How does digitalisation support firms' strategies for climate change mitigation and adaptation

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Abstract

This paper investigates how firms navigate the dual challenges of digitalisation and climate change. Our comprehensive approach considers climate change strategies, distinguishing adaptation-only, mitigation-only and 'dual' adaptation and mitigation strategies. Drawing on theoretical insights from the literature on digital affordances, we argue that digitalisation enables firms to recognise better the opportunities and risks associated with climate change. These affordances significantly influence strategic decisions regarding adaptation, mitigation, or a combination of both, ultimately impacting the intensity of their implementation efforts. To empirically examine these dynamics, we analyse data from the 2022 and 2023 European Investment Bank Investment Survey waves. Our sample includes over 24,000 firms, spanning small and medium-sized enterprises (SMEs) and large businesses across 27 EU Member States and the USA. Our results reveal that firms with higher digitalisation are more likely to adopt a 'dual' strategy that combines mitigation and adaptation efforts rather than pursuing a single climate strategy or no climate response. Furthermore, we find a positive relationship between digitalisation and climate action intensity across mitigation and adaptation measures. Importantly, these patterns hold consistently across different sectors and firm sizes. Overall, our study sheds light on the critical role of digital technologies in shaping firms' climate responses, emphasising the need for organisations to leverage their technological strengths to address environmental challenges effectively.

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1 INTRODUCTION

The climate crisis poses an existential threat to humankind, necessitating decisive action at scale from both businesses and governments to achieve sustainable and inclusive growth (Stern & Valero, 2021). The emergence of novel Industry 4.0 digital technologies signifies another significant structural transformation for businesses, potentially intertwined with the ongoing pursuit of environmental sustainability.

The decisions firms make regarding implementing green technologies and sustainable business practices are influenced by a complex interplay of factors, reflecting a balance between the private and social benefits of adaptation and mitigation. *Climate mitigation* refers to actions aimed at reducing greenhouse gas emissions to prevent further climate change. In contrast, *climate adaptation* refers to adjustments made by businesses to increase their resilience by moderating climate change risks or capitalising on beneficial opportunities (Klein, Schipper, & Dessai, 2005, p. 580). Until recently, much attention has focused on business efforts to mitigate climate change, which has been at the top of the international agenda since the Kyoto Protocol of 1997. However, there is growing recognition of the unavoidable physical impacts of climate change, such as floods, severe droughts, rising sea levels, and wildfires (Bleda & Pinkse, 2023). These impacts directly and indirectly affect businesses and society, making it imperative to pursue climate adaptation alongside mitigation efforts. This was recognised by the Paris Agreement of 2015 (Gasbarro, Iraldo, & Daddi, 2017).

Emerging research has explored possible applications of advanced digital technologies for climate mitigation (Abd El-Mawla, Badawy, & Arafat, 2019) and climate adaptation purposes (Leal Filho et al., 2022). However, the understanding of how firms take advantage of these digitally enabled opportunities to address climate-related challenges remains limited (Montresor and Vezzani, 2023).

This paper considers whether firms' *digitalisation,* understood as the creative application of digital technologies (DTs), enables firms' climate response explicitly distinguishing between adaptation and mitigation actions. We draw on theoretical insights from the organisational learning and digital affordances literature and posit that more advanced digitalisation is related to the probability of adopting climate change strategies and the intensity of their implementation. Our findings also provide insight into whether digitalisation is conducive to a dual strategy, wherein a firm undertakes both mitigation and adaptation actions. Our empirical analysis draws on the 2022 and 2023 waves of the European Investment Bank Investment Survey (EIBIS), covering about 25,000 firms from 27 EU countries and the USA. Therefore, the study overcomes some of the limitations of previous studies which examined the relationship between firms' digitalisation and sustainability within the context of specific countries (Daddi et al., 2020; Feng et al., 2022; Li & Shen, 2021; Montresor & Vezzani, 2023).

Our study also responds to a recent call by Daddi et al. (2018) to conduct quantitative studies drawn from original survey data to extend further the knowledge base obtained by studies based on the Carbon Disclosure Project (CPD) database (Gasbarro et al., 2017; Gasbarro & Pinkse, 2016; Kolk & Pinkse, 2004). Additionally, George et al. (2021) urge scholars to investigate further the convergence of sustainability and digital imperatives in entrepreneurial ventures. In this paper, we contribute to this understanding by shedding light on how the relationship between digital technologies and climate adaptation and mitigation is shaped by firm size. In this way, we contribute to a better understanding of the environmental practices of SMEs, an emerging but still understudied area of research (Cecere, Corrocher, & Mancusi, 2020; Johnson, 2015; Kumar, Singh, & Dwivedi, 2020; Montresor & Vezzani, 2023; Parrilli, Balavac-Orlić, & Radicic, 2022).

The remainder of the paper is structured as follows. Section 2 briefly reviews the literature on factors influencing businesses' climate adaptation and mitigation first and introduces the notion of climate change strategy before focusing specifically on the role of digitalisation. Section 3 outlines our view on the mechanisms relating to digitalisation and businesses' climate change strategy and the intensity of its implementation by introducing the notion of digital affordances. Section 4 describes the data and methods, and Section 5 summarises the results. Finally, Section 6 concludes and considers the managerial and policy implications of the findings.

2 LITERATURE OVERVIEW

2.1 Mitigation, adaptation, and climate change strategy

Previous studies have identified a range of factors affecting businesses' responses to climate change. There is an overall understanding that both mitigation and adaptation are affected by a range of influences, which can be broadly grouped into *individual* factors (focusing on cognitive processes of key decision-makers), *organisational* factors (within the firm, focusing on organisational capabilities, managerial practices and routines, organisational learning, resources), and factors *external* to the firm (including regulatory, institutional, social, and cultural contexts). However, these factors are interrelated and interdependent (Linnenluecke, Griffiths, & Winn, 2013; Kesidou, Krammer, & Wu, 2024; Brito, 2022).

Sectoral differences play a role in business climate responses, with previous studies on climate mitigation focusing on highly polluting sectors and research on adaptation examining more vulnerable sectors, such as agriculture, wineries, ski resorts, and the energy sector (Brito, 2021). External stimuli, such as environmental policy stringency (Demirel, Iatridis, & Kesidou, 2018), stakeholder pressure and customer demand (Cadez, Czerny & Letmathe, 2019; Daddi et al., 2020), drive mitigation efforts. In contrast, adaptation is more strongly influenced by the uncertainty of predicting extreme weather events. Therefore, previous studies focused on how the experience of extreme weather events influences adaptation (Fankhauser, Smith, & Tol, 1999; Hamilton-Webb et al., 2017; Kang, Yoon, & Rhee, 2017; Linnenluecke, Griffiths, & Winn, 2012).

In uncertain environments, individual factors, such as cognition, managerial sensemaking and interpretation, and even emotions, play an important role in influencing adaptation behaviour (Bleda et al., 2023; Bleda & Pinkse, 2023; Mazutis & Eckardt, 2017; Sharma, 2000). For example, Daddi et al. (2020) find that managerial climate change sensitivity plays a mediating role between institutional pressures and climate change responses. Businesses that perceive higher institutional pressures are more likely to demonstrate higher climate change sensitivity, leading to a higher likelihood of adopting mitigation and adaptation strategies.

In conjunction with external and individual factors, organisational factors are unsurprisingly fundamental in analysing business adaptation and mitigation responses, with a large body of literature disentangling different drivers of change. Organisation-centric literature, building on managerial theories such as the Resource-Based View of the firm (RBV), organisational learning theories, and the dynamic capabilities framework, focus on different resource domains and their interaction in understanding firms' proactive climate responses (Backman et al., 2015; Bowen & Sharma, 2005), and the role of organisational routines, core competences (and competences-enhancing investments), culture and capabilities (Berkhout et al., 2006; Kolk and Pinkse, 2004).

Some previous studies do not explicitly distinguish adaptation and mitigation when examining business decisions related to climate change (Mazutis & Eckardt, 2017; Wade & Griffiths, 2022). The majority of studies focus on either adaptation (e.g. Berkhout et al., 2006, Bleda & Pinkse, 2023), or mitigation (Kolk & Pinkse, 2004; Sharma, 2000), and only a few examine both adaptation and mitigation strategies and actions at the same time (Daddi et al., 2020; Pinkse & Kolk, 2011). However, given the increasing understanding that both mitigation and adaptation are crucial for businesses to navigate the challenges and opportunities of a changing climate (Bleda et al., 2023), and following Tol (2005), we argue that it is vital to analyse mitigation and adaptation in conjunction to draw a holistic understanding of businesses' climate responses.

Business responses to climate change involve strategic decision-making, which translates into tangible actions or outcomes. Following previous studies, we define a *climate change strategy* as ‘a pattern in action over time’ (Mintzberg, 1989, p.27) or ‘outcomes in the form of actions’ intended to manage the relationship between business operations and the natural environment, be it for compliance or voluntary considerations (Sharma, 2000, p.682). In this paper, we consider three pro-active climate change strategies in contrast to a ‘no climate response’ choice: (1) a business chooses to adapt to minimise risks of climate change without mitigating its environmental impact; (2) a business chooses to mitigate its environmental impact without adaptation measures; and, (3) a business chooses a dual climate strategy pursuing both adaptation and mitigation. This relates to the long-standing debate on trade-offs versus synergies between mitigation and adaptation at the macro and policy levels. If synergies between these two responses are possible, the next question is under what enabling conditions can these be realised (Duguma et al., 2014; Jones et al., 2007; Klein et al., 2005; Tol, 2005). Digitalisation, among other organisational factors, may play a decisive role by offering tools and creating enabling conditions for climate adaptation and mitigation within organisations. Therefore, our main interest is to examine to what extent the level of digitalisation facilitates climate change strategy and its implementation.

2.2 Digitalisation and climate change strategy

A growing body of literature explores different ways in which information technologies (IT) and, more recently, advanced digital technologies, such as AI, the Internet of Things, advanced robotics, blockchain etc., may be used to address environmental sustainability challenges (Bai et al., 2020; Cooper & Molla, 2017; Elliot, 2011; George, Merrill, & Schillebeeckx, 2021) and to drive eco-innovation (Faucheux & Nicolaï, 2011; Hanelt, Busse, & Kolbe, 2017).

George and Schillebeeckx (2022) point out that digitalisation, resulting in businesses dealing with a massive influx of diverse data at unprecedented speed, is a major force behind organisational change: it affects organisational learning, and in the context of multinationals, also influences international learning. With the fast-paced development of new technologies, digitalisation, even on its own, creates organisational challenges, which are magnified when coupled with climate change and the post-pandemic context. Ciulli and Kolk (2023) also note that digitalisation increases complexity, which may exacerbate the challenges multinational corporations face in achieving sustainability goals. Pinkse, Demirel and Marino (2024) offer a framework to map the role of digital technologies (DTs) as enablers of net zero innovation by enhancing 'unique organisational capabilities'. They suggest that DTs foster firms' recombinative capabilities, enabling the integration of knowledge from different technological domains in new and unexpected ways and facilitating better coordination of knowledge flows within the firm (e.g. between the firm's R&D department and other functional domains such as marketing, logistics, etc.) and across the supply chain.

However, the question arises whether businesses, especially those that do not have sustainability and green innovation at their core, take advantage of the opportunities offered by digital tools in forming climate change strategies (Montresor and Vezzani, 2023). Research providing quantitative evidence on the relationship between digitalisation and businesses' climate responses is still in its infancy. Li and Shen (2021) and Feng et al. (2022) find a positive relationship between the digitalisation level and green innovation, measured by the number of patent applications, in the context of Chinese A-share listed corporations. In a recent study, Montresor and Vezzani (2023) found a positive relationship between Italian firms' investment in DTs and their propensity to eco-innovate by redesigning production processes and adopting new production models to promote environmental sustainability. They also found that investing in more than one technology, called 'digital bundling', increases the probability of undertaking eco-innovation. Ardito (2023), using Flash Eurobarometer survey data on over 14,000 European firms and studying the relationship between digitalisation and social and eco-innovation, concluded that the degree of digitalisation is positively related to the probability of environmental innovation. However, firm-level quantitative evidence of the relationship between digitalisation and climate change strategies, comprising mitigation and adaptation, still needs improvement.

3 CONCEPTUAL FRAMEWORK AND HYPOTHESES

To embrace the complex relationship between digitalisation and climate change response, our analysis builds upon two major theoretical influences: a micro-evolutionary view of capabilities derived from organisational and managerial studies and an affordances perspective from studies of Information Systems (IS).

3.1 The capabilities perspective

A fundamental tenet in evolutionary economics is that firms are heterogeneous (Dosi, 1997). Specifically, a firm's distinctive behaviour is attributed to its distinct organisational capabilities. Organisational capabilities refer to 'the know-how that enables organisations to perform', such as creating a tangible product or providing a service and developing new products and services (Dosi et al., 2001, p.16), and account for differences in firm performance. In turn, a firm's know-how is embedded in the organisation's activities and routines rather than as well as in technologies and individuals.

Overall, we build our arguments on the evolutionary economics' premise that firms are heterogeneous and that their idiosyncratic behaviour stems from their distinct organisational capabilities. From this, it follows that firms do not adopt or use DTs uniformly. Instead, organisational capabilities underpin firms' heterogeneous responses to digitalisation, which at the organisational level understands 'digitising internal organisational processes' (Nambisan et al., 2017; p. 224) or else deploying novel digital technologies for various purposes and functions (Ciuli & Kolk, 2023). Furthermore, digitalisation leads to the development of a variety of organisational routines and capabilities. It is essential to highlight that digitalisation does not occur in one day but instead refers to a transformative process taking place in a continuum. Therefore, to differentiate the level of digital advancement, scholars proposed different approaches to measure the degree or level of digitalisation: by the number of DTs concurrently adopted (Ardito, et al., 2023; Montresor & Vezzani, 2023), by the scope of deployment of DTs in different business functions, such as production, sales, R&D, or management (Li & Shen, 2021), or else by the total number of texts mentioning the use of advanced DTs (Feng et al., 2022). In what follows, we posit that both breadth (the deployment of multiple DTs) and depth (the implementation of DTs in different business operations and functions) are essential to judge the degree of digitalisation.

3.2 Digital affordances

The concept of *affordances* originated in ecological psychology (Gibson, 1986). Gibson contended that the initial perception of animals and humans is not directed towards the inherent physical properties of objects (e.g., a terrestrial surface's horizontality, flatness, and rigidity). Instead, they perceive the functional possibilities that objects, places, or events can *afford* (e.g., affordance of support to an animal or human). This affordance is not an inherent property of the environment. Instead, it emerges from the relationship between the actor/user (animal or human) and the objects, i.e., it can be defined only relative to the actor. Furthermore, context plays an important role in conditioning the relationship between the user and the object so that 'affordances are neither a property of the artefact, the user, nor the context of use, but a property of their relationship' (Faik et al., 2020; p. 1364).

The concept of affordances has been adapted and applied in IS studies to describe a relationship between technical objects (IT artefacts and their components) and a user (or a group of users). This relationship identifies 'what the user may be able to do with the object, given the user's capabilities and goals' or 'the possibilities for goal-oriented action afforded to specified user groups by technical objects' (Markus & Silver, 2008). It has been referred to as *functional* (Marcus & Silver, 2008; Seidel, Recker & vom Brocke, 2013), *technological* (Nambisan et al., 2017)*, or IT affordances* (Faik, Barrett & Oborn, 2020), and more recently, in the context of digitalisation, as *digital affordances* (Autio et al., 2018; Belitski, Korosteleva & Piscitello, 2023), the term which we will also use.

Digital affordances allow us to conceptualise how businesses formulate strategies and enact a range of practices responding to climate change 'through creative deployment of technologies' (George et al., 2021, p. 1000). Digital affordances do not create necessary or sufficient conditions for business climate responses; instead, they offer potential that may or may not be realised depending on business objectives, context, external stimuli, and organisational resources and capabilities (Ciulli and Kolk, 2023; Seidel, Recker & vom Brocke, 2013). We introduce two categories of digital affordances that enable climate response behaviour: *sensemaking affordances* and *sustainable practising affordances*.

3.3 Hypotheses development

3.3.1 Sensemaking affordances and climate change strategy

Drawing on Weick's influential work (1995, Weick et al., 2005), *sensemaking* within organisations describes a process of 'making sense', allowing managers to navigate complexity and uncertainty. It typically involves three sequential steps (Hahn et al., 2014): 1) *scanning*: managers gather information, which is often more abundant than they can process, based on their 'cognitive frame' and objectives; 2) *interpreting*: this information is analysed and given meaning based on existing knowledge and cognitive frameworks; 3) *responding*: based on the interpreted meaning, decision-makers take action or adjust their approach. The uncertainty and complexity of climate change make it difficult for firms to identify relevant climate-related events for their operations and to assess their potential impact (Bleda et al., 2023; Wade and Griffits, 2022). These impacts can be direct, affecting businesses through physical changes, or indirect, influencing them through policy, regulations, or shifts in customer and stakeholder behaviour (Bleda et al., 2023). Furthermore, conflicting information about the severity and likelihood of climate change and its impacts is also confronted with existing meanings, often creating contradictions and tensions within the firm and challenging beliefs and organisational practices in place (Bien & Sassen, 2020; Seidel et al., 2013). Therefore, sensemaking can be a foundation for formulating strategic responses to address climate change threats and opportunities (Bleda et al., 2023; Linnenluecke et al., 2013).

Digital technologies contribute to the climate change sensemaking process in several ways. DTs with features such as *monitoring*, *analysing*, and *presenting* information may *afford* collecting and monitoring environmental indicators such as carbon emissions, energy consumption, waste, and machinery and equipment productivity under varying climate/temperature conditions. These DTs enable efficient processing of information, allowing managers and teams to reconsider their beliefs and actions and assess outcomes. Seidel et al. (2013) define these sensemaking affordances as *reflective disclosure affordances,* which, 'if realised, enable seeking information about current work practice beliefs, actions, and outcomes, and support the imagination, articulation, and assessment of alternative actions and outcomes based on environmental sustainability considerations' (Seidel et al., 2013, p.1282).

Additionally, DTs that allow the *expression*, *interpretation,* and *communication* of information can open up information democratisation affordances. These affordances help share climate and sustainability-related information both internally and externally. For example, an enterprise portal solution with dynamic information visualisation and live feedback and commenting features, used to share environmental performance metrics within an organisation, can encourage active employee participation, increase overall awareness of climate-related impacts, reveal alternative actions and outcomes, and spur the formation of new goals and strategic choices (Seidel et al. 2013).

We assume that a higher degree of digitalisation leads to increased digital sensemaking affordances. Hence, we hypothesise that the degree of digitalisation, through the sensemaking affordances mechanism, makes businesses more sensitive to climate change both in terms of their environmental footprint and impact of physical events on business operations, and therefore influences the choice of climate change strategy (Figure 1):

Hypothesis 1: Firms with a higher degree of digitalisation are more likely to adopt a dual (adaptation and mitigation) climate change strategy.

3.3.2 Practice making affordances and intensity of climate actions

DTs also provide actionable potentials that directly influence business mitigation and adaptation actions. Building on Seidel et al.'s (2013) concept of sustainable practice affordances, we propose the notion of *practice making affordances*. These refer to practical mechanisms that allow business managers to use deployed DTs to minimise physical risks and reduce a business's carbon footprint. DTs may *afford* a more efficient input and output management and reduce waste and carbon footprint through digitally enabled controlling systems (e.g. smart manufacturing). Additionally, digitally controlled configuration systems can support adaptation actions, such as calibrating operational regimes of machinery and equipment to changing environmental conditions, avoiding overheating, implementing pre-alert systems, and minimising equipment losses during extreme weather events.

Moreover, DTs afford the conduct of 'location-independent' operations and practices by digitising work artefacts and electronically transmitting tasks and outputs (Seidel et al., 2013., p. 1285). They also help firms gain 'greater control over material flows and activities within the value chain' and reduce 'dependency on location-specific intermediaries' (Autio et al., 2018, p.76). This is relevant for both mitigation actions (e.g. reducing emissions by minimising travel) and adaptation actions (e.g. reducing the number of sites exposed to frequent extreme weather events or holding less stock of inputs and outputs in warehouses subject to material damage in case of extreme weather) (Fankhauser et al., 1999).

Based on these arguments, we hypothesise that the degree of digitalisation, through the practice making affordances mechanism, is related to the climate response actions:

Hypothesis 2a: *Firms with higher digitalisation are more intensively engaged with climate mitigation actions*

Hypothesis 2b: *Firms with higher digitalisation are more intensively engaged with climate adaptation actions*

Hypothesis 2c: Digitalisation is more strongly linked with climate action intensity in firms with a dual climate strategy than in those with only a mitigation or adaptation strategy.

Figure 1 summarises our conceptual framework.

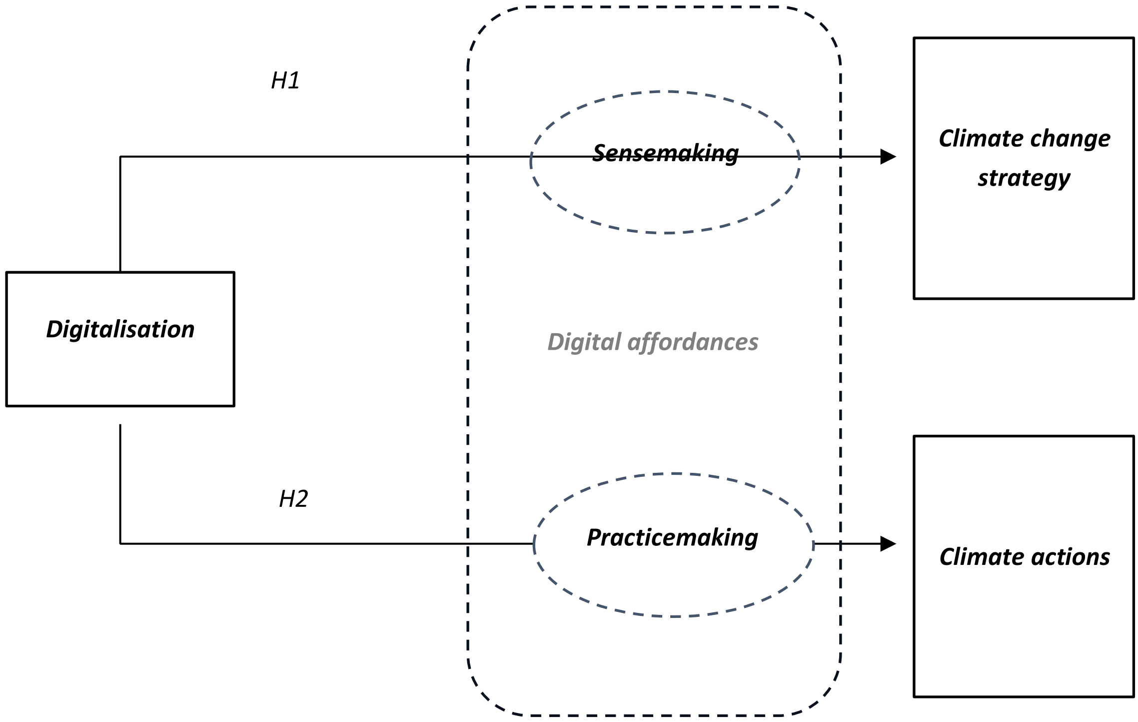

Fig 1. Conceptual framework

4 DATA AND METHODS

Data were collected from the 2022 and 2023 waves of the European Investment Bank Investment Survey (EIBIS). The EIBIS is a pan-European survey that collects information on the investment activities and financing requirements of SMEs and large businesses. It has been conducted annually since 2016. The survey recently included questions on digital investments and firms' climate responses. This firm-level data complements existing macroeconomic investment data, allowing full comparability across countries (Brutscher et al., 2020). The EIBIS covers firms in 27 EU countries and the USA, offering an opportunity to examine the relationship between digitalisation and firms' climate responses across different policy and regulatory contexts.

The EIBIS uses a stratified sampling methodology and is designed to be representative at the country level for both the EU and the USA. It includes four sectoral groupings (manufacturing, services, construction, and infrastructure) and four firm-size class levels (micro, small, medium-sized and large). Hence, it provides a unique source of information for studying digitalisation and firms' climate responses across different firm size groups. It is particularly suited to studying structural societal transformations, like digitalisation and green transition.

All firms interviewed were sampled from the BvD ORBIS database, which allows survey data to be matched with firms' financials and administrative information. Each year, the survey covers approximately 12,000 firms across the EU and around 800 firms in the US. Brutscher et al. (2020), reviewing the data quality of the EIBIS data and comparing the EIBIS sample with two other databases, Eurostat Structural Business Statistics and CompNet, conclude that the sampling framework is adequate and captures well the business population with little evidence of selection bias, thus confirming that EIBIS is a reliable data source to study firms' investment and innovation activity. Our final dataset is a pooled cross-section covering the 2022 and 2023 waves and consists of 22,484 observations.

4.1 Dependent variables

The 2021 and 2022 waves of EIBIS asked firms two key questions to assess their climate-related engagement:

1. Climate Adaptation: Respondents were asked whether they developed or invested in measures to build resilience to physical climate change risks. In particular, firms were asked whether they introduced an adaptation strategy for physical climate risks, solutions to avoid or reduce exposure to physical climate risks (technological and engineering solutions or nature-based solutions), and insurance products to offset climate-related losses (e.g. parametric insurance).
2. Climate Mitigation: Respondents were also asked whether they were investing or implementing sustainable practices to reduce GHG emissions. Specifically, the following mitigation measures were captured: investing in new, less polluting business areas and technologies; investing in energy efficiency including heating and cooling improvements, energy management (e.g. energy smart technologies, EMAS); onsite/offsite renewable energy generation; waste minimisation and recycling; sustainable transport options (e.g. fuel efficient and hybrid/electric vehicles, electric rolling stock).

Based on firms' responses, we construct three different dependent variables to explore the role of digitalisation on business climate response: (a) Climate Change Strategy (CCS) – related to Hypothesis 1, (b) Intensity of Climate Mitigation actions (ICM) – related to Hypotheses 2a and 2c and (c) Intensity of Climate Adaptation actions (ICA) – related to Hypotheses 2b and 2c.

(a) The **Climate Change Strategy (CCS)** variable measures whether a firm engages in climate adaptation, climate mitigation, or both. It is a categorical variable taking values from 0 to 3. Where 0 indicates *No Climate Response* (the firm answered 'no' to all adaptation and mitigation options in questions (1) and (2)); 1 indicates

A*daptation On*ly (the firm answered 'yes' to at least one adaptation measure stated in question (1) and 'no' to all mitigation measures in question (2)); 2 indicates *Mitigation Only* (the firm answered 'yes' to at least one mitigation measure stated in question (2) and 'no' to all adaptation measures in question (1)); 3 denotes A*daptation and Mitigation* (the firm answered 'yes' to at least one adaptation measures in question (1) and at least one mitigation measures in question (2)).

(b) The **Intensity of Climate Mitigation actions ICM** variable measures the extent of a firm's engagement with climate mitigation practices. It is derived from the responses to question (2) by dividing the number of mitigation measures undertaken by the firm by the overall number of mitigation measures (5 in total). Hence, ICM takes values in the interval [0 to 1] where 1 indicates that the firm is engaging with all 5 out of 5 measures of climate mitigation and 0 – with none.

(c) Similarly, the **Intensity of Climate Adaptation actions (ICA)** variable measures the extent of a firm's engagement with climate adaptation practices. It takes values in the interval [0 to 1] where 1 indicates that the firm engages with all 3 adaptation measures of the question (1) and 0 – with none.

4.2 Explanatory variables

Our main variable of interest, *digitalisation*, reflects both the breadth and depth of digitalisation. Firms were asked whether they adopted 'any of the four digital technologies that can be considered state-of-the-art for their sector' (Veugelers, Faivre, Rückert et al., 2023). These state-of-the-art DTs are:

- in manufacturing: (a) 3D printing, (b) robotics, (c) the internet of things (IoT), (d) big data/artificial intelligence (AI).
- in construction: (a) 3D printing, (b) drones, (c) the internet of things (IoT), and (d) virtual reality (VR).
- in services: (a) virtual reality, (b) platforms, (c) the internet of things (IoT), and (d) big data/artificial intelligence (AI).
- in infrastructure: (a) 3D printing, (b) platforms, (c) the internet of things (IoT), and (d) big data/artificial intelligence (AI).

In addition, the dataset contains information on whether DTs were adopted partially ('implemented them in parts of your business') or fully ('whether your entire business is organised around them'). For each of the four state-of-the-art digital technologies of the sector we assign value 0 if firm did not adopt the technology, 1 – if adopted partially, and 2 – if adopted fully. Our *digitalisation* variable is obtained by summing up the scores for all four DTs relevant to the sector. It takes value from 0 to 8 and reflects the breadth of digitalisation (the number of technologies used) and depth of digitalisation (to what extent technology is implemented in the business).

We posit that both the breadth and depth of digitalisation are conducive to higher digital affordances for climate change strategy and its intensity. Indeed, the deployment of DTs in the business is associated with learning-by-using processes, entailing trial and error processes, increased competencies of the staff when using the technology and, hence, more creative use of it for other purposes. At the same time, novel DTs, when combined in use, may create new affordances compared to one DT used in isolation, something reported by previous studies (Ardito, 2023; Montresor and Vezzani, 2023). For example, the data generated by IoT devices, collected and analysed using AI and machine learning, may provide a clearer picture of alternative outcomes of different actions.

4.3 Control variables

To control for the effect of motivations internal to the firm on mitigation and adaptation, we consider a number of additional firm-level variables following Kalantzis and Dominguez (2022). First, we introduce a categorical variable *Transition,* which takes the value of 1 if the firm expects that transition to stricter climate regulations will be associated with risk, the value of 2 if the firm expects that it will be associated with an opportunity, and 0 if the firm expects no impact. This variable captures perceptions of future external regulatory pressures, which we may expect to influence mitigation behaviour. Second, a categorical variable *Climate impact* gauges the vulnerability of the firm to extreme weather events which may influence adaptation. It takes value of 1 if the firm evaluates the current impact of climate change on the firm as minor, a value of 2 – if the impact is major, and 0 if no impact is reported. Third, we also control for carbon emissions monitoring and targeting by introducing a dummy *Carbon target,* taking a value of 1 if the firm actively sets and monitors internal targets on carbon emissions and energy, and 0 otherwise. Finally, a binary variable *Energy costs* takes value of 1 if the firm perceives energy costs as a major obstacle to their investment activities, and 0 otherwise. Among these four control variables, three (Transition, Carbon Target, and Energy costs) are expected to directly influence mitigation behaviour, and one (Climate impact) – adaptation behaviour. However, we may also argue that they are also related to a latent process reflecting climate awareness and climate change exposure. Therefore, we include all four controls in all our models (alternative specifications were also tested without affecting the results).

Additionally, we control for other firm characteristics: *Business monitoring* is a binary variable taking a value of 1 if the firm has a formal strategic business monitoring system to reflect the quality of management practices; *Innovator* is a dummy equal to 1 if the firm introduced new products, processes or services in the last financial year; *Subsidiary* is a dummy equal to 1 if the firm is a subsidiary of another company; *Size* is a continuous variable relating to firm size measured as number of employees working full time or part time (more than 12 hours per week), in log scale. Finally, we also control for the sector, country and year of the survey. Summary statistics are reported in Table A1 in Annex.

4.4 Modelling strategy

The empirical analysis is conducted in four steps. First, to test Hypothesis 1, we model the Climate Change Strategy (CCS). Given the categorical nature of the CCS dependent variable without any particular ordering, we use a multinomial logit model. Second, we use an OLS model to test Hypothesis 2a, 2b and 2c modelling the Intensity of Climate actions– adaptation (ICA) or mitigation (ICM). Third, to check the robustness of our findings, we also run additional regression analysis using an instrumental variable approach. Finally, we explore how the results vary depending on size, sector, and region.

5 EMPIRICAL RESULTS

5.1 Climate change strategy

Table 1 reports the results of multinomial logit analysis modelling the probability that a firm chooses between four strategic choices regarding climate change: No Climate Response, to undertake Only Adaptation, to undertake Only Mitigation, or to do both, Adaptation and Mitigation, depending on the level of digitalisation and a set of other factors. Three alternative specifications are presented: (Model 1) includes the primary explanatory variable (*digitalisation*) and controls for firm size, the survey wave, sector and country. Model 2 also controls for other potential drivers of climate response choice: whether the firm perceives the transition to stricter climate regulations as a risk or opportunity (*transition*), currently experiences an impact of climate change (*climate change*), sets and monitors carbon targets (*carbon targets*), evaluates energy costs as a major barrier to investment (*energy costs – major barrier*). Moreover, this model takes into account other firm characteristics, which may affect climate response, such as general innovativeness (innovating firms are more open to change and may have routines in place enabling them to better respond to uncertain environment and innovate beyond the core business activity) (*innovator*), managerial practices proxied by whether a formal strategic business monitoring system is in place (*business monitoring*), and whether a firm is as subsidiary of another company (*subsidary*) and hence can formulate an independent strategic choice. Model 3 also includes a dummy variable if the firm is a listed company (*listed*) to account for stakeholder pressure. Including the *listed* variable comes with the drawback of a drastically reduced sample size. Therefore, we consider Model 2 as the baseline, where columns (4) to (6) relate to three alternative CCS models compared to a reference outcome of 'no climate response'.

The results of all three specifications show that digitalisation is an important factor in the choice of climate change strategy. Specifically, firms more digitalised firms are more likely to pursue a 'dual' climate change strategy rather than doing nothing, while the likelihood of choosing an adaption-only or mitigation-only strategy is broadly similar. We also find strong associations between other firm-level explanatory variables and climate response choices. In particular, firms' perceptions of future transition risks and opportunities and the perception of the extent to which climate change currently affects business are very important. Thus, for firms perceiving climate change as having a major impact on the business, the relative probability of choosing an 'adaptation only' strategy increases by a factor of 4.225 and of choosing a dual strategy by a factor of 5.627 compared to firms not impacted by climate change. As expected, for subsidiary companies, the relative risk of choosing climate response as opposed to no response is lower than independent firms (by a factor of 0.821 in the case of the dual strategy). This means that independent firms are more likely than subsidiary firms to choose a climate response over a 'no response' option.

Table 1. Climate change strategies and Digitalisation: multinomial logit (in odds)

	Model 1			Model 2			Model 3		
	Adaptation Only	Mitigation Only	Adaptation and Mitigation	Adaptation Only	Mitigation Only	Adaptation and Mitigation	Adaptation Only	Mitigation Only	Adaptation and Mitigation
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Digitalisation	**1.201*****	**1.170*****	**1.382*****	**1.150*****	**1.088*****	**1.216*****	**1.107****	**1.065*****	**1.197*****
	(0.046)	*(0.022)*	*(0.027)*	*(0.045)*	*(0.020)*	*(0.024)*	*(0.050)*	*(0.023)*	*(0.027)*
Transition (Reference - no impact)									
– a risk				1.171	1.390***	1.616***	1.179	1.330***	1.502***

				(0.144)	*(0.068)*	*(0.092)*	*(0.168)*	*(0.074)*	*(0.097)*
– an opportunity				1.528***	1.925***	2.763***	1.710***	1.940***	2.678***
				(0.230)	*(0.121)*	*(0.192)*	*(0.296)*	*(0.141)*	*(0.214)*
Climate change (Reference: no impact)									
– a minor impact				2.008***	1.544***	3.359***	1.837***	1.551***	3.387***
				(0.239)	*(0.071)*	*(0.182)*	*(0.252)*	*(0.081)*	*(0.208)*
– a major impact				4.225***	1.438***	5.627***	3.776***	1.398***	5.618***
				(0.621)	*(0.104)*	*(0.440)*	*(0.645)*	*(0.115)*	*(0.498)*
Carbon target				1.337	2.693***	5.251***	1.496*	2.863***	5.527***
				(0.243)	*(0.200)*	*(0.411)*	*(0.325)*	*(0.255)*	*(0.515)*
Energy costs				1.176	1.336***	1.466***	1.251*	1.361***	1.471***
				(0.127)	*(0.058)*	*(0.074)*	*(0.156)*	*(0.068)*	*(0.085)*
Business monitoring				1.433***	1.421***	2.032***	1.530***	1.567***	2.286***
				(0.182)	*(0.075)*	*(0.120)*	*(0.236)*	*(0.099)*	*(0.160)*
Innovator				1.387***	1.378***	2.054***	1.473***	1.398***	2.110***
				(0.167)	*(0.068)*	*(0.113)*	*(0.204)*	*(0.079)*	*(0.133)*
Subsidiary				0.932	0.836***	0.821***	0.836	0.839***	0.816***
				(0.136)	*(0.048)*	*(0.053)*	*(0.145)*	*(0.055)*	*(0.060)*
Listed company							1.324	1.090	1.284
							(1.078)	*(0.436)*	*(0.524)*
Size	1.087**	1.316***	1.560***	1.036	1.243***	1.332***	1.007	1.253***	1.318***
	(0.040)	*(0.019)*	*(0.025)*	*(0.042)*	*(0.022)*	*(0.026)*	*(0.047)*	*(0.025)*	*(0.030)*
Wave 2023	1.370***	1.156***	1.555***	1.217*	1.189***	1.532***	1.128	1.134***	1.374***
	(0.132)	*(0.043)*	*(0.065)*	*(0.128)*	*(0.049)*	*(0.074)*	*(0.144)*	*(0.055)*	*(0.078)*
Sector (Reference: Construction)									
Manufacturing	1.076	1.482***	1.521***	1.143	1.444***	1.409***	1.080	1.416***	1.370***
	(0.159)	*(0.081)*	*(0.095)*	*(0.182)*	*(0.088)*	*(0.102)*	*(0.206)*	*(0.099)*	*(0.113)*
Services	1.163	1.200***	1.294***	1.215	1.200***	1.356***	1.351*	1.232***	1.399***
	(0.159)	*(0.063)*	*(0.079)*	*(0.178)*	*(0.069)*	*(0.093)*	*(0.233)*	*(0.082)*	*(0.110)*
Infrastructure	1.048	0.854***	0.917	1.045	0.811***	0.823***	1.141	0.814***	0.791***
	(0.147)	*(0.046)*	*(0.057)*	*(0.158)*	*(0.048)*	*(0.058)*	*(0.202)*	*(0.055)*	*(0.063)*
Country dummies		*Yes*			*Yes*			*Yes*	
N		**25278**			**22484**			**17761**	
pseudo R-sq		0.074			0.144			0.148	
AIC		49865.603			41036.267			32131.483	
BIC		50695.647			42070.919			33159.071	
Log-likelihood		-24830.802			-20389.133			-15933.741	
chi2		3318.214			69202.326			46796.220	

Note: relative risk ratios are reported (reference: 'No Climate Response'); robust standard errors are in parentheses. $P<0.01$***, $p<0.05$**, $p<0.1$*.

To have a clear picture of the effect of digitalisation on each of the climate strategic choices, Figure 2 plots predicted probabilities of each outcome at different levels of digitalisation based on Model 2, Table 1. It shows that higher digitalisation is associated with an increased likelihood of dual mitigation and adaptation strategy, thus confirming Hypothesis 1. On the contrary, the probability of 'no climate response' is declining with higher levels of digitalisation. We do not find any clear relationship between digitalisation and the choice of 'Adaptation-only' strategy. Interestingly, the probability of a firm choosing 'Mitigation-only' declines with higher levels of digitalisation. This confirms our proposition that more digitalised firms with higher sensemaking affordances are more likely to develop holistic responses to climate change, addressing both public and private objectives.

Figure 2. Predicted probabilities of climate change strategy alternatives

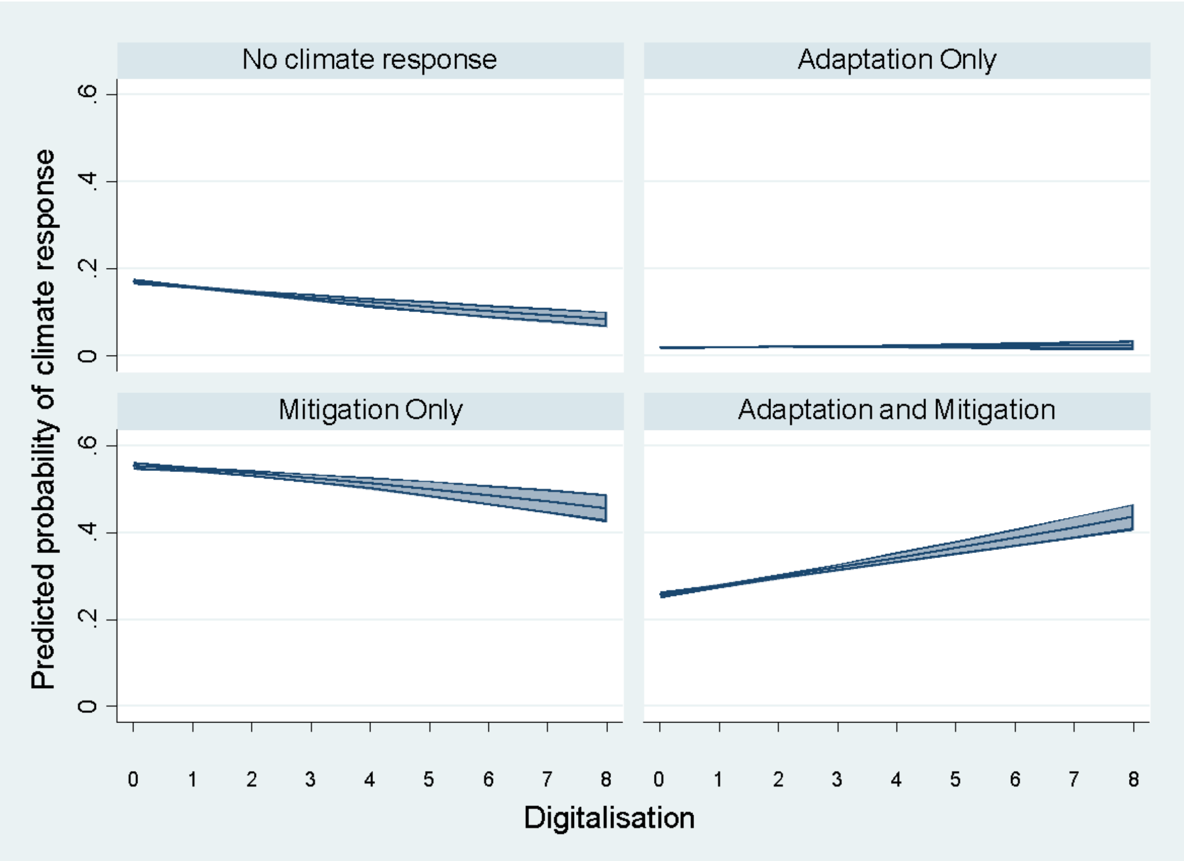

Table 2 presents the average marginal effects of the variables of interest on climate change strategy for our baseline model (Model 2 in Table 1) to highlight the magnitude of the effects. It shows that for a firm increasing its digitalisation level by one unit, the probability of choosing a dual strategy (Adaptation and Mitigation) is increased by 2 percentage points (column 4). Interestingly, firms that perceive the transition to stricter climate regulations as an opportunity, are 8 percentage points more likely to adopt a holistic — mitigation and adaptation response to climate change — compared to those who estimate that it will have no impact on the business. This is much higher than the effect for firms perceiving transition as a risk (3.4 percentage points). In line with previous literature, firms already dealing with the consequences of climate change, are considerably more likely to choose either 'Adaptation only' or the 'Adaptation and Mitigation' strategy, with the magnitude of the effect being higher in the case of the dual strategy. Those firms which evaluate energy costs as a major barrier to investment activity are more likely to engage with mitigation either on its own (by 1.2 percentage points) or in conjunction with adaption (by 2.3 percentage points) compared to firms not considering energy costs as a major impediment to investment.

Table 2. Probability of adopting Climate Change Strategy : Average marginal effects

	No climate response	Adaptation Only	Mitigation Only	Adaptation and Mitigation
	(1)	(2)	(3)	(4)
Digitalisation	**-0.013*** **	**0.001**	**-0.009*** **	**0.020*** **
	(0.002)	*(0.001)*	*(0.002)*	*(0.002)*
Transition (Reference - no impact)				
– a risk	-0.042***	-0.002	0.010	0.034***
	(0.005)	*(0.002)*	*(0.008)*	*(0.007)*
– an opportunity	-0.078***	-0.003	0.001	0.080***
	(0.006)	*(0.003)*	*(0.009)*	*(0.008)*
Climate change (Reference: no impact)				
– a minor impact	-0.072***	0.004*	-0.071***	0.139***
	(0.005)	*(0.002)*	*(0.007)*	*(0.006)*
– a major impact	-0.088***	0.018***	-0.182***	0.250***
	(0.007)	*(0.004)*	*(0.010)*	*(0.009)*
Carbon target	-0.105***	-0.011***	-0.035***	0.151***
	(0.005)	*(0.002)*	*(0.008)*	*(0.008)*
Energy costs	-0.033***	-0.001	0.012*	0.023***
	(0.005)	*(0.002)*	*(0.007)*	*(0.006)*
N	22484			

Note: Average marginal effects correspond to the results of Model 2 in Table 1; full results are reported in Table A2 in Annex; robust standard errors are in parentheses. *p*<0.01***, *p*<0.05**, *p*<0.1*.

5.2 Intensity of mitigation and adaptation actions

Moving now to our second set of hypotheses, which assumes that digitalisation relates to the intensity of climate mitigation and adaptation actions, Table 3 presents the main results of OLS models. The main estimation results for the intensity of climate mitigation (ICM) are presented in column (1), and the intensity of climate adaptation (ICA) is presented in column (4). A one-unit increase in digitalisation is associated with an increase in the intensity of mitigation action by 0.017 if all other variables are held constant, and with an increase in the intensity of climate adaptation action by 0.012. Hence, we find evidence in support of *H2a* and *H2b*. Firms with higher digitalisation are more intensively engaged with climate mitigation and adaptation actions.

Table 3. Intensity of mitigation and adaptation actions and digitalisation: OLS models

	Intensity of Climate Mitigation (ICM)			**Intensity of Climate Adaptation (ICA)**		
	Full sample	**Firms with CM only response choice**	**Firms with simultaneous CM and CA choice**	**Full sample**	**Firms with CA only response choice**	**Firms with simultaneous CM and CA choice**
	(1)	(2)	(3)	(4)	(5)	(6)
Digitalisation	**0.017*** **	**0.012*** **	**0.018*** **	**0.012*** **	**-0.001**	**0.007*** **

	(0.001)	*(0.002)*	*(0.002)*	*(0.001)*	*(0.004)*	*(0.002)*
N	*22484*	*12074*	*6412*	*22484*	*432*	*6412*
R-sq	0.312	0.190	0.236	0.178	0.165	0.117

Note: Coefficients are reported; full results are reported in Table A3 in Annex; and robust standard errors are in parentheses. *p*<0.01***, *p*<0.05**, *p*<0.1*.

To further explore how digitalisation affects ICM and ICA in different strategic settings, we run additional models dividing the sample and testing for significant coefficient differences across sample sub-groups. OLS estimation results for ICM for businesses who engage with mitigation only are reported in column 2, Table 3, and for those who choose to mitigate the impact of climate change and adapt to its consequences are reported in column 3, Table 3. In both cases, digitalisation is positively and significantly related to the intensity of climate mitigation, with the effect being stronger in the case of dual strategy. There is a statistically significant difference in coefficients across models (2) and (3) (at 5%, p value of 0.0305).

Similarly, we also compare the relationship between digitalisation and ICA for those businesses that choose an adaptation-only strategy (column 5, Table 2) and for those who choose a dual strategy (column 6, Table 2). Due to the small sample size, the coefficient for the 'adaptation only' group is insignificant. On the contrary, we find a statistically significant and positive relationship between digitalisation and ICA for the dual choice group of firms. The difference in coefficients across models (5) and (6) is statistically significant at 10% (p value of 0.0766). Therefore, we find evidence supporting H2c assuming that the relationship between digitalisation and the intensity of engagement with climate mitigation and climate adaptation is stronger in firms choosing dual strategy than firms doing either mitigation or adaptation.

As an additional robustness check, we also analysed fractional response models (using the normalised dependent variables varying from 0 to 1) and Poisson models where dependent variables are not normalised by the total number of actions and are count variables. The results are similar to the results of OLS models.

5.3 Robustness check: Instrumental variable approach (2SLS)

Despite controlling for firm-level characteristics and sector and country effects, our models may still suffer from omitted variable bias. To address endogeneity issues, we apply an instrumental variable methodology. To instrument digitalisation, we use quarterly data on fixed average download speed from *Ookla* Speedtest aggregated at NUTS2 regions level. We compare quarterly data with the same quarter in the previous year and compute an annual growth rate which captures an improvement in digital infrastructure from year to year. First-stage results show that our instrument is negatively and significantly associated with digitalisation and can be considered exogenous to our dependent variables ICM/ICA. We interpret this as a catching-up effect: in regions with highly developed digital infrastructure, the year-to-year change is likely to be moderate compared to regions which recently started developing their digital infrastructure, and hence associated with a higher firms' digitalisation. We use Stock and Yogo's (2005) rule of thumb to avoid a situation where a weak instrument may lead to substantial bias and distorted statistical inference: the first-stage F-statistic is 110.02, well above the standard threshold of 10. The second-stage results are reported in column 2 for ICM and column 3 for ICA.

Furthermore, we introduce country-level controls to account for differences in the business environment, which can influence mitigation and adaptation. We use a logarithm of greenhouse gas to GDP intensity (tCO2/MillionEuro) to account for *Emissions intensity*, to differentiate more polluting countries from less polluting. We expect that firms in the countries with higher emissions intensity would be more aware of the consequences of CO_2 emissions and hence, more likely to develop a range of climate mitigation measures. We also introduce the log of climate-related economic losses (Euro per inhabitant, thirty years average) as a proxy of *Exposure* to extreme weather events. We expect that firms in countries suffering more extensive losses due to climate-related events would be driven to intensify adaptation measures; it may also affect mitigation indirectly via cognitive mechanisms. Finally, to account for differences in *Environmental regulation*, we use the Environmental Policy Stringency (EPS) Index provided by OECD, which "measures predominantly the stringency of policies to regulate carbon emissions and air pollution" (Kruse et al., 2022, p.32). The latest available EPS data is for 2020, hence we use a 2-year lag. The EPS index has three dimensions: market-based instruments (CO_2 trading schemes, CO_2 taxes etc.), non-market-based instruments (emissions limits), and technology support policies (including R&D expenditure and renewable energy support). First, we use the overall EPS index. Then, we use the three dimensions of EPS to examine how separate components of environmental regulation influence mitigation and adaptation intensity.

Table 4. The intensity of mitigation and adaptation actions and digitalisation: Instrumental variable approach (2SLS)

	ICM/ICA	ICM	ICA	ICM/ICA	ICM	ICA
	First stage	Second stage	Second stage	First stage	Second stage	Second stage
	(1)	(2)	(3)	(4)	(5)	(6)
Digitalisation		0.070***	0.038**		0.146***	0.124***
		(0.020)	(0.016)		0.035	(0.028)
Av fixed speed growth	-0.098***			-0.077***		
	(0.009)			(0.012)		
Subsidiary	0.123***	-0.010*	-0.001	0.112***	-0.015*	-0.005
	(0.025)	(0.006)	(0.005)	(0.027)	(0.008)	(0.006)
Size	0.205***	0.048***	0.020***	0.215***	0.030***	0.001
	(0.007)	(0.004)	(0.003)	(0.008)	(0.008)	(0.006)
Wave 2023	0.085***	0.018***	0.022***	0.129***	-0.007	0.008
	(0.021)	(0.005)	(0.004)	(0.024)	(0.007)	(0.006)
Emmissions Intensity				-0.131**	0.031**	0.054***
				(0.051)	(0.013)	(0.011)
Exposure				0.070***	-0.038***	-0.003
				(0.015)	(0.004)	(0.003)
EPS Market based policies				-0.104***	0.004	0.017***
				(0.014)	(0.006)	(0.005)
EPS Non-market based policies				0.277**	-0.165***	-0.094***
				(0.121)	(0.030)	(0.025)
EPS Technology support policies				-0.054***	0.005	0.015***
				(0.013)	(0.004)	(0.003)
Sector	Yes	Yes	Yes	Yes	Yes	Yes
Country group	Yes	Yes	Yes	Yes	Yes	Yes
_cons	0.110	0.207***	0.000	-0.610	1.060***	0.153
	(0.033)	(0.008)	(0.006)	(0.769)	(0.176)	(0.147)
R-sq	0.095	0.118	0.045	0.109		

F-test	110.022			44.419		
N	20667	20667	20667	16123	16123	16123

Note: coefficients are reported; robust standard errors in parentheses. *P*<0.01***, *p*<0.05**, *p*<0.1*.

Table 4 shows the second-stage results of 2SLS estimations for ICM (columns 2 and 5) and ICA (columns 3 and 6). Across all specifications, results confirm our previous findings: firms with higher digitalisation levels are more intensively engaged with mitigation and adaptation. We also find evidence of a positive relationship between each country's carbon intensity level and firms' mitigation and adaptation efforts. Surprisingly, firms in countries that suffered important losses from climate events in the past are less pro-active. Finally, and most unexpectedly, higher environmental policy stringency is positively and significantly associated with climate adaptation intensity (market-based and technology support policies drive this) and is insignificant for climate mitigation. Further analysis is needed to get a better understanding of the impact of different regulatory instruments on firms' adaptation and mitigation efforts, however, this is beyond the scope of the present paper.

5.4 Heterogeneity: by size, sector and region

Table 5 reports the average marginal effects of digitalisation on the probability of adopting one of four climate change strategies separately for each sector, size group and geographical region. It confirms support for H1 across all sectors, firm sizes and regions: higher digitalisation leads to a higher probability of adopting a dual mitigation and adaptation strategy. Interestingly, in services, increased digitalisation also fosters the 'adaptation only' choice, and this result is most likely to be driven by the tourism, accommodation, and hospitality sectors.

Table 5. Effect of digitalisation on climate change strategy: by sector, size, and region

	No climate response (1)	Adaptation Only (2)	Mitigation Only (3)	Adaptation and Mitigation (4)	N
Full sample – baseline	**-0.013*** **	**0.001**	**-0.009*** **	**0.020*** **	**22484**
	(0.002)	*(0.001)*	*(0.002)*	*(0.002)*	
by Sector					
Manufacturing	-0.018***	0.000	-0.012**	0.029***	*6657*
	(0.004)	*(0.001)*	*(0.005)*	*(0.004)*	
Construction	-0.024***	0.000	0.000	0.023***	*4649*
	(0.007)	*(0.002)*	*(0.007)*	*(0.005)*	
Services	-0.017***	0.003**	-0.008	0.023***	*5914*
	(0.004)	*(0.001)*	*(0.005)*	*(0.004)*	
Infrastructure	-0.004	-0.001	-0.008*	0.013***	*5264*
	(0.003)	*(0.001)*	*(0.005)*	*(0.004)*	
by size					
Micro	-0.023***	-0.002	0.006	0.019***	5095
	(0.005)	*(0.002)*	*(0.006)*	*(0.004)*	
Small	-0.012***	0.003***	-0.008*	0.018***	*8006*
	(0.004)	*(0.001)*	*(0.004)*	*(0.003)*	
Medium	-0.008**	0.000	-0.015***	0.022***	*6399*

	(0.003)	*(0.001)*	*(0.005)*	*(0.004)*	
Medium or Large	-0.008***	0.000	-0.016***	0.024***	*9383*
	(0.003)	*(0.001)*	*(0.004)*	*(0.003)*	
by Region					
Central and Eastern EU	-0.019***	-0.000	-0.005	0.024***	8422
	(0.004)	*(0.001)*	*(0.004)*	*(0.003)*	
Southern EU	-0.006	0.003	-0.016***	0.020***	*4414*
	(0.004)	*(0.002)*	*(0.005)*	*(0.004)*	
Northern and Western EU	-0.009***	0.001*	-0.009**	0.017***	*8231*
	(0.003)	*(0.001)*	*(0.004)*	*(0.003)*	

Note: multinomial logit models, average marginal effects of digitalisation are reported for each of 4 possible outcomes; robust standard errors in parentheses. *P*<0.01***, *p*<0.05**, *p*<0.1*.

Turning to the intensity of climate actions, the results by sector, size and region, the results reported in Table 6 also align with previous findings, confirming H2a and H2b. Higher digitalisation is associated with higher intensity of climate mitigation and climate adaptation. The magnitudes of the effect are comparable across sectors, with most differences in coefficients across models being statistically insignificant, with some exceptions. The effect of digitalisation on ICM in the infrastructure sector is statistically significantly lower compared to manufacturing (Prob = 0.0073) and services (Prob = 0.0376). We can explain this difference by the case of information and communication firms which being included in the infrastructure sector demonstrating disproportionally higher digitalisation levels. The effect of digitalisation on ICA in the infrastructure sector is also statistically significantly different compared to manufacturing (Prob=0.0270), and marginally different to Construction (Prob=0.0890) and Services (Prob=0.0774). Except for the difference between micro and small firms (Prob=0.0188), we do not find any other statistically significant differences in coefficients across firm sizes for the effect of digitalisation on ICM, meaning that the effect is homogenous across all firm sizes. The effect of digitalisation on ICA is (marginally) statistically significantly lower in micro-firms compared to medium (Prob=0.0948) and large firms (Prob=0.0565).

For firms in the Central and Eastern EU, the benefits of digitalisation for ICM appear to be higher than their analogues in the Southern EU (Prob=0.0046) and Northern and Western EU (Prob=0.0099). This finding may be explained by a catching-up process, where even small initial changes in digitalisation have important consequences on firms' capabilities, which, through practice making digital affordances, are transformed into higher mitigation intensity.

Table 6. Effect of digitalisation on intensity of mitigation and adaptation actions and digitalisation: by sector, size, and region

	Intensity of Climate Mitigation Action (1)	Intensity of Climate Adaptation Action (2)	N
Full sample – baseline	0.017***	0.012***	22484
	(0.001)	*(0.001)*	
by Sector			
Manufacturing	0.022***	0.015***	6657
	(0.002)	*(0.002)*	
Construction	0.022***	0.015***	4649

	(0.004)	*(0.003)*	
Services	0.020***	0.014***	5914
	(0.003)	*(0.002)*	
Infrastructure	0.013***	0.009***	5264
	(0.003)	*(0.002)*	
by size			
Micro	0.022***	0.009***	5095
	(0.003)	*(0.002)*	
Small	0.014***	0.010***	8006
	(0.002)	*(0.002)*	
Medium	0.017***	0.014***	6399
	(0.003)	*(0.002)*	
Large	0.020***	0.017***	2984
	(0.003)	*(0.003)*	
by Region			
Central and Eastern EU	0.023***	0.013***	8422
	(0.002)	*(0.002)*	
Southern EU	0.013***	0.013***	4414
	(0.003)	*(0.003)*	
Northern and Western EU	0.015***	0.010***	8231
	(0.002)	*(0.002)*	

Note: OLS coefficients for digitalisation are reported; all models include country dummies; robust standard errors in parentheses. *P*<0.01***, *p*<0.05**, *p*<0.1*.

6 DISCUSSION AND CONCLUSION

This paper makes several key contributions to the literature. It examines the role of digital technologies in enabling businesses to respond to climate challenges. Research on the intersection of digitalisation and business climate change response is still in its infancy (Montresor and Vezzani, 2023). This paper contributes to this research agenda by arguing that DTs enable firms to formulate climate change strategies and to implement both mitigation and adaptation actions more intensively. In doing so, we contribute to the debate on trade-offs vs. synergies (Duguma et al., 2014; Tol, 2005) in climate action. Specifically, our evidence suggests that DTs support synergies between mitigation and adaptation by enabling sensemaking and practicemaking processes, allowing firms to manage climate change holistically. By explicitly separating adaptation and mitigation actions and analysing them as distinct climate change strategies, we build on previous studies (Daddi et al., 2020; Pinkse & Kolk, 2011; Tol, 2005) to advance the understanding of how businesses address the challenges of climate change holistically. We also extend the existing literature by empirically testing our hypotheses on a multi-country sample, compared to Pinkse & Kolk's (2011) conceptual approach and Daddi et al.'s (2020) single-country study.

Our analysis suggests three key findings, which prove robust across sectors, firm sizes, and regions. First, firms with higher levels of digitalisation are more likely to respond to climate change using a dual mitigation and adaptation strategy. This reflects firms' realisation of digital affordances, which enable strongly digitalised firms to embrace the complexities of addressing climate adaptation and mitigation, implying complementarity rather than substitutability. In this sense, digitalisation can help firms to adopt climate change strategies, which yield both public benefits (through mitigation) and private benefits (through adaptation).

Second, we find consistent evidence that stronger digitalisation is associated with higher-intensity mitigation actions and more intensive dual mitigation/adaptation actions. However, due to small sample sizes, the relationship between digitalisation and the intensity of adaptation actions remains unclear. The role of digital affordances driving the intensity of climate action is central here. Stronger digitalisation creates richer affordances for firms to intensify their climate actions with both private and public benefits. Again, these relationships hold across all sectors, sizes, and regions. However, the relationship between digitalisation and the intensity of climate mitigation actions is particularly strong in micro firms.

Third, while digitalisation is important in shaping firms' climate change strategies, other external and eco-system factors also prove important determinants of firms' strategic choices. For example, a perception that climate change will have a major impact on the business sharply increases the relative probability of adopting an 'adaptation only' and a dual adaptation/mitigation strategy. Policy effects also prove important, with higher environmental policy stringency being positively and significantly associated with climate adaptation intensity actions but having little effect on climate mitigation intensity actions. In this sense, policy action seems to be stimulating strategic steps, which increase business resilience and ensure continuity in the face of climate-related risks rather than encouraging steps which have broader impacts on reducing greenhouse gas emissions.

Generally, our results suggest the strong and positive role of digital affordances in enabling firms to adopt climate change strategies. However, firms' willingness to capitalise on these digital affordances clearly depends on their perceptions of climate threat as well as the nature of the environmental regulation they face. Organisational factors also matter in our analysis, with independent firms, who typically have greater strategic autonomy, more likely to adopt climate change strategies than subsidiaries. Our evidence on the positive role of digital affordances in enabling climate change strategies – both adaptation and mitigation – suggests that managerial decisions related to digitalisation should ideally reflect this potential benefit. Digitalisation can, for example, enable climate adaptation, reducing climate-related risks to business continuity and promoting resilience. These benefits should be considered in cost-benefit calculations related to digital investments. It may also be important to consider how firms can build complementary resources to their digital investments to help maximise the value of digital affordances to climate change strategies and other aspects of business performance. For example, investments in digital skills may enable firms to maximise the business benefits of digital affordances.

In policy terms, our results emphasise the complementarity between measures that support digitalisation and encourage climate action. Informational market failures may occur if firms are unaware of digitalisation's climate response benefits. Further, promoting digital adoption can create affordances that may translate into benefits in terms of adaptation (contributing to more resilient business demography) and mitigation (with wider public benefits). These climate benefits may occur alongside the productivity and growth benefits that derive from enhanced digitalisation.

While our analysis sheds new light on the role of digital affordances in enabling firms' adaptation and mitigation responses to climate change, some limitations remain. Perhaps the most significant of these is the cross-sectional nature of the data, which allows only association rather than causation to be established. Longitudinal studies, which follow firms through their digitalisation and climate response journeys, would provide useful additional insight. Our study also provides only a general indication of the digitalisation-climate response relationship. Future analyses could usefully explore which specific digital technologies generate the strongest affordances relevant to climate change strategy. Finally, we do not consider in detail the potential complementarities between digital investments and firms other, potentially complementary, investments. This too, would be a valuable area for future investigation.

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ANNEX

Table A1. Summary Statistics

Variable	N	mean	sd	min	max
Climate Adaptation Strategy	22484	1.949	0.968	0	3
No Climate Response	22484	0.159	0.365	0	1
Adaptation only	22484	0.019	0.137	0	1
Mitigation only	22484	0.537	0.499	0	1
Adaptation and Mitigation	22484	0.285	0.452	0	1
Intensity of Climate Mitigation (ICM)	22484	0.411	0.306	0	1
Intensity of Climate Adaptation (ICA)	22484	0.135	0.230	0	1
Digitalisation	22484	1.262	1.471	0	8
Business monitoring	22484	0.384	0.486	0	1
Innovator	22484	0.339	0.473	0	1
Carbon target	22484	0.262	0.440	0	1
Transition	22484	0.770	0.800	0	2
Climate impact	22484	0.703	0.717	0	2
Subsidiary	22484	0.253	0.435	0	1
Listed	17761	0.011	0.103	0	1
Size (Log of Employment)	22484	3.617	1.535	0	11.225
Wave 2023	22484	0.728	0.445	0	1
Manufacturing	22484	0.296	0.457	0	1
Construction	22484	0.207	0.405	0	1
Services	22484	0.263	0.440	0	1
Infrastructure	22484	0.234	0.423	0	1
Austria (AT)	22484	0.038	0.192	0	1
Belgium (BE)	22484	0.037	0.189	0	1
Bulgaria (BG)	22484	0.038	0.191	0	1
Croatia (HR)	22484	0.037	0.189	0	1
Cyprus (CY)	22484	0.014	0.119	0	1
Czech Republic (CZ)	22484	0.038	0.192	0	1
Denmark (DK)	22484	0.036	0.187	0	1
Estonia (EE)	22484	0.030	0.170	0	1
Finland (FI)	22484	0.040	0.197	0	1
France (FR)	22484	0.046	0.208	0	1
Germany (DE)	22484	0.047	0.212	0	1
Greece (EL)	22484	0.032	0.177	0	1
Hungary (HU)	22484	0.035	0.183	0	1

Ireland (IE)	22484	0.032	0.175	0	1
Italy (IT)	22484	0.048	0.214	0	1
Latvia (LV)	22484	0.030	0.170	0	1
Lithuania (LT)	22484	0.032	0.175	0	1
Luxembourg (LU)	22484	0.014	0.119	0	1
Malta (MT)	22484	0.014	0.118	0	1
Netherlands (NL)	22484	0.039	0.195	0	1
Poland (PL)	22484	0.037	0.189	0	1
Portugal (PT)	22484	0.040	0.196	0	1
Romania (RO)	22484	0.037	0.189	0	1
Slovakia (SK)	22484	0.030	0.170	0	1
Slovenia (SI)	22484	0.031	0.173	0	1
Spain (ES)	22484	0.047	0.212	0	1
Sweden (SE)	22484	0.036	0.186	0	1
United States (US)	22484	0.063	0.243	0	1
Central and Eastern EU	21067	0.400	0.490	0	1
Southern EU	21067	0.210	0.407	0	1
Northern and Western EU	21067	0.391	0.488	0	1
Emmissions intensity	21067	5.763	0.532	4.559	6.925
Exposure	21067	3.051	0.716	1.188	4.016
EPS Market based policies	17938	1.991	0.960	1	4.167
EPS Non-market based policies	17938	5.550	0.133	5.5	6
EPS Technology support policies	17938	2.366	1.251	0.5	6
Fixed average download speed gr, std	20668	-0.004	0.988	-1.597	6.235

Table A2: Probability of adopting Climate Change Strategy: average marginal effects

	Model 2			
	No climate response	Adaptation Only	Mitigation Only	Adaptation and Mitigation
	(1)	(2)	(3)	(4)
Digitalisation	**-0.013*** **	**0.001**	**-0.009*** **	**0.020*** **
	(0.002)	*(0.001)*	*(0.002)*	*(0.002)*
Transition (Reference - no impact)				
– a risk	-0.042***	-0.002	0.010	0.034***
	(0.005)	*(0.002)*	*(0.008)*	*(0.007)*
– an opportunity	-0.078***	-0.003	0.001	0.080***
	(0.006)	*(0.003)*	*(0.009)*	*(0.008)*
Climate change (Reference: no impact)				
– a minor impact	-0.072***	0.004*	-0.071***	0.139***
	(0.005)	*(0.002)*	*(0.007)*	*(0.006)*
– a major impact	-0.088***	0.018***	-0.182***	0.250***
	(0.007)	*(0.004)*	*(0.010)*	*(0.009)*
Carbon target	-0.105***	-0.011***	-0.035***	0.151***
	(0.005)	*(0.002)*	*(0.008)*	*(0.008)*
Energy costs	-0.033***	-0.001	0.012*	0.023***
	(0.005)	*(0.002)*	*(0.007)*	*(0.006)*
Business monitoring	-0.046***	-0.000	-0.024***	0.071***
	(0.005)	*(0.002)*	*(0.008)*	*(0.007)*
Innovator	-0.046***	-0.000	-0.032***	0.078***
	(0.005)	*(0.002)*	*(0.007)*	*(0.006)*
Subsidiary	0.020***	0.001	-0.014	-0.008
	(0.007)	*(0.003)*	*(0.008)*	*(0.007)*
Size	-0.025***	-0.003***	0.010***	0.018***
	(0.002)	*(0.001)*	*(0.002)*	*(0.002)*
Wave 2023	-0.023***	0.000	-0.021***	0.047***
	(0.005)	*(0.002)*	*(0.006)*	*(0.006)*
Sector (Reference: Construction)				
Manufacturing	-0.038***	-0.002	0.035***	0.005
	(0.007)	*(0.003)*	*(0.010)*	*(0.008)*
Services	-0.024***	0.000	-0.002	0.025***
	(0.006)	*(0.003)*	*(0.010)*	*(0.008)*
Infrastructure	0.024***	0.004	-0.023**	-0.005
	(0.007)	*(0.003)*	*(0.010)*	*(0.008)*
Country dummies	Yes			
N	22484			

Note: Average marginal effects reported; robust standard errors in parentheses. $p<0.01$***, $p<0.05$**, $p<0.1$*.

Table A3. Intensity of mitigation and adaptation actions and digitalisation: OLS models

	Intensity of Climate Mitigation			*Intensity of Climate Adaptation*		
	Baseline	**Split sample**		**Baseline**	**Split sample**	
	Full sample	**Firms with CM only response choice**	**Firms with simultaneous CM and CA choice**	**Full sample**	**Firms with CA only response choice**	**Firms with simultaneous CM and CA choice**
	(1)	(2)	(3)	(4)	(5)	(6)
Digitalisation	**0.017*** **	**0.012*** **	**0.018*** **	**0.012*** **	**-0.001**	**0.007*** **
	(0.001)	*(0.002)*	*(0.002)*	*(0.001)*	*(0.004)*	*(0.002)*
Transition (Reference - no impact)						
– a risk	0.037***	0.013***	0.031***	0.018***	-0.009	0.023***
	(0.004)	*(0.005)*	*(0.007)*	*(0.003)*	*(0.014)*	*(0.006)*
– an opportunity	0.094***	0.059***	0.077***	0.042***	-0.027*	0.028***
	(0.005)	*(0.006)*	*(0.008)*	*(0.004)*	*(0.016)*	*(0.006)*
Climate change (Reference: no impact)						
– a minor impact	0.060***	0.027***	0.022***	0.064***	0.004	0.022***
	(0.004)	*(0.004)*	*(0.007)*	*(0.003)*	*(0.013)*	*(0.005)*
– a major impact	0.079***	0.027***	0.042***	0.144***	0.038**	0.063***
	(0.005)	*(0.007)*	*(0.009)*	*(0.005)*	*(0.017)*	*(0.007)*
Carbon target	0.130***	0.093***	0.074***	0.077***	-0.001	0.032***
	(0.005)	*(0.006)*	*(0.007)*	*(0.004)*	*(0.018)*	*(0.005)*
Energy costs – major barrier	0.022***	0.014***	-0.002	0.010***	-0.002	0.007
	(0.004)	*(0.004)*	*(0.006)*	*(0.003)*	*(0.013)*	*(0.005)*
Business monitoring	0.055***	0.031***	0.044***	0.039***	0.024	0.025***
	(0.004)	*(0.005)*	*(0.007)*	*(0.003)*	*(0.016)*	*(0.005)*
Innovator	0.052***	0.033***	0.036***	0.036***	-0.012	0.008*
	(0.004)	*(0.005)*	*(0.006)*	*(0.003)*	*(0.013)*	*(0.005)*
Subsidiary	-0.023***	-0.015***	-0.020***	-0.001	0.030	0.006
	(0.004)	*(0.005)*	*(0.007)*	*(0.004)*	*(0.024)*	*(0.006)*
Size	0.031***	0.023***	0.023***	0.009***	0.003	0.005***
	(0.001)	*(0.002)*	*(0.002)*	*(0.001)*	*(0.006)*	*(0.002)*
Wave 2023	0.014***	0.005	-0.005	0.017***	-0.009	-0.001
	(0.004)	*(0.005)*	*(0.007)*	*(0.003)*	*(0.014)*	*(0.006)*
Sector (Reference – Construction)						
Manufacturing	0.027***	0.020***	-0.008	-0.001	-0.020	-0.006
	(0.005)	*(0.006)*	*(0.010)*	*(0.004)*	*(0.016)*	*(0.007)*
Services	0.011**	0.003	-0.017*	0.010**	-0.016	0.002
	(0.005)	*(0.006)*	*(0.010)*	*(0.004)*	*(0.017)*	*(0.007)*
Infrastructure	-0.021***	-0.005	-0.038***	-0.003	-0.011	-0.008
	(0.005)	*(0.006)*	*(0.010)*	*(0.004)*	*(0.016)*	*(0.008)*
Country dummies	yes	yes	yes	yes	yes	yes
N	*22484*	*12074*	*6412*	*22484*	*432*	*6412*
R-sq	0.312	0.190	0.236	0.178	0.165	0.117

Note: Coefficients reported; robust standard errors in parentheses. p<0.01***, p<0.05**, p<0.1*.