply considered a technological transition; rather, it represents a revolutionary phenomenon that could deeply change the competitive landscape for wireless services. Due to its potential impact on the economy and society, 5G has been classified by both scholars and practitioners as an enabling technology. According to the literature, enabling technologies (ET) are adaptable and upgradable technologies with improvement potential and broad applicability. Even though they share some characteristics with General-Purpose Technologies (GPTs), their economic impact in terms of pervasiveness in wide use is still uncertain.
Although 5G represents a revolutionary technology, it has not yet become widespread across industries. For this reason, 5G deployment requires a change in the telecommunications actors' attitude, especially regarding Mobile Network Operators (MNOs), who have traditionally been the key players in the telecom industry. Over the past years, they have made substantial investments in this technology (e.g., 5G spectrum licenses, infrastructure) but are now struggling to capitalize on the expected returns. This is the case in Italy, where frequencies for 5G service provision are exclusively held by MNOs who made investments in 2018. These actors feel an urgent need to commercialize the technology since (1) their investment in these frequencies was very costly and (2) they are going through a period of crisis that has seen a significant reduction in revenues in recent years.
From both a theoretical and a practitioner's perspective, the approach taken so far to analyze the multifaceted 5G phenomenon has been mostly technology-driven, as it places a strong emphasis on 5G's technicalities and features, which are said to possibly enable a plethora of yet-to-be-defined services and applications. This emphasis on the technological superiority of 5G over other alternatives, however, fails to make a compelling case for its adoption and comes at the expense of a sound strategic analysis of its business implications, in terms of the emerging business models it could catalyze, as well as the changes in strategic approaches and industry reconfigurations it could require.
As a result of this disproportionate focus on 5G's potential, this infrastructural technology, which was expected – possibly too superficially or enthusiastically – to drive "revolutionary" business impacts, has given rise to a market that is currently struggling to emerge and stabilize.

Looking at the literature on 5G, this issue clearly emerges: in the bibliometric analysis conducted by Mendonça and colleagues (2022), most of the included publications belong to the fields of "Electronics and Telecom Engineering" and "Information Technology and Processing." However, it is rather surprising that only 0.23% of the publications belong to the "Business and Economics" category, considering that the first release (Release 15) was issued in 2018 and that, from a technological perspective, 5G appears to have reached an appropriate level of development.
Upon further exploration, it became evident that even in the literature on ET, the strategic analysis concerning ET adoption is partially neglected. Indeed, when a GPT emerges, the literature tends to focus on its broad applicability and economic impact or on defining its scope. Only recently have scholars begun examining GPTs from a firm-level perspective, particularly regarding the innovator's value capture challenges.
However, unlike discrete technologies (DTs), which are designed for specific purposes, ETs pose significantly more complex and intriguing challenges for innovators seeking to profit from them. This complexity stems from the need to consider an additional dimension in their decision-making process: the horizontal scope of commercialization across multiple vertical industries.
Furthermore, when proposing strategic alternatives, the existing perspective in ET literature does not highlight the relationships between the various downstream actors responsible for commercializing the technology; instead, it only emphasizes a "vertical" relationship between those who own the technology and those who are supposed to implement and sell it further. In other words, the ecosystem structure, defined as "the collaborative arrangements through which firms combine their individual offerings into a coherent, customer-facing solution" (Adner 2006, p. 98), is notably absent from the existing literature on ET. However, it is reasonable to assume that during the initial stages of ET commercialization, both coordination (i.e., who should do what, when, and in what quantities?) and cooperation (i.e., how are actors incentivized to engage in coordinated innovative efforts?) challenges would likely arise.
In light of these considerations, this study aims to investigate the strategic implications of 5G adoption, considering its ET nature, both from a firm-specific and an ecosystem perspective.
This study has three main objectives. Firstly, it aims to trace the state of the art of 5G technology and review existing theories used to investigate 5G's strategic challenges, positioning the topic within managerial literature (RO1). Secondly, it aims to contribute to the BMI and ET literature by examining the strategic impact of ETs from a firm-specific perspective, specifically that of Italian MNOs (RO2). Thirdly, it seeks to contribute to the literature on ecosystems by exploring the business and management impacts of ecosystem dynamics based on ETs such as 5G (RO3). This involves understanding the bottlenecks in 5G commercialization within the telecommunications industry and beyond and examining how the roles of various players are evolving with the introduction of 5G.
This research can thus contribute to both theory and practice. From a theoretical perspective, the thesis highlights the need for a strategic analysis of 5G challenges, moving beyond technology-driven approaches, and provides a thorough review of the existing literature on the topic, which is then used to suggest a future research agenda. Furthermore, this thesis bridges the ET and BMI literature streams, offering fresh perspectives on how MNOs can navigate strategic dilemmas. Additionally, it contributes to the ecosystem literature by identifying critical bottlenecks in 5G commercialization and presenting a comprehensive framework that addresses both firm-level and ecosystem-wide challenges.
From a practical standpoint, the thesis provides valuable managerial insights for MNOs and other stakeholders, helping them develop sustainable business models that harness 5G's potential.

THE DIGITAL TRANSFORMATION OF HEALTH PROFESSIONALS' WORK: COORDINATING THROUGH, WITH, AND AROUND DIGITAL HEALTH TECHNOLOGIES

Mattia Vincenzo Olive - Supervisor: Luca Gastaldi

Digital technologies reshape **knowledge work** by changing how information is encoded, transmitted, stored, and accessed. This shift is particularly relevant for **professionals** whose work is based on specialized knowledge. Digital solutions are increasingly automating tasks traditionally performed by these individuals, altering work distribution and interactions with clients or colleagues. Advances in artificial intelligence even suggest that algorithms could take over some tasks traditionally within the jurisdictions of professions, changing how knowledge is produced and accessed and enabling delegation to machines or non-professional workers. The COVID-19 pandemic accelerated these trends: while digital technologies played a role in maintaining business continuity during a global crisis, distributed work through digital technologies became the norm for professionals.

Coordination is a useful perspective for understanding how digital technologies reshape the work of professionals. It may be defined as the integration of individuals' work under conditions of task interdependence and uncertainty. Digital tools affect coordination by introducing new tasks, modifying existing ones, eliminating others, creating or dissolving interdependencies, and generating uncertainty. Moreover, observing coordination allows to understand how people act and inter-act to perform work.

Empirically, this study focuses on **healthcare professionals**, primarily doctors and nurses. Healthcare work, as a key topic in the study of professions, is undergoing significant transformation due to digitalization. The digital tools available to healthcare professionals range from **telemedicine** to **electronic health records** and **algorithmic tools** for automating clinical tasks.
The literature has long focused on the adoption and diffusion of these technologies. However, the current challenge for practitioners is integrating these technologies into daily use while ensuring reliability, safety, and effectiveness. This integration is influenced not only by technological features but also by organizational and cultural factors.

Through a pragmatic epistemological approach that embraces theoretical pluralism, this thesis aims to describe *how the adoption of digital health technologies, by altering coordination processes, affects relational coordination among physicians, and constitutes an opportunity for nurses to assert control over new tasks at the micro level and gain legitimacy*.

The thesis consists of **three coherent pieces of research**, employing triangulation to deepen the understanding of the phenomena under investigation while ensuring conceptual and epistemological parsimony. The research framework is represented in Figure 1.

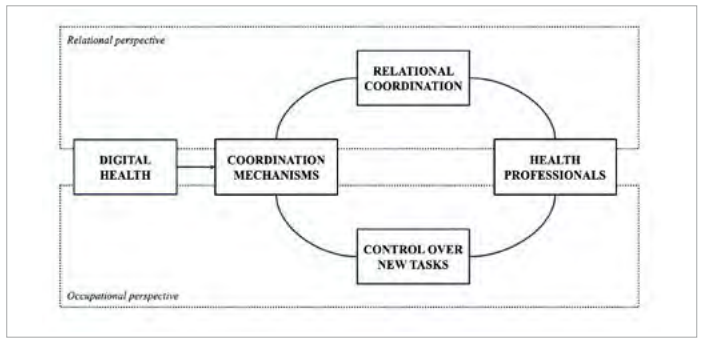

Fig. 1 - Research framework

The **first study** examines the introduction of a teleconsultation platform for doctor-to-doctor consultation, showing its positive impact on **relational coordination** (*coordinating through digital health*). This technology provides structure to traditionally informal processes of interprofessional consultation, improving relationships and information exchange.

The **second study** combines relational coordination theory with the **sociomaterial perspective**, moving beyond deterministic assumptions to understand how digital technologies shape coordination through sociomaterial practices. It argues that the effects of digital technologies on relational coordination depend on how professionals use, appropriate, and make sense of them, rather than merely on their design or features (*coordinating with digital health*).

The **third study** takes an occupational perspective, analyzing how a group of nurses leverages the introduction of telemedicine to gain **control** over coordination work. By performing coordination tasks, managing dependencies, and asserting **legitimacy** around the technology, nurses increased their visibility and formal authority over digital coordination processes (*coordinating around digital health*).

This research **contributes to organization studies in the healthcare field** in several ways. First, it links the use of digital technologies to relational coordination, using the empirical case of teleconsultation for multidisciplinary patient management. Second, it integrates relational coordination theory with a sociomaterial perspective, arguing that the effects of digital technologies on relational coordination arise from sociomaterial practices. Third, it extends research on the evolving relationship between nurses and physicians, showing how telemedicine not only redistributes tasks but also makes coordination work more visible, allowing nurses to formalize their role beyond caregiving and gain legitimacy. Finally, it provides insights into how digital technologies shape professional hierarchies, illustrating how lower-status professionals can consolidate control over emerging technological domains by leveraging institutional recognition of digital tools.

The findings of this research offer **practical insights**. The integration of digital technologies into healthcare practice is not merely about adding new tools but about reshaping how healthcare work is coordinated to improve patient outcomes. Healthcare managers play a key role in ensuring that digital technologies support effective communication and strong professional relationships, which are critical for coordinated healthcare efforts. Organizations can strategically use these technologies to redefine task boundaries among occupational groups, addressing challenges such as workforce shortages while improving coordination. Policymakers should support the diffusion of digital technologies in healthcare by fostering conditions that enable their effective integration into practice, rather than merely investing in infrastructures.

MEDTECH INNOVATION IN HOSPITALS: RE-FRAMING THE INTEGRATION BETWEEN SCANNING AND ASSESSMENT AND THE DETERMINANTS OF VALUE

Maria Pinelli - Supervisor: Emanuele Lettieri

The healthcare sector operates within a rapidly evolving technological landscape, where promising MedTech innovations, which include medical devices, in vitro diagnostics and digital health solutions, are advancing at a rapid pace. The continuous expansion of scientific and technical knowledge has led to the development of innovative and strategically significant technologies, posing both present and future challenges for hospitals, which represent the field of research of this Thesis.
Hospitals serve as the main access points and key pillars of national healthcare systems, and dedicate substantial investments to medical technologies, that are driving up healthcare expenditures.
Thus, hospitals should be equipped with a *Technology Strategy*, which is essentially about selecting and managing the right projects that align with organizational goals. Then, hospitals should determine which technologies to focus upon considering their organizational goals, their needs and their staff characteristics. Moreover, decision-makers must stay ahead of new technologies and their potential consequences to avoid being unprepared, through *Technology Scanning* (TS), a subset of Environmental Scanning, which involves the active monitoring and analysis of changes by organizations and individuals within them.
However, standardized guidelines to conduct the scanning of technologies in hospitals are not present. Then, choices made regarding novel technologies should follow the Value-Based Healthcare (VBHC) principles, aimed at transforming the care delivery from a model based on volumes to one based on value for the patients. According to VBHC, value should be measured as the ratio between the outcomes that matter to the patient throughout the care cycle and the costs associated with delivering those outcomes. As for TS, also for assessing the value of those technologies, through *Hospital-Based Health Technology Assessment* (HBHTA), guidelines are still not completely adopted in the different hospital settings.
Thus, this Thesis seeks to contribute to the ongoing discourse surrounding the TS of MedTech innovations and, subsequently, technology assessment (TA), in hospitals.
Moreover, the Thesis acknowledged that, despite the need for alignment between these two logically interconnected phases, previous research has treated them as separate, isolated processes.
This Thesis, with the first research objective, seeks to bridge this gap understanding the challenges of the two processes and emphasizing their inherent interconnection. Then, as a second research objective, this Thesis aims to advance and strengthen the current practices of HBHTA, addressing the existing gap in standardized guidelines for its implementation, and broadening its scope to include criteria for assessing value from the perspective of various stakeholders, including the environment.
These two research objectives are addressed with a collection of 5 papers.
Paper 1 explores the open challenges hospitals face in setting their technology strategy in terms of scanning and assessment practices; the results showed a lack of defined approaches to health technology strategies, scanning, and assessment.
Then, recognizing the absence of standardized TS and TA processes, **Paper 2** contributes to their conceptualization, addressing the gap concerning the interrelationship between technology strategy, scanning, and assessment in hospitals.
The primary contribution of this paper is the development of three frameworks that categorize hospitals based on their TS and TA practices, and their integration, according to their Innovation Orientation and their Specialization of Care.
Then, the Thesis focuses on HBHTA, which is closely linked to the decision-making process and therefore merits an in-depth study. **Paper 3** provides a practical application of HBHTA, focusing on a technology available in the market. This study represents the assessment of a technology with a high Technology Readiness Levels (TRL) and, consequently, a high level of evidence. Indeed, the assessment was conducted in collaboration with clinicians who had prior evidence regarding the technology. As a result, this type of assessment may not apply to technologies with lower TRLs and thus lower levels of evidence. Additionally, this study analyzed the impact of the technology only concerning the hospital and the patients, overlooking the impact on other relevant stakeholders such as the economic system and the environment.
Conversely, **Paper 4** presents an assessment of a technology with low TRL through the Social Return on Investment; due to limited evidence, numerous assumptions had to be made. This analysis incorporates a comprehensive evaluation of all stakeholders that hospitals should consider when assessing technologies, including the patient, the hospital itself, society, the economic system, and the environment. Although this type of evaluation offers a more holistic perspective, it is important to note that, due to the novelty of the technology, the analysis is replete with assumptions that may prove inaccurate.
These two papers align with the hospital typologies presented in Paper 2: Paper 3 corresponds to hospitals with a low innovation orientation, which primarily assess mature technologies with established evidence, while Paper 4 relates to hospitals with a high innovation orientation, evaluating novel technologies with limited or no prior evidence.
Finally, building on this foundation, **Paper 5** makes the effort to create a comprehensive framework of criteria that hospitals should consider to assess the value of technologies, bridging, in this way, a significant gap in the existing literature. Indeed, HBHTA lacks agreed-upon guidelines and standardized frameworks for ensuring consistency. Furthermore, current practices are constrained by the consideration of only a limited number of stakeholders. This paper aims to design a model that incorporates all the relevant actors hospitals should consider when assessing novel technologies.

The primary theoretical contribution of this thesis lies in the development of innovative frameworks that advance the discussion surrounding decision-making related to novel technologies in hospitals. By emphasizing the integration of TS and TA within hospital settings, this work makes a substantial contribution to the existing literature. Additionally, the thesis provides a systematic synthesis of the current literature on HBHTA, proposing a framework that bridges the gap between HBHTA and VBHC. This framework includes criteria for value generation and value capture within hospitals, building on existing models such as the One Health framework, which highlights the interdependence of human, animal, and environmental health.
The Thesis also offers practical insights for hospital professionals, as the frameworks developed are intended for direct application, particularly by hospital managers and policymakers. Frameworks in Paper 2 enable hospital managers to identify and prioritize technologies that not only address immediate clinical needs but also contribute to the institution's long-term success.
Furthermore, Papers 3 and 4 provide practical insights into the assessment of technologies at different TRLs, incorporating various stakeholders in the evaluation process. Finally, the framework in Paper 5 can guide the conduction of HBHTA, ensuring that assessments are not only consistent but also aligned with the overarching goals of VBHC. In this approach, patient outcomes remain a central factor in the assessment of MedTech innovations. At the same time, economic and environmental impacts are also considered essential. Given that environmental factors directly influence human health, this framework establishes a connection between them, ensuring a more comprehensive evaluation of technological advancements in healthcare.

A NOVEL ICT DATA-DRIVEN ARCHITECTURE FOR SUSTAINABLE MANUFACTURING IN THE COSMETICS INDUSTRY

Roberto Rocca - Supervisor: Luca Fumagalli

Co-Supervisor: Marco Taisch - Tutor: Sergio Terzi

Sustainable and digital cosmetics manufacturing paradigm has attracted a great deal of attention over the last years as an emerging manufacturing approach meant to empower cosmetics enterprises to cope with sustainability challenges and issues. One of the most important challenges sustainable cosmetics manufacturing has to face, is the right assessment and management of productive contents or embodied values of the consumed resources within its systems. At the same time, digital technologies provide several opportunities for the development of an intelligent and sustainable cosmetics manufacturing. The project aims to connect Sustainable Manufacturing and Digital Transformation paradigm under the same umbrella, to propose a new Information and Communication Technology (ICT) data-driven industrial architecture for resource consumption assessment and traceability for manufacturing systems in the cosmetics industry. To this aim, the PhD project find its bases on three main level of studies: (i) cosmetics industry sustainability requirements; (ii) quantitative assessment methodologies for environmental sustainability in cosmetics industry; and (iii) industrial architectures and data spaces for Green Transition in the cosmetics industry. The main scope of the PhD project is to deepen the study of these levels to carry on with an overall approach the advance of the state of the art and the design of the novel ICT industrial architecture customized for cosmetics industry. The focal point of this research project is therefore the *environmental sustainability data* of cosmetics production and consumption, intended as the source of information strictly related to cosmetics industry environmental sustainability (e.g., materials and energies consumed, waste produced, emission and pollution, water consumption, etc.), whose correct collection, analysis and tracing can lead to enormous benefits for the natural resources management within cosmetics manufacturing systems. According to the "life cycle vision" of product and processes sustainability in cosmetics industry, the cooperation with industrial entities, external to the company, and with final consumers are fundamental to undertake a sustainable and circular-oriented path. This vision led the author to try to analyse the main important requirements to tackle sustainability transition challenge in cosmetics industry, both from a life cycle and supply chain point of view (i.e., first pillar of PhD project - cosmetics industry sustainability requirements).

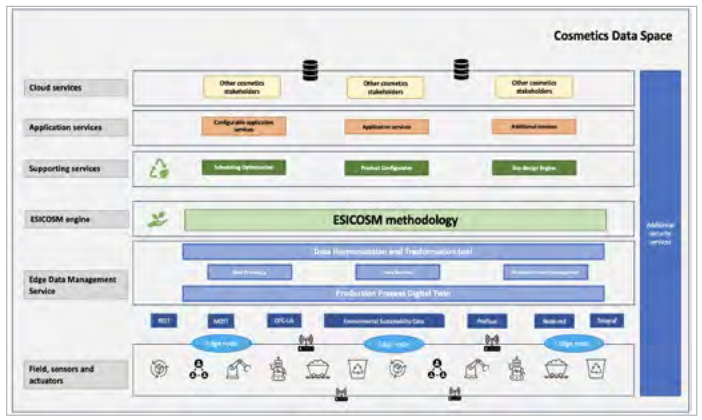

Fig. 1

Moreover, since the scope of this PhD project has been to put the attention on quantitative assessment methodologies for environmental sustainability in cosmetics industry (i.e., second pillar of the project - quantitative assessment methodologies for environmental sustainability in cosmetics industry), the analysis of the state of the art and the effort for the development of new methodologies has been focus on environmental indicators, indices, and product-related assessment tools. This choice led the author to develop the Environmental Sustainability Improvement for COSMetics products and processes (ESICOSM) methodology for the Green Transition in the cosmetics industry. ESICOSM methodology represents the key exploitable result of the PhD project. Finally, the outcomes and results coming from the first two pillars of the project, have been exploited in the third pillar to propose some insight for developing a data-driven industrial architecture to foster sustainable manufacturing and cleaner production in cosmetics environments.

PORTFOLIO CONSTRUCTION, BRAND CAPITAL, AND STOCK FORECASTING IN A SUSTAINABLE FINANCE AND CLIMATE RISK ANGLE

Nico Rosamilia – Supervisor: Giancarlo Giudici

This thesis explores the integration of environmental, social, and governance (ESG) factors into financial models, emphasizing portfolio construction, stock price forecasting, and the impact of climate risk on corporate brand capital. ESG metrics are increasingly influential in financial decision-making, yet traditional models struggle to capture their complexity. This research employs machine learning techniques and traditional econometrics analysis to bridge this gap, offering insights for investors, businesses, and policymakers.

The first paper, "Profit or Planet? Both! ESG Drivers of Efficient Portfolios and the Costs of Disclosure," incorporates ESG factors into the Fama-French five-factor model and applies a customized random forest algorithm to assess the materiality of ESG variables. The findings highlight key drivers of portfolio returns. Additionally, results support the idea that non-financial disclosure is costly in the short term but yields long-term benefits.

The second paper, "The Impact of Firm-Level Climate Risk on Corporate Brand Capital," examines how climate risk affects brand equity. Using a 20-year panel dataset of 5,862 firms and a quasi-natural experiment based on the Paris Agreement, the study establishes that firms with high climate risk exposure suffer significant brand erosion. The findings highlight the financial materiality of climate risk management and suggest that firms prioritizing environmental responsibility maintain stronger brand capital and market positioning.

The third paper, "What's News with You: Price Forecasting and Sentiment Scores," focuses on news and ESG sentiment analysis using advanced deep learning models, including N-HiTS and RoBERTa. The study finds that ESG-related news sentiment enhances stock price prediction accuracy, particularly in identifying downward trends. The results indicate that investors can leverage ESG sentiment analysis for improved risk assessment and market forecasting. This research contributes to the growing literature on machine learning applications in finance and sustainable investing.

Together, these three papers contribute to the evolving field of sustainable finance by integrating ESG and climate factors into financial forecasting, portfolio management, and risk assessment. The findings advocate for a paradigm shift in financial decision-making, where climate and ESG considerations are not only ethical imperatives but also fundamental determinants of financial performance. Investors and businesses that embrace sustainable principles are likely to achieve both financial resilience and long-term sustainability. Future research could explore dynamic asset pricing models, sector-specific ESG impacts, and standardized ESG disclosure formats to further refine financial models in the era of sustainability.

RIGHT TO REPAIR: DESIGN PRACTICES AND USERS' PERCEPTION TO EXTEND PRODUCT LIFECYCLE AND ENABLE MORE SUSTAINABLE CONSUMPTION

Nataliia Roskladka - Supervisor: Giovanni Miragliotta

Many manufacturing companies design products to minimise development and production costs, which often implies short product obsolescence. Thus, such products end up in landfills quite quickly, creating a negative footprint on our planet. Today, society and the planet make an urgent call to reduce waste, enable sustainable consumption and get closer to the circular economy (CE). By extending the product life cycle as long as possible, we slow down the resource usage pace, as products are disposed of more rarely, and thus end-of-life waste is minimised.

One of the ways to extend product durability is to repair products when they fail instead of replacing them. However, repair is less prevalent in more developed countries, where people can easily afford new products, than in low-income areas, where repairing is a vital need. Even if repairing products may be economically convenient, it is a socially dispraised practice in some areas. Besides, when a user can easily pay for a new product, replacing an old one may seem simpler because of the time and effort saved. However, missing repair creates a gap in a CE and sustainable consumption path.

This scenario might change thanks to the "Right to Repair" (RtR), a legislative directive and a social movement that promotes repair culture. It emerged in 2012 in Massachusetts, making car manufacturers share information on product repair with independent repairers, dealers and authorized repair facilities to facilitate and promote repair activities. Later, RtR spread out in several countries, like the USA, Australia, the UK, and the European Union, aiming to guarantee consumers can repair their products under favourable conditions: easily, safely, and cheaply enough.

Over the last several years, repair has been popularised more in some countries, such as the Netherlands, France and Belgium, thanks to active repair associations, a strong network of repair cafes, and the implementation of repairability (and soon durability) index. Also, the EU Commission issued regulations that considered repair substantial leverage to extend product duration and fight product obsolescence.

Nevertheless, many unrepairable products are on the market, and repair infrastructure is not always convenient, so consumers in more developed countries often ignore repairing. At the same time, manufacturers prefer to capture most of the value from the new sales and keep producing hardly repairable products to incentivise new product sales. However, several "best-in-class" manufacturers are famous for producing and selling long-life products and warranties, including repairing and promoting sustainable consumption. Thus, this PhD aims to explore the motivations of those companies that promote product durability and those that keep producing hardly repairable products, introducing planned product obsolescence.

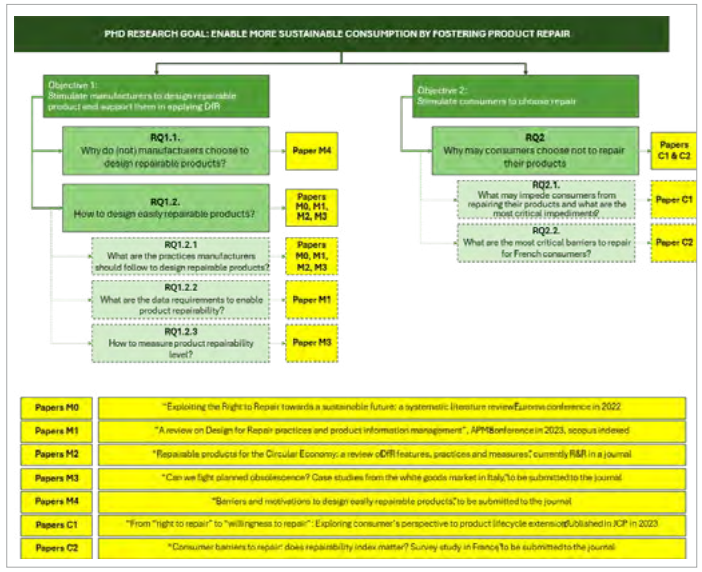

Fig. 1 - Research questions and related papers included in this doctoral research

There is a "chicken-egg" issue in this context: who should first enable repair culture: consumers or manufacturers? Because consumers would repair if products were repairable, and manufacturers would produce repairable products if consumers required them. This loop is far more complicated if we consider repairing infrastructure availability and affordability, manufacturers' business models and other external factors that may influence consumer's and manufacturer's decisions. Having said that, it becomes clear that this research requires considering at least two perspectives: the manufacturer's one and the consumer's one. By understanding both perspectives, we strive to develop the appropriate strategy to endorse the latest to produce more repairable products, looking at the internal drivers and external powers that may induce that change.

The scientific literature review performed at the beginning of this PhD research has demonstrated that product design practices favouring repairability were rarely discussed, and the concept of Design for Repair (DfR) is under-investigated compared to other design strategies. This PhD research covers this literature gap by providing a comprehensive DfR framework and guidelines for manufacturers to improve product repairability, estimate the repairability level and fight planned obsolescence to enable sustainable consumption.

Complementary to the manufacturers' perspective, this research also aims at finding ways to stimulate consumers to choose repair. By exploring consumer barriers to repairing their products and identifying the most critical ones, we aim to complete the guidelines for manufacturers, policymakers, and repair associations on what should be solved first to promote repair among the users.

Thus, the primary goal of this research contains the following two objectives: stimulate manufacturers to design repairable products and stimulate consumers to choose repairable products.

Understanding the consumer's perspective will help policymakers and repair associations to come up with the right strategy to make companies apply DfR in a way convenient for both sides and thus bring the most value to enable sustainable consumption.

The representation of research questions and related papers included in this doctoral research is in Figure below.

To sum up, this PhD research covers the literature gap on product DfR architecture, manufacturer barriers to implement it and consumer barriers to repair. Thus, the goal of this PhD is to investigate how to encourage manufacturers to design and produce easily repairable products and make repairing more attractive among consumers.

NET-ZERO TRANSITION AND PROJECTS: THE PROJECT STUDIES PERSPECTIVE ON SOCIOTECHNICAL TRANSITIONS

Marco Terenzi - Supervisor: Giorgio Locatelli

Research Background

The transition towards a Net-zero economy is a critical global imperative, marked by the pressing need to balance greenhouse gas emissions and their absorption through substantial transformations across multiple sociotechnical systems. Unlike previous technological and societal transitions, the Net-zero transition is uniquely characterized by its extensive scope, encompassing multiple sectors simultaneously (e.g., energy, transport, agriculture, housing), and its predominantly institutional-driven nature. Rather than emerging organically through free market dynamics, it is actively guided by policy interventions, international agreements, and significant government investments.

The existing body of literature extensively explores the Net-zero transition primarily through a technological and policy-oriented lens. Studies often investigate specific technological innovations, such as renewable energy adoption, electric vehicles, or carbon capture and storage systems, or analyse macro-level policy implications and economic evaluations, frequently neglecting the role of projects as pivotal agents of systemic change. This narrow focus results in a fragmented understanding of the complexities involved in transitioning to Net-zero, particularly in understanding how projects, as organized temporary efforts, contribute significantly beyond their immediate scope and lifecycle.

Addressing this gap requires integrating insights from sustainable transition research—especially the Multi-Level Perspective (MLP)—with contemporary project management scholarship. Sustainable transition research conceptualizes sociotechnical systems as stable configurations fulfilling societal needs, where transitions occur through shifts from dominant regimes to emerging sustainable alternatives. Within this context, projects become instrumental vectors capable of disrupting entrenched carbon-intensive regimes and establishing alternative, sustainable configurations. Hence, projects must be reconceptualized beyond conventional project management perspectives that typically limit analysis to internal project dynamics or lifecycle management.

This research contributes to the existing body of knowledge by positioning projects at the core of sociotechnical transitions, analysing how they function as strategic vectors that destabilize existing regimes and facilitate systemic shifts toward sustainable configurations. It explores not merely individual projects but broader classes and types, recognizing the collective impact of multiple interconnected projects in shaping large-scale transformations.

Thesis Structure

The thesis structure is designed to offer a comprehensive, multi-layered examination of the Net-zero transition by adopting a hierarchical analytical framework comprising three interconnected levels: missions, programs, and projects. Each of these levels corresponds closely with concepts from the Multi-Level Perspective (MLP) in transition studies, facilitating an integrated analysis of the Net-zero transition's systemic nature:

- Missions: At the highest analytical level, national Net-zero missions represent broad policy frameworks and strategic objectives set by governments. These missions transcend individual projects and programs, involving complex governance mechanisms, inter-sectoral coordination, and substantial financial investments. They encompass diverse project types ranging from large-scale infrastructure developments to smaller-scale behavioural interventions, necessitating nuanced governance and oversight structures to manage complexity effectively.
- Programs: Programs operate as intermediaries between national missions and specific project implementations. They are structured initiatives comprising clusters of interrelated projects, each contributing strategically to achieving predefined sustainability goals. The thesis investigates programs by focusing on the interdependencies among technologies, institutions, and organizational resources, emphasizing the necessity for coherent and aligned program management practices to ensure systemic coherence and maximize sustainability outcomes.
- Projects: At the granular analytical level, the research explores specific classes of projects that exemplify the diversity and complexity inherent in transitioning to Net-zero. The thesis emphasizes classes of projects rather than individual instances, encompassing a wide spectrum, from large-scale, technologically intensive megaprojects, such as renewable energy infrastructures, to small-scale initiatives such as residential building retrofits and behavioural intervention projects. Particular attention is given to the determinants and dynamics underlying homeowners' decisions to adopt low-carbon technologies, thus highlighting the crucial role of individual-level adoption and the broader societal implications.

Main Findings

The thesis provides several significant findings, contributing novel insights and implications across theoretical and practical dimensions:

Projects as Vectors of Change: A core finding of this research is that projects significantly influence sociotechnical transitions by driving systemic innovation, disrupting incumbent regimes, and establishing sustainable alternatives. Projects play a pivotal role in materializing policy goals into tangible outcomes, thereby serving as fundamental instruments for policy implementation and achieving Net-zero targets.

Policy-Project Nexus: The analysis clearly illustrates that policy frameworks profoundly shape the planning, execution, and success of projects. The effectiveness of policies such as Germany's Energiewende demonstrates how clear policy directives and robust institutional support are necessary but also reveals the complexities and unintended consequences arising during transitions. The research underscores the importance of strategic policy design, implementation coherence, and adaptive management to effectively leverage project outcomes for sustainable transitions.

Complementarities and Interdependencies: One of the key contributions is identifying and analysing technological, organizational, and infrastructural complementarities that exist within and between sociotechnical systems, using France's decarbonization strategy as a case study. These complementarities significantly enhance the performance and feasibility of Net-zero transitions. Effective management of these interdependencies is essential, as neglecting these relationships can lead to suboptimal outcomes and impede the pace and scope of transitions.

Behavioural Determinants of Project Adoption: Through in-depth qualitative research involving homeowner interviews, this thesis uncovers critical insights into the factors influencing individual decisions regarding low-carbon technology adoption. Findings indicate that economic incentives alone are insufficient to drive widespread adoption; rather, broader awareness and understanding of technology benefits, long-term economic gains, and environmental impacts play more substantial roles. Incentive schemes must be complemented by comprehensive informational and educational efforts to improve homeowners' perceptions and enhance the adoption rate.

In summary, the thesis provides substantial theoretical and empirical contributions by integrating project studies and sustainable transition research. It advances the understanding of the crucial role projects play within the broader context of sustainability transitions and offers valuable practical insights for policymakers, practitioners, and project managers aiming to navigate and expedite the global journey towards achieving Net-zero emissions.

GOING CIRCULAR IN THE FOOD SECTOR: A SUPPLY CHAIN PERSPECTIVE ON FOOD WASTE PREVENTION AND VALORIZATION PRACTICES

Stella Viscardi – Supervisor: Claudia Colicchia

Every year, one-third of the food produced worldwide goes to waste, accounting for 1.3 billion tons of food and causing negative impacts on the three pillars of sustainability. Circular economy holds promise to minimize food waste, as this economic paradigm reframes waste as a resource. Integrating the principles of circular economy within food systems can lead to reconfigurations in the supply network, towards the creation of circular food supply chains.

The transition toward circular food supply chains requires extensive changes and strong commitment. Therefore, it is crucial to understand how food companies can tackle these challenges to successfully build circular food supply chains. Logistics and supply chain management are crucial in supporting the creation of functioning circular food supply chains; however, the literature falls short of providing a holistic discussion of the role of logistics and supply chain management in supporting a circular economy of food waste. Therefore, the overarching objective of this research is to *explore how companies operating in the food sector can be facilitated in the introduction of circular economy in their supply chains for food waste prevention and valorization. By focusing on supply chain management and logistics within circular economy, this project aims to offer tools and guidance that can support food companies in the shift towards circularity while also contributing to the academic knowledge in this research field*.

The objective and boundaries of the thesis are defined based on the findings of Paper 1, which presents a systematic review of the literature on the themes of food waste, circular economy, and logistics and supply chain management. The paper highlights several research gaps that guided the formulation of research questions.

The first research question relates to the firm's operations, focusing on the influence of food and food waste characteristics on food waste generation and minimization. Paper 2 investigates the characteristics of food products in relation to causes of food waste and circular economy practices. The study is conducted using a systematic literature review, whose main output is the proposal of a classification of food products in light of circular economy evidencing how the intrinsic variability of food products influences food waste generation and recovery practices along the supply chain. Causes of food waste and circular economy practices are systematized according to the proposed classification to provide clear guidance to food industry actors on how to effectively reduce food waste. Paper 3 focuses on the characteristics of food waste flows. The study employs contingency theory to isolate those attributes of food waste that push companies to develop circular economy solutions for its prevention and recovery. Food waste data have been gathered from fifteen food manufacturers operating in Italy, and the analysis has been performed through qualitative comparative analysis. The analysis pinpoints the contingency factors embedded within food waste flows that drive the implementation of circular economy practices, fostering their recognition and, therefore, circularity in the food sector.

The second research question has a broader scope and focuses on the restructuring of supply chains to accommodate circular flows. Paper 4 investigates how the prevention and recovery of food waste using circular economy fosters collaborations. The paper employs a case study methodology, focusing on a large and a small company operating in the Italian fish processing sector. The phenomenon is analyzed through the lens of resource dependence theory, identifying the elements that shape collaborations within circular food supply chains. Including a large and a small firm also allows for assessing the role of firm size when establishing collaborations for food waste. This paper identifies strategic motivators and mechanisms involved in collaborations for food waste prevention and recovery, providing clear guidance to companies. Paper 5 focuses on the relationships that can be created with "circularity brokers", who are found to foster the creation of circular supply chains. The paper aims to study who can be a circularity broker, which functions it can perform in support of circular supply chains, and how the supply network changes when circularity brokers are involved. The study is conducted on secondary data derived from the scientific literature by means of a qualitative meta-analysis. The data analysis has been guided by social network theory, providing a sound conceptualization of circularity brokers. These actors are found to be able to respond to different circular economy needs: firms can use these insights to identify missing capabilities and assess the potential of engaging circularity brokers to facilitate their circular activities.

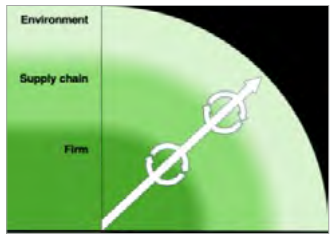

Fig. 1 - Research scope and findings.

The last research question delves into the relation between circular economy and environmental sustainability. The answer to this research question is centered around the development of a tool to assess the environmental impact of waste recovery, the WasteBound tool. The model was built in collaboration with GreenRouter S.r.l. during the internship held in 2023. Paper 6 discusses the development of the tool, whose validity has been tested through its application to the case of an Italian food manufacturing company. The development and application of the tool reveal how circular economy is not always sufficient to achieve sustainability: the tool promotes those solutions fostering value recovery from waste, which is crucial for a sustainable circular economy. Altogether, this work unveils the complex interactions existing between the considered levels of analysis (firm, supply chain, environment). For instance, firms may develop a food waste minimization plan based on their capabilities, food and food waste characteristics. However, the unavailability of partners may hinder some circular economy practices, pushing companies to go back to the firm level to find alternative but feasible solutions. On the other hand, the availability of circularity brokers facilitating the development of different circular economy practices may lead firms to consider implementing such alternative solutions, modifying the initially defined plan. This may also entail modifying the characteristics of their food waste flows, to make them adequate for the proposed recovery solutions. The existence of such feedback loops is even clearer when considering the environment level. When considering the environmental impact of a given circular economy practice, the firm may notice possible rebound effects, prompting the rethinking of the planned circular economy network to ensure its sustainability. These examples depict how the boundaries between scopes are not only permeable, but they blur within each other due to the complex interactions between the considered levels (Figure 1). The implementation of circular economy practices is not straightforward and can include feedback loops. While such loops may represent a hurdle, they also allow the precise tailoring of circular economy practices to the context of the firm.

Altogether, this study discusses a journey that may be followed by a food firm towards the implementation of circular economy practices for food waste prevention and valorization. Thanks to the definition of obstacles and facilitators that may be found along the way, it is possible to achieve the intended objective of this thesis.

THE EFFECTS OF DEMOGRAPHIC CHANGES ON STRUCTURAL CHANGE: EVIDENCE FROM CHINA

Yi Wang - Supervisor: Giulia Felice

Research Background:
Economic development is associated with a significant reallocation of economic activities across sectors, referred to as structural change in the literature. Since the reform and opening up in 1978, China's sectoral composition has sharply converged towards the trajectories of development that the high-income economies like the US and the UK experienced over a hundred years or more, showing a dramatic increase in the share of non-agricultural employment. According to the data from the National Bureau of Statistics of China (NBSC), the employment share and nominal value-added share in the non-agricultural sector were 76.4% and 92.3%, respectively, in 2020.

At the same time, during the past decades, demographic changes in China have been unprecedented, particularly in terms of sharp increases in internal migration and population aging. According to NBSC, the total number of internal migrants increased from 116 million to 376 million during the period of 2000-2020 (representing 8.95% and 26.6 % of the corresponding total population, respectively). Beyond that, China's total fertility rate sharply decreased from 6.1 to 1.28 between 1970 and 2020. However, during the same period, China's life expectancy significantly increased from 56.8 years to 78.1 years. The percentage of the population aged 65 and above increased to 28% in 2020 (NBSC).

Given the significant magnitude of these phenomena in China — industrial structural transformation and demographic changes — and considering the role of China's structural transformation in the world economy, it is relevant to deeply investigate and disentangle some potential channels linking demographic changes to structural change.

Research Results:
In the first paper, I attempt to disentangle the direct and indirect effects of internal migration on the sectoral composition of employment. My results show that internal migration can directly and negatively affect the share of agricultural employment at destinations by bringing a positive shock to both the non-agricultural labor market and the composition of non-agricultural consumption. At the same time, internal migration reduces the relative size of employment in the agricultural sector by activating the demand-side and supply-side engines of structural change. In the second paper, my results show that the consumption composition of migrant households was significantly different from that of urban resident households during the early stages of China's internal migration. However, a convergence in consumption patterns between migrants and residents has taken place in recent years. In the third paper, my results show that population aging significantly affects structural change by increasing the relative employment shares in the agricultural sector. A within-between analysis suggests that the change in the age structure of the population has a smaller effect on the process of employment reallocation compared to the other channels (demand-side and supply-side drivers); however, its influence is not negligible, especially considering the sharp increase in population aging projected for China's near future.