Introduction to the special issue on “The Twin (Digital and Green) transition: Handling the economic and social challenges”

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Abstract

In an era of increasing global challenges, two paradigmatic shifts – the digital and green transitions – have gained traction due to their potential impacts on industrial ecosystems and societal inequalities. Termed the "twin transition", these shifts underscore the synergies between technological advancements and environmental sustainability. Highlighting its importance in post-COVID-19 recovery, the special issue examines the twin transition's potential to drive industrial innovation and affect social, economic, and geographical inequalities. The seven articles in this special issue explore the impact of the twin transition on corporate innovation strategies and investment, alongside the economic, social, and geographical implications. Key findings underscore the need for diversified technological investments, especially in AI, and enhanced digital infrastructures. Policy recommendations advocate for aiding firms lagging in digitalization and developing region-specific innovation policies. The research sets a roadmap for future inquiries into the interplay of digital and green transition, broader economic impacts, and policy-driven strategies.

1. Background and objectives

Two paradigmatic transformations are stealing the spotlight due to their potentially extensive impact on industrial ecosystems and social inequalities. On the one side, emerging digital technologies, including Information and Communication Technology (ICT) and more recently, artificial Intelligence (AI), Industry 4.0, and blockchain, are profoundly influencing growth, productivity, and the labour market (Heyman et al., 2021). On the other, investment in environmental technologies and products – essential to facilitate the transition towards a low carbon economy (Dean and McMullen, 2007) – holds the potential to revitalize the competitiveness of advanced economies (Costantini and Mazzanti, 2012).

The term twin transition has entered the political discourse by highlighting the potential synergies between the green and digital transitions. It focuses on the role digital technologies can play in fighting climate change and mitigating environmental damage, thus contributing to a fair and sustainable recovery following the COVID-19 and energy crises (European Commission, 2022; Muench et al., 2022). In this framework, the development and integration of digital and green technologies with other key technologies become crucial to support such challenges; this also represents an opportunity for an economy to gain leadership position and improve its autonomy in strategic industries.

Notably, the convergence of digital and sustainability imperatives has been gaining momentum in the public and private sectors, each investing substantial resources with industrial innovation expected to play a key role in this twin transition. At the same time, the disruptions required to implement such transition will most likely affect inequalities at the economic, social, and geographical levels, which must be understood and acted upon.

Academic work has only recently highlighted the potential effects of the twin transition for regions, firms, technological innovation, overall environmental impact, and has started to scratch the surface of the "dark side" of innovation (Biggi et al., 2020; George et al., 2020; Coad et al., 2021; Cicerone et al., 2022). Nevertheless, there is still much to be done to deepen our understanding of this phenomenon. For example, while research has enhanced our understanding of sustainability practices (Eccles et al., 2014) and environmental technologies (Nesta et al., 2014) in relation to corporate innovation and performance, there is less evidence concerning the transition towards climate-neutral production processes. Further research is also needed to explore a number of open questions: what new skills and jobs will be required to accommodate the green and digital transitions (Amoroso and Moncada-Paternò-Castello, 2018; Vona et al., 2019; Lankhuizen *et al.*, 2022); which sources of funding are more effective (Gaddy et al., 2017); what relevant undertakings will deal with the sustainable development goals from large corporates; and what role young and high-growth firms will play in the these changes (Demirel et al., 2019, Coad et al., 2023). Similarly, the twin transition can exacerbate existing social inequalities in relation to gender and race. For instance, the role of gender in research and innovation warrants further examination. There is currently a strong research stream on gender diversity in innovation and research teams, but insufficient attention devoted to other equally relevant topics of discussion such as other gender biases – for example, in research methods and questions (Nielsen *et al*., 2018; Xie et al., 2020) – or the impact of gender policies on industrial innovation and performance (Foss et al., 2021; Dezsö and Ross, 2012; Lyngsie and Foss, 2017). Moreover, the twin transition might have a disparate territorial impact, as each country is likely to encounter unique challenges in the sustainable and balanced development of its regions (Moşteanu, 2020; Gereben, and Wruuck, 2021).

This special issue aims to bridge this twin-transition evidence gap for the advancement of the field of economics and management of innovation. It aims to collect relevant research that either directly or indirectly builds upon the two pillars of the twin transition, digital and environmental, with a particular emphasis on the intersection of both. Finally, it aims to provide academically-, managerially-, and policy-relevant insights concerning the implementation and consequences of the twin transition.

Based on the aforementioned background, this Special Issue includes seven articles, which centre around two themes: the implications of the twin transition for corporate innovation strategies and investment; and the economic, social, and geographical repercussions of the digital and green transformations.

2. Innovation and the twin (green and digital) transition

One anticipated synergy of the twin transition refers to the role of digital technologies in generating innovations that contribute to achieving climate neutrality, reducing pollution, and restoring biodiversity. From the firms' point of view, investments in digital technologies can help them to increase their capabilities to introduce eco-innovations related to production (Ardito et al., 2021; Ning et al., 2023). However, since eco-innovations usually imply higher knowledge complexity than

standard innovations (Barbieri et al., 2020), digital technologies, particularly those possessing the characteristics of General Purpose Technologies (GPT), might be more suitable to facilitate the complex process of knowledge recombination necessary for the generation of green innovations.

In the first paper of this special issue, Montresor and Vezzani (2023) test this hypothesis using Italian firm-level data. They posit a greater eco-innovation impact from AI because it is the only digital technology exhibiting the essential characteristics of a GPT, while the others are at most enabling technologies (Martinelli et al., 2021; Benassi et al., 2022). They also study whether investing in bundles of digital technologies can spur complementarities that enhance the eco-innovating impact of individual technologies. Their findings confirm a more significant contribution of investments in AI application areas to a firm's eco-innovation. In fact, the AI domain is the only area in which a firm profits from eco-innovation at an extensive margin.

In addition, they discover that the generation of eco-innovations benefits from bundling investments in different digital technologies, but the effect varies among firms of different size. More specifically, the relationship between investments in digital technologies and the propensity for eco-innovation appears less selective for micro, small, and medium firms, which have many digitalisation and decarbonisation policy initiatives reserved for them. In contrast, a positive correlation emerges for large firms only when they invest in a wide array of digital technologies. Regarding avenues for future research, Montresor and Vezzani (2023) recommend a deeper analysis of the specific typologies of digital bundling selected by firms and their impact on eco-innovation. They also point out the need to consider industry and regional specificities that may emerge in the twin transition.

Santos et al. (2023), in the second article of the special issue, contribute to the study of regional specificities of the twin transition by constructing three novel indicators. These markers gauge the competitiveness and/or environmental sustainability for all the regions of the European Union (EU) over the period 2008-2018. According to these indicators, which draw from shifts in sectoral employment shares towards more productive and greener sectors, EU regions demonstrate substantial heterogeneity and present also different dynamics over time.

Taking this into account, Santos et al. (2023), in a second stage, ponder about the role of EU structural regional funds as a determinant of these shifts, and whether this role fluctuates based on the level of regional development. Their analysis suggests that the injection of EU funds is positively associated with a restructuring of employment towards more competitive and environmentally sustainable sectors, with competitiveness taking precedence over sustainability. In addition, they find that EU funds are positively linked to the growth of competitiveness solely in the less developed regions.

In the third article in the special issue, Mazzei et al. (2023) connect to the literature linking industry-specific capabilities to green patenting strategies. This pertains specifically to the development of Low Emission Vehicles (LEVs) in the automotive industry. In their investigation, they consider two green trajectories: on the one hand, they explore the incremental trajectory of improving the efficiency of the internal combustion engine, the dominant design. On the other hand, they investigate the radical trajectory associated with the advancement of hybrid, electric, and fuel cell vehicles.

While eco-innovation literature often draws on the dichotomy between green and brown inventions (Barbieri et al., 2020), recent empirical evidence finds a strong degree of relatedness between these two domains (Barbieri et al., 2023), where relatedness plays a significant role in fostering green specialization (Montresor and Quatraro, 2020; Santoalha et al., 2021). Building on this approach,

Mazzei et al. (2023) study whether firms patenting in either incremental or radical green trajectories master brown technologies. They also explore the extent to which brown patent portfolios are cognitively close in terms of knowledge to each trajectory. For their analysis, they use a novel dataset of automotive firms with patenting activity at the United States Patent and Trademark Office (USPTO) and adopt a recent classification scheme that enables them to clearly assign patents to each of the distinct green trajectories.

Their results corroborate that leadership in green patents is rooted in firms' knowledge and capabilities accumulated in brown domains. In particular, understanding brown-related technologies proves essential for inventing green across all types of firms. In addition, a high degree of technological diversification is strongly associated with leadership in the incremental green trajectory, whereas it does not characterize leaders in the radical green trajectory. This evidence underscores the importance of identifying firm-level factors behind leadership positions to stimulate the transition towards the most radical green trajectories.

3. Consequences of the twin (digital and green) transition

The organisational disruptions caused by the COVID-19 pandemic crisis have accelerated the pace of digitalization in countries worldwide. This has spurred the interest in understanding the role of digitalization in the resilience of firms during crisis. Two complementary articles in the special issue tackle this question. Calza et al. (2023) explore the extent to which advanced digital production technologies affected the resilience of manufacturing firms in developing and emerging economies. Teruel et al. (2023), focusing on European countries, analyse whether firms in sectors with a higher degree of digitalization experienced less employment adjustment during the pandemic period. Both studies conclude that, in general, the process of digitalization is positively associated with the resilience of firms, albeit with unique aspects in each study.

Employing the novel UNIDO COVID-19 survey, Calza et al. (2023) specifically explore firms' resilience, considering their robustness (ability to resist) and readiness (ability to adapt) during the pandemic. They infer robustness from smaller declines in yearly profits and monthly sales, while they determine readiness based on the implementation of transformational changes as response to the shock. The results are consistent with the hypothesis that the adoption of the latest generation of digital technologies reinforced both aspects of firms' resilience in developing and emerging countries.

In the study by Teruel et al. (2023), firm resilience is established in terms of their short-term and 'expected' long-term adjustments in employment to weather the pandemic. Several elements are considered as key potential drivers of this resilience: the firm's productivity level, prior experience with high-growth periods, and the degree of digitalisation. The results show that, as expected, firms with higher productivity levels were less likely to reduce their employment both in the short and the long term due to the COVID-19 pandemic. Moreover, high-growth firms and those in more digitalized sectors appear to be more resilient to the pandemic, evident in their ability to avoid negative employment effects.

Despite the various positive effects of the twin transition, and digital transition in particular, they may have pernicious effects on societies, particularly by increasing inequality. On the one hand, these transitions favour the demand for workers possessing skills that are associated with high levels of training and technical knowledge (Santoalha et al., 2021). Indeed, evidence suggest that the digital

transformation may exacerbate existing inequalities if it is not accompanied by skill upgrading (Iammarino et al. 2020). There are also concerns that robotization will replace labour in routine tasks, leading to technological unemployment and promoting labour market polarization. On the other hand, employees with lower incomes and educational levels may not only find it more difficult to benefit from new digital services, but also face the twin transition costs associated with the automation of jobs or poverty in transportation (European Commission, 2022). These inequalities can be exacerbated by territorial disparities in the levels of economic development, and digital and green production and consumption patterns.

The sixth article in this special issue, Consoli et al. (2023) look at this territorial dimension and analyse whether and to what extent the expansion of digital skills in EU regions is related to intra-regional income inequalities. Their analysis considers two potential channels of influence: the skill-bias of digital technologies towards highly educated workers performing non-routine tasks, and the enabling character of e-skills to generate innovations. They suggest that the development of digital skills could exacerbate inequalities if the skill-bias effect dominates, leading to a larger wage dispersion in the region, or when innovations strengthen the position of oligopolistic incumbents. Accordingly, digital skills are expected to increase inequalities in the lower end of the regional income distribution, while potentially having the opposite effect on the upper end of the income spectrum.

Consoli et al. (2023) test these expectations using an unbalanced panel of 103 European regions for the period 2003-2013. Their results confirm the influence of digitalization on intra-regional income inequalities, although the effects vary among different income groups. The intensity of regional e-skill mitigates inequalities among those with high levels of income, while it increases inequalities among those with lower levels of income. This evidence underscores the role of digitalization as determinant of within-regions inequalities. However, as indicated by the authors, future research on the drivers of regional cohesion should jointly consider the effect of the adoption of digital technologies on cross-regional convergence.

Besides the effects on territorial inequalities, the twin transformation can also deepen existing disparities between the most advanced firms and those lagging in the transition process. The adoption of digital and green technologies may require great initial investments and implies high technological capabilities in terms of equipment and qualified personnel (Andrews et al., 2018). This is a hurdle more difficult to address by small and medium-sized enterprises (SMEs) than by larger firms, which typically possess greater financial and human resources. The gap between leading and lagging firms in the twin transition may enlarge if, as the empirical evidence suggests, firms that make more investments in the digital and green transformation are also more likely to keep the path of investments in the future (Teruel et al., 2023), and become technology leaders in their sector (Veugelers et al., 2023). This has crucial implications for policy measures, which must seek to support and facilitate the transition for all businesses, irrespective of their size or current technological capabilities.

In this regard, a fundamental element for staying competitive during this transition process is securing access to equity finance for such investments, a task that could be especially challenging in the case of green innovative ventures. Compared to other high-tech ventures, green initiatives may be less attractive for venture capital (VC) because they usually require higher capital intensity and take longer to reach the maturity phase (Criscuolo and Menon, 2015; Demirel et al., 2019). They are also exposed to higher risk of market exit due to the complex nature of the environmental technologies and the nascent stage of market acceptance and commercialization in the sector (Ghosh and Nanda, 2010).

However, these dynamics may shift in presence of green patenting, which might act as a distinctive signal that mitigates information asymmetries, particularly in the initial stages of investments. From this perspective, in the final article in this special issue, Bellucci et al. (2023) use a unique dataset that matches information on equity transactions with firm-level balance sheets and patented innovation data. Their empirical analysis examines whether the probability of raising VC compared to other equity financing varies for firms that have registered a green patent. Their results show that a larger share of green versus non-green patents in a firm's portfolio increases the probability of receiving VC finance over other equity. This attractiveness of green patenting for VC investment is robust considering various dimensions of heterogeneity, including the stage of investment financing, the investor type, and country-specific factors. Therefore, public policy that stimulate the growth of VC markets could assist firms in undertaking high-risk eco-innovation projects. However, further research is needed to compare the effectiveness and suitability of different alternatives of public intervention (subsidies, tax credits, co-investment, etc.) aimed at improving financial conditions for these types of projects.

4. Conclusions and policy implications

Throughout this special issue, we have delved into the dynamics of the twin transition, exploring the potentially profound effects of digitalization and environmental sustainability on industrial innovation and social inequalities. The seven articles featured in this special issue have shed light on the multifaceted dimensions of the twin transition, offering insights and avenues of future research into the implications for firm innovation strategies and investments, as well as the far-reaching economic, social, and geographical repercussions of the digital and green transformation. As this introduction to the special issues draws to a close, we have some overarching firm- and policy-level recommendations.

First, to stimulate the synergies of the twin transition, firms should diversify their investments across a diverse array of digital technologies, with a focus on AI applications. From a policy point of view, given that the firms' capability to eco-innovate is strongly related to the use of AI systems, an effort should be made to extend and upgrade the infrastructures on which advanced digital applications run. When devising instruments to encourage eco-innovations, policy makers should acknowledge that the adoption and use of digital technologies is different across firms of different size.

Second, in the specific context of the automotive industry, to guide firm transitions towards radical low-emission trajectories, the firm's existing body of "brown" knowledge and the level of diversification across alternative green solutions should be taken into account. On the one hand, understanding "brown" technologies appears fundamental for inventing green. On the other, highly diversified firms are more likely to lead the internal combustion engine technological landscape. This is in line with recent empirical findings that highlight the positive effect of environmental policies on the development of green technologies, without hampering progress in related non-green technological domains (Barbieri et al., 2023).

Thirdly, advancing firms' digitalization appears to be a key element to promote competitiveness, enhance productivity, and maintain resilience during crisis such as the COVID-19 pandemic. However, as firms' digitalization efforts tend to persist, public policy should aim at assisting firms lagging in the digitalization process to overcome their initial investments in this field to prevent widening the digital gap.

Fourthly, to mitigate potential adverse effects of digitalization on societies, public policy should complement digitalization initiatives with the introduction or enhancement of training schemes for less skilled workers to counteract the uneven diffusion and utilization of ICTs. Given that digitalization may increase income inequality not only between regions but also within regions, a locally tailored design and implementation of Smart Specialization / Partnerships for Regional Innovation Policies is needed to leave no place behind[1].

Lastly, both firms and policy makers should be aware that the presence and intensity of green patenting within firms' portfolios increase the attractiveness for VC investment. Consequently, the development of VC markets can play an important role in stimulating firm's eco-innovation projects.

Building on the discussions and insights of the studies collected in this special issue, there are several future avenues of research at the intersection of the twin (digital and green) transition. We propose some of these potential avenues for exploration here.

First, there has been limited research exploring the interplay between the Digital and Green transitions. Future research should delve further into the synergistic relationships between green and digital technologies. This could involve the examination of how recent advancement in digital technologies can enhance the implementation and effectiveness of green technologies and vice versa.

Second, an understanding of the broader economic implications of the twin transition remains little investigated. Scholars are encouraged to investigate the consequences (economic growth, productivity, further technological development, climate change mitigation) that the twin transition can entail for various stakeholders (including workers and consumers) and at different levels of analysis (e.g., individuals, ecosystems, regions and nations).

Third, future research should continue to explore the potential for digital-green transitions to either exacerbate or alleviate economic inequalities. This includes the examination of how the development of twin technologies affect access to resources and employment opportunities across different industries and occupations.

Organisational adaptation to the twin transition is a fourth area of future research. Future work could consider how organisations adapt and transform in response to the digital and green transitions. Understanding how private and public organisations adapt in response to the challenges of digital and green transformations could yield valuable insights for practitioners, policy makers and society at large.

More cross-country comparative studies are also needed, particularly for the effect that the twin transition in Western developed countries can have across the value chain, as well as the impact on the production capacity and the exploitation of natural resources in developing countries.

Finally, given the leading role of policy in promoting the twin transition, scholars are advised to further evaluate the role of specific policies and regulations enacted to implement the twin transition. This could include investigating how policy can balance and manage trade-offs between digital and green goals, as well as the ways in which policy can stimulate innovation and adaptation to these changes within firms and industries.

[1] Partnerships for Regional Innovation is a new approach to innovation-driven territorial transformation based on the experience on Smart Specialisation, linking EU priorities with national plans and place-based opportunities and challenges to assist territories to align these policies better with their specific needs.

By exploring these areas, researchers can shed further light on the complex challenges and opportunities presented by the twin transition, contributing to the refinement of our theoretical and empirical understanding of this nascent topic in the economics and management of innovation.

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