Twin Net Zero and Digital transition – Myth or Reality?
Evidence from UK SMEs

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Working paper – Please do not quote

ECONOMICS OF INNOVATION:

Where are we, how did we get here, and where are we heading?

September 13–15, 2023

Catholic University of the Sacred Heart, Milano

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ABSTRACT

This paper examines the relationship between digital and net zero innovations in small and medium enterprises (SMEs). Are there complementarities between these two types of innovation? Or, do the constrained resources and managerial attention of SMEs mean that there are trade-offs? Drawing on novel data from a dedicated survey on around 1,000 UK SMEs conducted in 2020, and models of the adoption process, we explore how categories of digital adopters relate to categories of adopters of net zero innovations. Using Ordered Probit estimation, we find a strong complementary relationship between digital and net zero adoption, i.e., that the probability of belonging to the least advanced category of net zero adoptors - late majority - decreases with digital innovativeness. On the contrary, the probability of belonging to more advanced net zero categories - early majority, early adopters, and innovators - increases with more advanced levels of digital innovativeness. These findings have important policy implications suggesting that business support schemes designed to facilitate digital transition may also be beneficial for achieving net zero.

Keywords: digital innovation, net zero innovation, diffusion of innovation, SMEs

1. Introduction

In this paper we consider whether, and how, digital diffusion relates to the diffusion of net zero innovations in small and medium enterprises (SMEs). Through the lens of Diffusion of Innovation (DoI) theory, we explore how categories of digital adopters relate to categories of adopters of net zero technologies and organisational innovations. Is the relationship between digital diffusion and net zero innovation positive or negative, however? Arguments based on potential complementarities-in-use or adoption approach (Ballot et al., 2015; Battisti & Stoneman, 2010) suggest that more advanced digital adopters are also more likely to be more advanced net zero adopters. However, both digital and net zero innovation are demanding in terms of financial and human resources and managerial attention (Soluk, 2022; Borsatto, & Bazani 2023), suggesting potential trade-offs as firms concentrate limited resources and attention on either digital or net zero innovation.

Understanding potential complementarities or trade-offs between net zero and digital innovation matters as the twin net zero and digital transitions have risen to the top of policy agenda in many developed countries over the last years, a tendency only reinforced post-covid and during recent geopolitical shifts (BEIS, 2020; European Commission, 2020, 2022). These two ongoing structural transformations are likely to shape the future of economy in the next decades (Geels et al., 2021; Muench et al., 2022), and may be a pathway to sustainable recovery and growth (Bai et al., 2020; Hanelt et al, 2017; Kunapatarawong and Martínez-Ros, 2016). There is also an expectation that the digital and net zero transitions may have substantial implications for productivity by unlocking productive opportunities (Pilat & Criscuolo 2018; Geels et al. 2021; Kalantzis & Niczyporuk 2022), albeit with potential time-lags (Brynjolfsson et al., 2018).

However, little is known about how these two transition processes relate to each other and how organisations may leverage digital technologies to innovate for environmental sustainability (Elliott and Webster, 2017; Melville, 2010). Crucially, empirical quantitative micro-evidence of their connection is scarce, especially in the context of SMEs, where resource constraints and therefore trade-offs may be more significant (OECD, 2021). Until recently prior studies and policy efforts have mostly been focused on large firms, typically larger polluters, and front-runners of digital adoption. Yet, as recent reports highlight, there will be no net zero without SMEs given that the aggregate contribution of SMEs to carbon emissions is significant (BBB 2021; OECD, 2021). Digital transition and its expected productivity benefits are also incomplete without SMEs among which the diffusion of digital technologies remains slower than among larger businesses even despite the acceleration prompted by COVID-19 (EIB 2022, ERC 2020, OECD 2021).

Our analysis makes use of a novel data from a dedicated survey covering around 1000 firms, and providing representative coverage of UK SMEs. The dataset contains information on a wide range of digital and net zero innovations that UK SMEs undertake and use in their business operations. We use ordered Probit estimation to test whether membership of specific categories of digital diffusion adopter (e.g., early majority, early adopters, innovators) is positively or negatively related to comparable net zero adopter categories. Estimation results provide evidence supporting complementarities, ie., we find that the probability of belonging to the least advanced category of net zero adoption (late majority) decreases with digital innovativeness. Conversely, the probability of belonging to more advanced net zero categories increases with more advanced levels of digital innovativeness.

We make three main contributions to the existing literature. First, we provide empirical evidence for complementarities in the twin transition of UK SMEs, with digitally more advanced firms being also more likely to be advanced net zero adopters. Second, we contribute to the literature of the Diffusion of Innovation (DoI) by providing evidence of the inter-relation between digital and net zero diffusion processes. We extent the complementarity literature by unravelling the conceptual mechanisms through which the adoption of digital innovations complement-the-use of net zero innovations. Finally, we make a methodological contribution by using the number of technologies/organisational practices adopted as a measure of innovativeness instead of time of adoption.

The remainder of the paper is structured as follows. Section 2 introduces our conceptual framework and competing hypotheses. Section 3 profiles the data and discusses our empirical approach. Section 4 presents findings and Section 5 discusses the implications.

2. Conceptual framework and hypotheses

2.1 Diffusion of innovation and diffusion processes in different domains

Diffusion is defined as 'the process by which an innovation is communicated through certain channels over time among the members of a social system' (Rogers, 2003, p.21). Rogers' (1962, 2003) Diffusion of Innovations (DoI) theory has received widespread recognition and 'tied together' different strands of diffusion-adoption research which has been very prolific over the last half-century (Van Oorschot et al., 2018). Scholars have applied DoI to explore inter-firm and intra-firm diffusion of a wide variety of technological innovations including digital and eco-innovations (Agarwal et al., 1998; Battisti and Stoneman, 2003; Johnson, 2015; Kapoor, et al., 2014; VÖLlink et al., 2002; Zhu et al., 2006).

To conceptually model the relationship between two diffusion processes, net zero and digital, we employ the notion of *adopter categories* that Rogers first proposed in his 1958 article and developed in the first and subsequent editions of DoI (Rogers, 1958, 1962, 2003). *Adopter categories* represent 'the classifications of members of a system on the basis of their innovativeness', where *innovativeness* is 'the degree to which an individual (or another unit of adoption) is relatively earlier in adopting new ideas than other members of a system…

innovativeness indicates behavioural change… rather than just cognitive or attitudinal change. Innovativeness is the bottom-line behaviour in the diffusion process' (Rogers, 2003, p.249). In this conceptualisation, innovativeness, is continuous and measured by the time of adoption of innovation. Then, adopter categories are obtained by partitioning members of a system into five discrete categories based on their innovativeness. The average time of adoption ($\bar{x}$) and standard deviations (*sd*) are used to operationalise this partitioning.

Rogers' adopter categories, from Innovators to Laggards, represent 'ideal types'[1] that possess certain characteristics which Rogers also labeled in psychographic terms as 'venturesome', 'respect', deliberate' 'sceptical' and 'traditional'. Importantly, the earlier adopter categories – innovators and early adopters – are characterised by an 'ability to understand and apply complex technical knowledge', ability to 'cope with uncertainty' and have substantial resources to 'absorb the possible losses from unprofitable innovation'. They are also more likely to 'seek information about innovations more actively than do later adopters'; '… have greater knowledge of innovations than do later adopters'; be 'highly interconnected through interpersonal networks in their social system'; '…have higher aspirations'; '.. have more favourable attitude toward science'; 'have a more favourable attitude toward change'; and 'have more contact with change agents than do later adopters' (Rogers, 2003, p. 269-273). Appendix A shows the classification of adopters for one technological innovation based on innovativeness measured by time of adoption.

Here, we extend the Rogers framework to the situation where multiple inter-related innovations (e.g., different types of net zero innovations) diffuse at the same time. This simultaneous diffusion process is illustrated by Figure 1. For the three S-shape curves the speed of diffusion is different with 'Innovation 1' diffusing faster among the population of firms than

[1] Rogers (2003) insists that these 'ideal types' although based on observation of reality are concepts that have a certain degree of abstraction where exceptions are possible.

'Innovation 2' and 'Innovation 3'. At a certain point in time A, all three innovations are adopted by earlier adopters, while later adopters - 'late majority' or 'laggards' - have not adopted either of the three innovations. Later, at time point B, these later adopters' categories would have adopted only one technology, i.e. Innovation 1. Finally, with time all three innovations will be adopted by all categories of adopters, including laggards (point C).

But what can be told about diffusion of innovations belonging to diffrenent technological domains? Previous studies have raised the question of the generality or specificity of innovativeness by differentiating global or 'innate' innovativeness from domain-specific innovativeness (Midgley and Dowling, 1978; Goldsmith et al., 1995; Flores and Jansson, 2022). Goldsmith et al. (1995) stressed that domain-specific innovativeness is a better predictor of consumers' purchase behaviour compared to global innovativeness and highlighted the hierarchical structure of innovativeness constructs where domain-specific innovativeness plays a mediating role in the relationship between global innovativeness and concrete behaviour. Following this line of research, a number of studies in marketing focused on this intermediate level of innovativeness (domain-specific) to analyse innovation adoption behaviour of consumers. Flores and Jansson (2022) in a study of adoption of green transport innovations by individuals (shared e-bike and e-scooters) have demonstrated that domain-specific innovativeness (in the field of transport) is associated with the adoption of green transport innovations and reinforces the positive emotions associated with the use of these innovations. Paparoidamis and Tran (2019) have used the concept of domain-specific innovativeness in the domain of eco-innovative products and have found that it affects innovation adoption intentions indirectly via enhanced consumers' perceptions of product eco-friendliness.

Here, we explore the mechanisms that may connect *diffusion processes in two different domains* - the net zero and digital innovation domains in our case. Van Oorshot et al. (2018)

highlight that diffusion-adoption research, despite its maturity, would benefit from bringing in other theoretical perspectives from the fields of management, organisation behaviour and marketing studies. In the next sections, we use insights from the complementarities and managerial attention literatures to suggest the mechanisms that could underpin synergies or trade-offs between the two diffusion processes.

2.2 Complementarities between the diffusion processes in the digital and net zero domains: digital technology affordances

The *complementarities* perspective is useful in understanding the mechanism that links two different diffusion processes because it sheds light on how relationships between elements of a system could generate greater value than the system's individual parts (Milgrom and Roberts, 1990, 1995). We follow the complementarities-in-use or adoption approach (Ballot et al., 2015; Battisti & Stoneman, 2010), which postulates that complementarity occurs when adoption of one innovation (e.g. digital or net zero) involves the use of another jointly supportive practice. In essence complementarity-in-use captures the relatedness in the use of distinct practices but does not provide a theoretical mechanism for joint adoption. We build on the notion of *digital technology affordances* and argue that digital innovations have the potential to facilitate net zero innovations.

Net zero innovations reduce carbon emissions, and in this sense represent a subset of eco-innovations. Eco-innovations are defined *as "the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organization (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution, and other negative impacts of resources use (including energy use) compared to relevant alternatives"* (Kemp and Pearson, 2007, p.7). The main specificity of net zero and eco-innovations relates to their contribution to environmental sustainability, be it intentional or not (Rennings, 2000; Horbach et al., 2013; Cecere et al., 2014a). This is not the case of other standard innovations, which may be detrimental to the environment.

Digital innovations, in essence information technologies/systems (IT/IS) related innovations[2], may be supportive of the environment. Indeed, a growing body of literature in innovation, information systems (IS), and entrepreneurship studies focuses on 'green IT/IS'. In general terms, green IT/IS refers to 'information technology and system initiatives and programs that address environmental sustainability' (Jenkin et al., 2011, p. 18).

There are two main mechanisms through which digital innovations may address environmental sustainability. The first mechanism involves a direct effect, whereby digital innovations minimise the negative effects of IT materiality (Faiq, 2020). For instance, 'greening IT' by reducing the amount of waste, energy consumption while designing, manufacturing, using and disposing IT 'efficiently and effectively with minimal or no impact on the environment' (Cecere et al., 2014b; Hu et al., 2016).

The second mechanism entails an indirect or mediating effect, whereby digital innovations act as an enabling or supporting mechanism (Cecere et al., 2014b; Elliot, 2011). To understand this indirect mechanism, one particualrely useful framework is 'technology affordances and constraints theory' famework, which focuses on dynamic interactions between people, organisations and technologies (Majchrzak and Markus, 2012). Digital technology affordances may be defined as the 'action potentials', i.e. all realised or unrealised potential actions that an individual or organisation can undertake using digital technology for a particular purpose (Majchrzak and Markus, 2012; Tim et al., 2018). This is different from technology

[2] Information Systems (IS) research literature use the term of IS comprising a 'combination of devices, software, data and procedures designed to address the information processing needs of individuals and organizations' (Majchrzak and Markus, 2012, p. 832) rather than the 'digital technologies', term commonly employed in non-specialist studies. Here, we use both interchangeably.

functionalities or features. Technology affordances require that a technology may be used for a certain purpose even if it was not initially designed for it, and that unintended or unexpected usages and outcomes may occur. And, vice versa, the potential may remain unrealised even if it is part of built-in functionalities. This implies that different organisations may use the same digital technology in many different ways depending on business goals, purporses and capabilities.

Recently, the attention of scholars has been directed towards the role that digital technology affordances may play in enabling environmental and broader societal change (Elliott, 2011; Elliott and Webster, 2017; Faik et al., 2020; Tim et al., 2018; Cooper and Molla, 2017). Thus, new concepts emerged in the literature, such as 'IT for green' as 'the impact of IT on other sectors' environmental productivity, particularly in terms of energy efficiency and carbon footprint'(Faucheux and Nicolaï, 2011, p.11), 'IS for environmental sustainability', defined as 'IS-enabled organizational practices and processes that improve environmental and economic performance' (Melville, 2010, p.2) and digital sustainability, 'the organizational activities that seek to advance the sustainable development goals through creative deployment of technologies that create, use, transmit, or source electronic data' (George et al, 2021, p.1000). This type of complementarity between digital innovation and net zero innovation suggests our first hypothesis:

Hypothesis 1. More advanced digital adopters are *more* likely to be more advanced net zero adopters.

2.3 Trade-offs between the diffusion processes in the digital and net zero domains: resource and attention constraints in SMEs

Implementing digital and net zero innovations can be time-consuming, resource intensive and will often require significant organisational change. Soluk (2022), for example, describes resource allocation and re-allocation in resource-constrained, German family firms as they undertook digital innovation as a response to the COVID-19 crisis. Here, managerial attention along with financial and human resources were focussed initially on digital process innovation as a crisis response, before 'resource recombination' to subsequently develop digital product and business model innovations. Critically, resource and managerial constraints in these firms meant that digital product innovation followed process change as scarce resources were redeployed rather than being undertaken simultaneously. More generally, de Massis et al. (2018) discuss the challenges involved in innovation in resource constrained smaller firms, particularly where firms such as those in the Mittelstand place a strong priority on self-financing and funding innovation and investment from prior profits. Such a reliance on internal funding and other resources may limit the scope of firms' investment in any given period, and/or their ability to respond to significant new market opportunities (Audretsch and Elston, 1997).

While recent evidence suggests a positive relationship between green innovation and firms' financial performance (Borsatto & Bazani, 2023), other studies have also suggested the time lags involved in the successful implementation and exploitation of green innovation. Rezende et al. (2019), for example, suggest that green innovation only has a positive effect on financial performance two years or more after its introduction. This reflects firms' experience of introducing other types of management and digital innovations which cause short-term disruption, and a consequent deterioration in performance, before yielding positive performance benefits (Bourke and Roper, 2016; Bourke and Roper, 2017). Effectively implementing green or net zero innovation may also be complex. For example, Gupta & Barua (2018) identify seven implementation barriers, barriers which may be particularly significant in resource constrained SMEs: management and human resources; technologies; finance; weak connectivity; lack of policy support; market resistance; and, insufficient knowledge. Pinkse & Kolk (2010) discuss the related trade-offs which may be involved in green innovation, a situation which they argue is complicated further by the lack of any clarity in which environmental innovations are likely to bring the greatest commercial and/or environmental benefits.

The requirements of net zero and digital innovation in terms of resources and managerial attention suggest the potential for trade-offs, ie., the more resources and managerial attention are devoted to green innovation, the fewer will be available for digital development. Management constraints may be particularly stringent in smaller firms where leadership teams may be smaller with managers playing numerous roles and performing different functions, often acting at the same time as executive and middle managers on projects, but also executing non managerial operational work as a 'back-up' person (Florén, 2006). In small firms, managerial time is characterised by a particularly high degree of fragmentation with managers changing their attention constantly from one issue to another, being often interrupted and feeling the necessity to react immediately and to keep control (Florén, 2006). This suggests a need to balance the proportion of managerial attention allocated to different types of innovation as well as more operational aspects of firms' operations (e.g., Von Stamm, 2003). Eggers and Kaplan (2009), for example, show that CEO attention is a key factor determining the timing of firms' adoption of new technologies, while Turner et al. (2022) consider the allocation of limited managerial attention to firms' competitive and cooperative strategies. Other studies have focussed on related trade-offs between firms' operational, customer-facing and innovation activities (e.g., Von Stamm, 2003). As Hortinha et al. (2011, p. 37), comment: 'the trade-off between customer orientation and technology orientation is of the utmost importance … resources are limited, and firms must make choices in their allocation'.

Attentional constraints on firms' innovation portfolio may be reinforced by resource constraints related to human resources, finance or cooperation capacity (Hewitt-Dundas 2006). As Kamm (2007, p. 26) comments: 'Innovative personnel are needed to develop new products and implement new technologies for their production. All three types of innovation—product, technological process, and administrative system—must be juggled simultaneously. Failure in one area can cause problems in other areas, as when development projects are delayed because manufacturing processes are not available to produce the device, or when there are not enough engineers to staff project teams.' Financial constraints may also limit firms' portfolios of innovation activity, requiring trade-offs and prioritisation, issues which again may be more significant for SMEs (Madrid-Guijarro et al. 2016).

Such resource and managerial attention trade-offs between digital and green innovation are likely to be most impactful in smaller companies or those with more limited technological resources. Pinkse & Kolk (2010) do suggest, however, that such trade-offs may be mitigated to some degree where green innovation or digital innovation are complementary to firms' existing technological assets. Resource trade-offs may also be mitigated by collaboration with external partners but, as collaboration is often time-consuming to manage, this may exacerbate any shortage of management attention (Laursen and Salter, 2006). Despite these potential mitigations, the potential attentional and resource trade-offs suggest our second hypothesis:

Hypothesis 2. More advanced digital adopters are *less* likely to be more advanced net zero adopters.

3. Data and methods

3.1 Data

We employ data from a novel telephone survey dataset of around 1,000 businesses conducted in 2020, the ERC Business Futures survey. The sample focused on businesses employing between 7 and 250 employees, with small businesses representing 86% and medium-sized businesses employing 50 or more employees accounting for 14% of the sample. The sampling frame for the survey was provided by a commercial list broker and intended to be representative of the UK SMEs population by size, sector and geography[3]. Well established businesses trading for mor than 5 years represent the vast majority sample, with young businesses acoounting for less tharound 5%. All interviewed repondents were senior people in day-to-day control of the business, typically business owner/managers. The data collection was realised in Autumn 2020, in between the UK COVID-19 lockdowns. The questionnaire design relies on previous letraure on eco-innovation and digital transformation, and was piloted on a small sub-sample of firms during summer 2020.

The dataset includes questions on a wide range of digital and net zero practices and technologies that SMEs undertake and use in their business operations. In particular, the dataset covers ten following digital technologies ranging from basic well established to more recent and advanced digital technologies: accounting and HR software, E-commerce, online marketing and social media, video conferencing, computer aided design software and CRM systems, cloud-computing solutions, Internet of Things, Augmented and Virtual Reality and Artificial intelligence and machine learning.

Net zero innovations represent both technological and organisational innovations that firms adopted to reduce their environmental impact such as: undertaking environmental reports or audits, changes in production and/or distribution processes, improved pollution filtering, engaged in environmental R&D, conducted training on environmental matters or conducted market research related to low carbon products or services, introduced new low carbon products and services to the market, switched to more renewable energy.

Additionally, the survey includes questions on business goals, barriers and attitudes towarda environmental sustainability and business characteristics. After restricting the sample

[3] Northern Ireland SMEs were overrepresented in the sample. Thus, in order to provide results which are representative of the UK population of SMEs, data was weighted.

to only those observations containing full information, our final estimation sample contains 964 firms.

3.2 Defining categories of adopters

We argue that for a set of related innovations in the same domaine, adopter categories may also be derived from innovativeness measured by the number of technologies adopted rather than by time as shown in Figure 2. For instance, consider a certain fixed number of innovations (technologies) and assume that these technologies are relevant to all firms (i.e. general purpose technologies although the applications may differ). Then, for each firm at a certain moment of time, higher innovativeness is associated with a higher number of innovations adopted. In sum, alike an innovator by the time of adoption, an innovator could be defined based on the number of innovations.

3.2.1. Digital adopter categories

We operationalise digital diffusion by constructing 'digital adopter categories' based on the number of digital technologies (*DG*) firms have adopted and each firm's innovativeness is in relation to the mean. Figure 3, drawing on our final estimation sample shows that the digital diffusion process among UK SMEs represented by the distribution of firms depending on digital innovativeness (number of digital technologies adopted) has the classic 'bell' shape. Adopter categories are therefore defined using the average ($\bar{x}$) and standard deviations (*sd*) of innovativeness measured by number of technologies (Figure 2). The 'Laggards' category includes firms that have not adopted any digital technology and firms that have adopted less than the difference between the mean ($\bar{x}$) and the standard deviation (*sd*) of digital technologies [0 to ($\bar{x}$) - *sd*)]; this category represents around 18% of the sample (Table1). 'Late majority' and ‘Early majority’ categories include firms in the interval of one standard deviation below or above the mean and represent around 33% of the sample each. ‘Early adopters’ use more than ($\bar{x}$ + *sd*) but less than ($\bar{x}$ + 2*sd*) of DG, with around 14% of firms of the sample falling into this category. Finally, ‘Innovators’ are those 2% of the firms who adopted the most, i.e. more than ($\bar{x}$ + 2*sd*).

To illustrate what DT are more likely to be adopted by each digital adopter category, Figure 4 provides adoption rates of UK SMEs of 10 DT for each adoopter category. It shows that digital innovators and early adopters are typically firms who have adopted either all ten DT or have very high adoption rates of the most adavanced DT including AI. On the other side of spectrum, digital laggards demonstrate modest adoption rates even for low cost and commun innovations, such as online marketing, e-commerce, CRM and even video conferencing.

3.2.2. Net zero adopter categories

Figure 5 shows that net zero diffusion process is not as advanced as digital with about a third of SMEs not engaging yet with net zero practices. This is in line with previous findings (BBB, 2021). Similarly to digital diffusion process, we construct net zero adopter categories by using innovativeness in net zero domain measured by number of net zero practices. Given that for net zero innovations (*NZ*), standard is higher than the mean, there are only 4 adopter categories: ‘late majority’, ‘early majority’, ‘early adopters’ and ‘innovators’. The diffusion of net zero innovation among SMEs started later than the diffusion of digital technologies, therefore it is too early to observe ‘lagging’ behaviour (Table 2).

Figure 6 shows across all net zero adopter categories, changes in production processes or transport and logistics demonstrate the highest adoption rates, followed by integrating rewable energy sources in energy mix. Low carbon market research and R&D on environmental matters have lowest adoption rates among the majority of UK SMEs.

3.3 Other explanatory variables and the empirical model

To test our hypotheses we consider the following ordered probit model to estimate the probability of belonging to any net zero adopter category ($NZcat_i$) depending on digital adopter category ($DGcat_i$) controlling for a set of other factors that may influence the net zero transition. More specifically we estimate,

$$NZcat_i = \beta_1 DGcat_i + \beta_2 Drivers_i + \beta_3 Controls_i + \beta_0 + \varepsilon_i$$

where $Drivers_i$ are a set of variables relating to individual, internal and external drivers that may spur net zero engagement of a firm, and $Controls_i$ are a series of firm-level controls.

3.3.1. Drivers of net zero adoption

Net zero adoption may be driven by both internal and external factors (Kesidou and Ri, 2021). Previous studies highlighted the importance of external factors such as *environmental regulations and taxes* (Johnstone and Labonne, 2006), *government grants and subsidies* (Fabrizi et al., 2018; Hockerts and Wüstenhagen 2010; Hofmann et al. 2012), *voluntary agreements within the sectors or across the supply chain* (Prakash and Potoski, 2013; Iatridis and Kesidou, 2018), *availability of external funding from banks*, and *customer demand for low-carbon products or services* (Kesidou and Demirel, 2012) in driving net zero adoption. Kesidou and Ri (2021) find that among external factors the most powerful are customer demand and environmental regulations and taxes.

Among internal factors that may motivate net zero adoption, we introduce *image and reputation* and *cost reduction objectives*, which may be achieved through an improved production efficiency or repla or input replacement (Kesidou and Ri, 2021). Additionally, as has been suggested previously, in the context of SMEs, the personal traits and attitudes of the owner-manager may play a crucial role in innovation decisions. Therefore, following Dibrell et al. (2011), we also introduce the attitudes of business owner-managers towards the natural environment .

3.3.2. Controls

Turning to the control variables, we include a dummy reflecting if a firm has a regularly updated business plan as an indicator of managerial capabilities. We also include in our analysis another binary variable taking the value of one if a firm exports. This follows previous studies which have established a relationship between exporting activity and innovation via learning and competition mechanisms (Love and Roper, 2015). We also control for firm size by incorporating the (log) of employment as an indicator of SME's resources. We incorporate firm age measured as the number of years since starting business as it might play a role in shaping firm's strategic flexibility and propensity to innovate business model (Miroshnychenko et al., 2021). Finally, we also control for sectoral and geographic heterogeneity.

In alternative specifications we also consider additional controls. Prior studies have stressed that SMEs, even being willing to adapt sustainability practices, may face constraints related to their size, and in particular those related to a deficit of skills and knowledge to assess available technologies and practices and sussessfully implement them (OECD, 2021). Because sustainability practices are sometimes associted with important costs, smaller firms may also improve difficulties in securing funding and access government support schemes compared to their larger counterparts. To account for heterogeneity in skills, we introduce a dummy variable *Skills* which takes value of 1 when firm firm replied 'strongly agree' or 'somewhat agree' to the statement 'We have the skills to introduce any new technologies' and 0 otherwise. To evaluate the overall hindrance to net zero transition, we also include *Barriers* variable taking value from 0 to 7 reflecting the number of barriers encountered by the firm[4].

Additionally, we also explore how the results change depending on whether firm's digital transition resulted in a significant change of business model. Prior literature underlines an important distinction between 'digitalisation' (standardising of business processes) and becoming 'digital' (Ross, 2019), i.e. profound transformation that a business undergoes to take advantage of opportunities that digital technologies create, involving a significant business model change reflected in new 'digital offerings'. Hence, we introduce a dummy variable *Business model change* taking value of 1 if a firm replied 'Yes, significantly' to the question 'Thinking about all digital technologies you introduced, to what extent has your business model evolved/changed as a result?'.

4. Empirical results

Table 3 presents the results of the econometric estimation of ordered probit models. In column (1) we report the odds ratios of our baseline model showing that the odds of belonging to a more advanced category of net zero adoption increase when a firm belongs to a more advanced category of digital adoption. Therefore, estimation results provide strong evidence supporting *hypothesis 1*: we find significant positive relationship between net zero innovativeness, operationalised by net zero adopter categories ($NZcat_i$), and digital innovativeness reflected in digital adopter categories ($DGcat_i$) and conclude that more advanced digital adopters are *more* likely to be more advanced net zero adopters. In Table 4 we report marginal effects in

[4] Businesses were asked the following questions: And thinking about the factors that might have prevented you from reducing [constrained your efforts to reduce] carbon emissions. Which of the following, if any, have been major obstacles? The response options were: lack of relevant skills, administrative or legal procedures, cost of meeting regulations or standards, difficulties in accessing finance, lack of information on low carbon technologies, uncertain demand for low carbon products and services, the Cororonavirus pandemic.

order to identify the scale of this effect. Thus, for example, *digital innovators* are 9.6 percentage points more likely than *digital laggards* to become *net zero early adopters* (Table 4, column (3)). In contrast, *digital innovators* are 29.9 percentage points less likely than *digital laggards* to be categorized *as net zero late majority* (Table 4, column (1)). This relationship is also illustrated by Figure 8 which shows that the probability of belonging to the least advanced category of net zero adoption (late majority) decreases with digital innovativeness. On the contrary, the probability of belonging to more advanced net zero categories (early majority, early adopters and innovators) increases with more advanced levels of digital innovativeness.

Regarding other factors that may condition net zero transition, as expected we find that *customer demand for low carbon products and services* has the largest magnitude of effect on net zero innovativeness. Thus, an increase in scale of importance of customer demand by one point is associated with an increase in probability of belonging to net zero early adopter category by 2.1 percentage points and in probability of belonging to net zero innovator category by 1.7 percentage point. Another external factor significantly affecting net zero innovativeness is *environmental regulations and taxes*, although the effect is smaller in magnitude.

Turning to internal factors, the results show statistically significant and relatively important in magnitude effect of *attitudes toward natural environment of owners-managers* and *image and reputation*. Thus an increase in the scale of attitudes toward natural environment by one point decreases the likelihood of belonging to the least advanced net zero category by 3.8 percentage point.

Additionally, in Table 3, we report alternative models including three additional controls: skills (column 2), obstacles encountered on net zero journey (column 3), and business model change as a result of digital transition (columns 4 and 5). The results still hold to the inclusion these additional controls, however the coefficients associted with the Digital Late Adopter category becomes not significant. Unsurprisingly, we find that *Skills* are positively and significantly associted with net zero innovativeness. Interestingly, the number of *Barriers* is also positively associted with net zero transition advancement.

Business model change does not affect significantly the probability of belonging to net zero categories (Table 3, column 4). However, when interacted with digital adopter categories, it dramatiquely icreases the odds of a business to be a more advanced net zero adopter (Table 3, column 5).

5. Discussion and Conclusion

Our analysis provides empirical evidence in support of twin transition in UK SMEs. Specifically, we find that firms belonging to more advanced digital adopter categories are also more likely to be more advanced net zero adopters. This is true when considering other potential drivers of net zero adoption behaviour, both external and internal. Moreover, the effect strengthens when considering business model change resulting from digital innovation.

Moreover, twin transition is not only about 'two concurrent transformational trends (the green and digital transitions)' but also about potential synergies of the two transitions, where one can reinforce the other to 'accelerate necessary changes and bring societies closer to the level of transformation needed' (Muench et al., 2022, p. 7). Building on the diffusion of innovation theory, we explicate the mechanisms via which the diffusion of innovations in two different domains could occur. Specifically, we conjecture that complementarities-in-use between digital and net zero innovations arise, allowing digital affordances in the net zero domain to unfold.

Examples of such digital technology affordances for environmental purposes may be the use of social media to increase environmental awareness and organise pro-environmental initiatives, Customer Relationship Management (CRM) systems for market research on environmental matters, use of AI to reduce energy consumption during the production process, environmental R&D etc. It is worth highlighting that the adoption by a firm of digital technologies with environmental affordances does not mean that this potential would be realised and result in adoption of net zero innovations automatically. However, these digital technology affordances make the adoption of sustainability or net zero practices more likely and easy to implement.

The results of this study have important policy implications suggesting that business support schemes designed to facilitate digital transition may also be beneficial for achieving net zero. Considering cumulative character of absorptive capacity and that communication often goes across the adopter categories rather than from top to down, i.e. innovators talking to other innovators (Rogers, 2003, p. 424-426), businesses in later adopter categories in digital may well be deemed to remain net zero laggards. At macro level it means that digital divide would be accompanied by net zero divide. Consequently, the focus should be on long-term relationship of change agents rather than on short-term to improve absorptive capacity.

TABLES AND FUGURES

Table 1. Digital adopter categories

Digital adopter category	N	%
Laggards	174	18%
Late majority	318	34%
Early majority	325	33%
Early adopters	130	14%
Innovators	17	2%
ALL	964	100%

Table 2. Net zero adopter categories

Net zero adoption category	N	%
Laggards	174	18%
Late majority	318	34%
Early majority	325	33%
Early adopters	130	14%
Innovators	17	2%
ALL	964	100%

Table 3. The probability of belonging to net zero adopter category and business model change as a result of digital transition (odds ratios)

	(1)	(2)	(3)	(4)	(5)
Digital adopter categories (*benchmark Laggards*)					
Late Majority	1.475**	1.317	1.301	1.296	1.203
	(0.262)	(0.240)	(0.234)	(0.233)	(0.223)
Early Majority	2.401***	2.027***	1.989***	1.965***	2.067***
	(0.428)	(0.374)	(0.363)	(0.360)	(0.392)
Early adopters	2.627***	2.240***	2.206***	2.156***	1.872***
	(0.525)	(0.459)	(0.448)	(0.439)	(0.412)
Innovators	3.091***	2.511**	2.662**	2.609**	1.847
	(1.184)	(0.983)	(1.016)	(0.984)	(0.790)
Drivers					
Attitudes toward natural environment	1.163***	1.158***	1.158***	1.156***	1.145**
	(0.064)	(0.064)	(0.063)	(0.063)	(0.062)
Improving your image and reputation	1.165***	1.170***	1.183***	1.181***	1.182***
	(0.058)	(0.057)	(0.059)	(0.059)	(0.059)
Reducing costs	1.081	1.090*	1.081	1.079	1.089*
	(0.052)	(0.053)	(0.054)	(0.053)	(0.053)
Environmental regulations or taxes	1.092*	1.084	1.069	1.066	1.050
	(0.056)	(0.056)	(0.055)	(0.055)	(0.055)
Government grants or subsidies	0.982	0.975	0.971	0.972	0.973
	(0.048)	(0.048)	(0.049)	(0.050)	(0.050)
Customer demand for low-carbon products or services	1.291***	1.290***	1.291***	1.291***	1.304***
	(0.063)	(0.063)	(0.064)	(0.064)	(0.064)
Voluntary agreements within your sector or supply chain	1.054	1.061	1.062	1.062	1.058
	(0.052)	(0.052)	(0.053)	(0.053)	(0.052)
Availability of external funding from banks	0.931	0.933	0.917*	0.916*	0.917*
	(0.044)	(0.045)	(0.044)	(0.045)	(0.045)
Other Controls					
Business plan	1.476***	1.448***	1.448***	1.444***	1.456***
	(0.169)	(0.166)	(0.165)	(0.165)	(0.167)
Exporting	0.795**	0.804**	0.809*	0.808**	0.792**
	(0.087)	(0.087)	(0.088)	(0.088)	(0.086)
Skills		1.474***	1.452***	1.436***	1.457***
		(0.175)	(0.173)	(0.170)	(0.176)
Barriers			1.068**	1.068**	1.067**
			(0.030)	(0.030)	(0.030)
Business model change				1.120	0.016***
				(0.156)	(0.005)
benchmark Laggards					
Late Majority#Business model change					94.729***
					(37.094)
Early Majority#Business model change					46.660***
					(16.337)
Early adopters#Business model change					101.407***
					(40.236)
Innovators#Business model change					197.397***
					(151.983)
Size	yes	yes	yes	yes	yes

Age	yes	yes	yes	yes	yes
Sector	yes	yes	yes	yes	yes
Nation	yes	yes	yes	yes	yes
Pseudo-R2	0.230	0.237	0.241	0.241	0.249
Number of observations	964	964	964	964	964

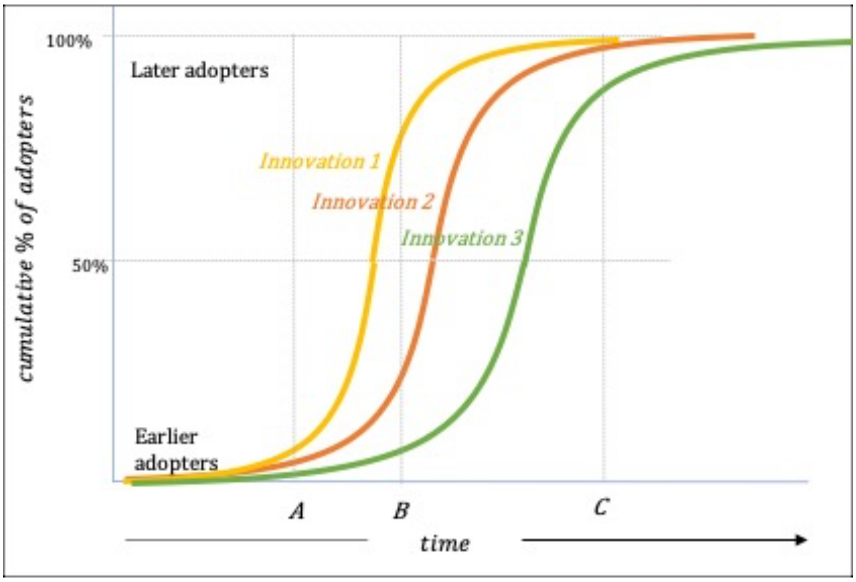
Sources: ERC Business Futures 2020.
Notes: Estimations includes sector and geography dummies.
Standard errors in parentheses.
*p < 0.05, ** p < 0.01, *** p < 0.001

Table 4. Marginal effects of the probability of belonging to net zero adopter category depending on digital adopter category and other factors (baseline model)

Variables	***Net zero adopter categories*** ***Late majority*** (1)	***Early majority*** (2)	***Early adopters*** (3)	***Innovators*** (4)
Digital adopter categories (*benchmark Laggards*)				
Late Majority	-0.088**	0.051**	0.026**	0.012**
	(0.038)	(0.023)	(0.011)	(0.005)
Early Majority	-0.223***	0.112***	0.069***	0.041***
	(0.041)	(0.024)	(0.014)	(0.009)
Early adopters	-0.250***	0.122***	0.078***	0.049***
	(0.049)	(0.026)	(0.017)	(0.013)
Innovators	-0.299***	0.139***	0.096**	0.065*
	(0.113)	(0.040)	(0.041)	(0.038)
Drivers				
Attitudes toward natural environment	-0.038***	0.016***	0.012***	0.010**
	(0.014)	(0.006)	(0.005)	(0.004)
Improving your image and reputation	-0.039***	0.016***	0.013***	0.010***
	(0.012)	(0.005)	(0.004)	(0.003)
Reducing costs	-0.020	0.008	0.006	0.005
	(0.012)	(0.005)	(0.004)	(0.003)
Environmental regulations or taxes	-0.022*	0.009*	0.007*	0.006*
	(0.013)	(0.006)	(0.004)	(0.003)
Government grants or subsidies	0.005	-0.002	-0.001	-0.001
	(0.012)	(0.005)	(0.004)	(0.003)
Customer demand for low-carbon products or services	-0.065***	0.027***	0.021***	0.017***
	(0.012)	(0.005)	(0.004)	(0.004)
Voluntary agreements within your sector or supply chain	-0.013	0.006	0.004	0.003
	(0.012)	(0.005)	(0.004)	(0.003)
Availability of external funding from banks	0.018	-0.008	-0.006	-0.005
	(0.012)	(0.005)	(0.004)	(0.003)
Other controls				
Business plan	-0.099***	0.041***	0.032***	0.025***
	(0.029)	(0.012)	(0.010)	(0.008)
Exporting	0.058**	-0.024**	-0.019**	-0.015**
	(0.027)	(0.011)	(0.009)	(0.007)
Number of observations	964	964	964	964

Notes: Standard errors in parentheses.
*p < 0.05, ** p < 0.01, *** p < 0.001

Figure 1. The simultaneous diffusion of multiple number of innovations



Source: Adapted from Rogers (2003)

Figure 2. Adopter categories based on innovativeness measured by number of adopted innovations

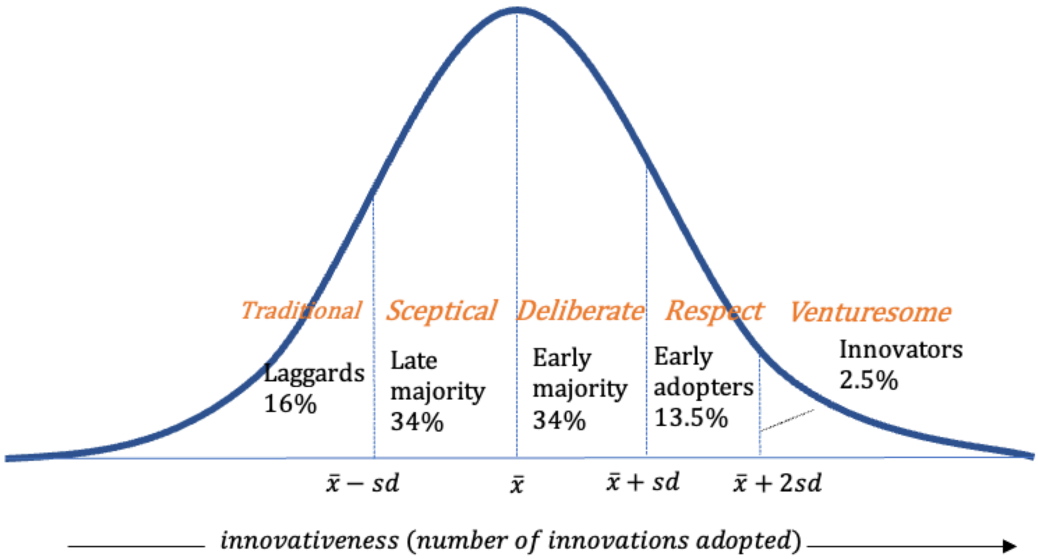
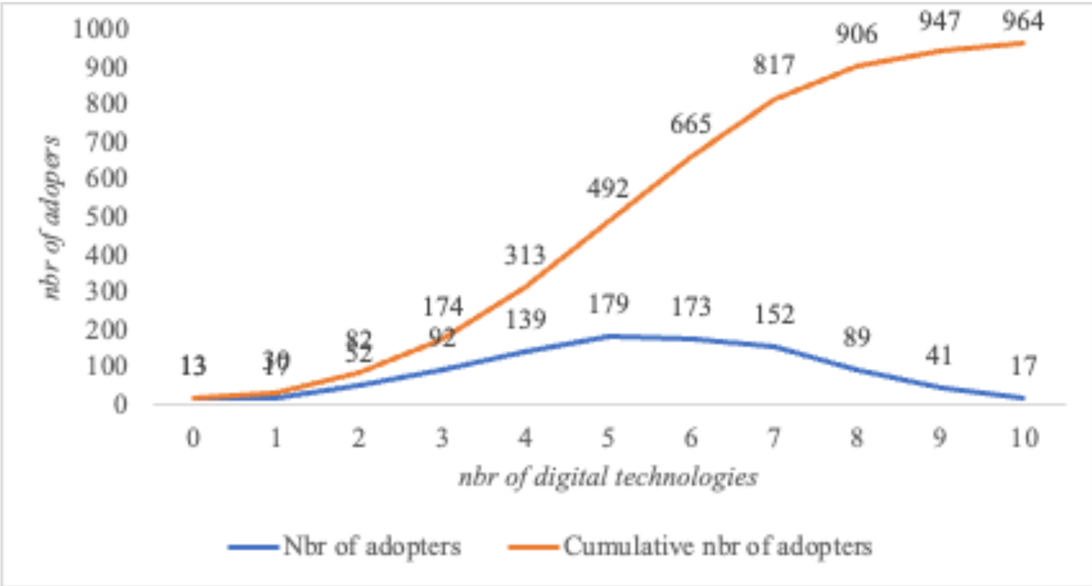


Figure 3. Distribution of 'digital innovativeness' (number of technologies adopted)



Source: Business Futures 2020 survey.

Figure 4. Adoption rates of 10 DT by digital adopter category

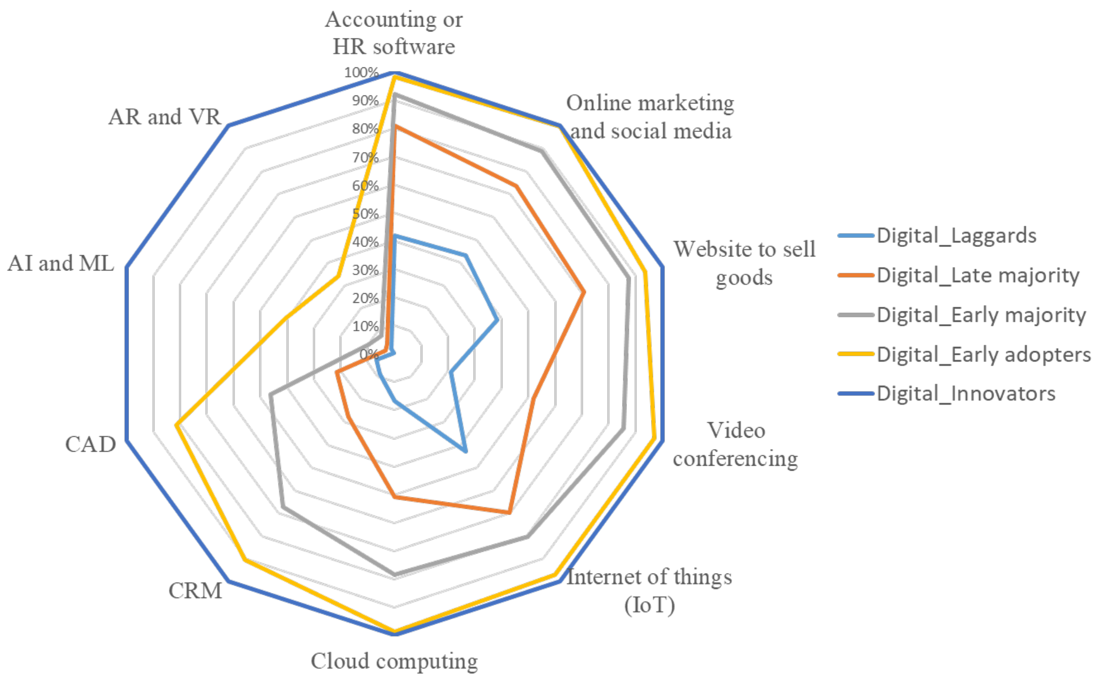
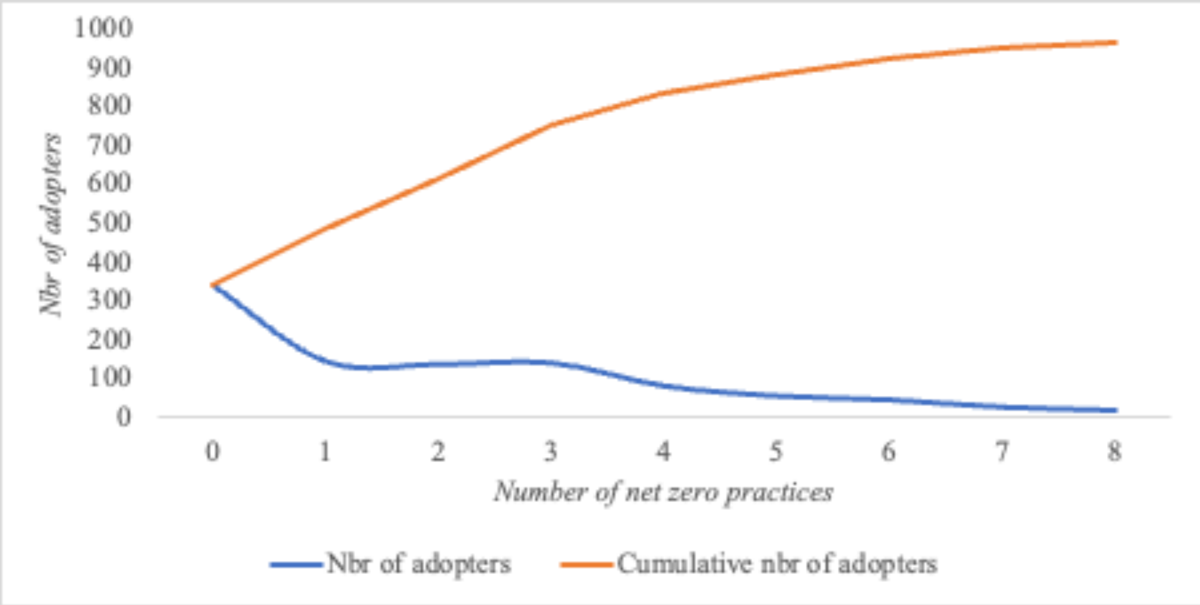


Figure 5. Distribution of 'net zero innovativeness' (number of technologies adopted)



Source: Business Futures 2020 survey.

Figure 6. Adoption rates of 8NT by net zero adopter category

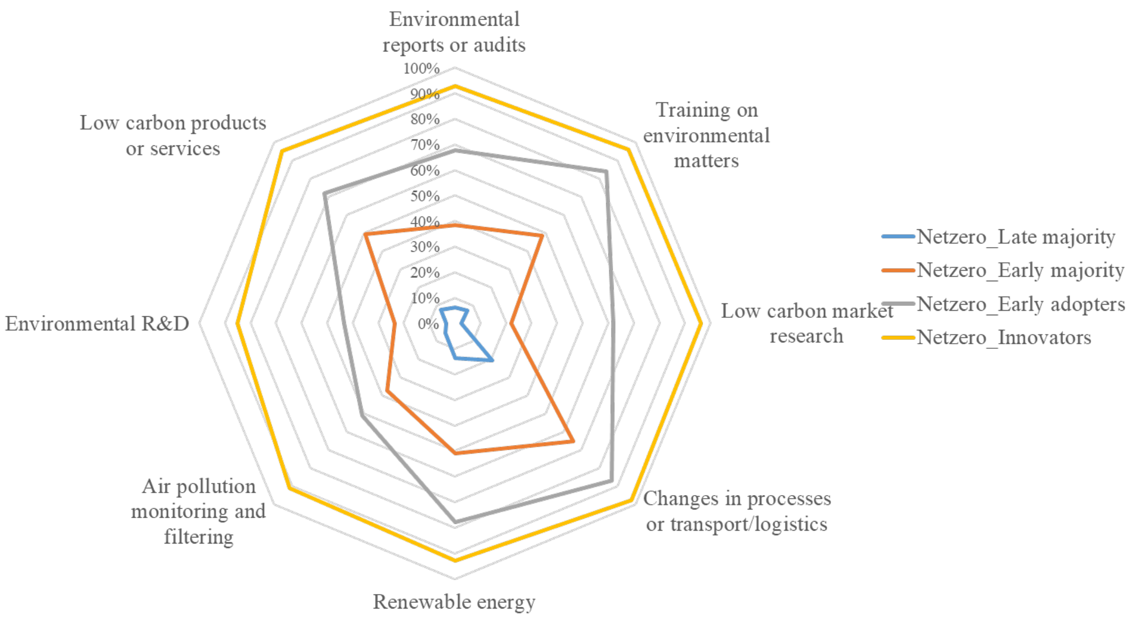
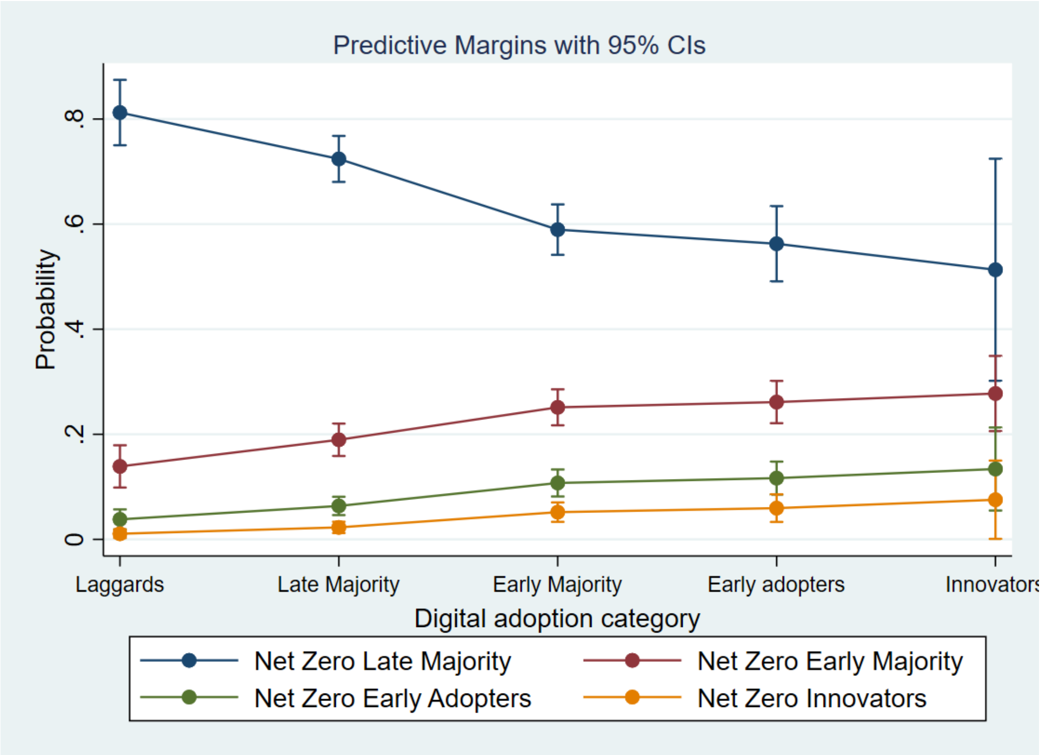


Figure 7. Predictive margins by net zero adopter category



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Appendix A

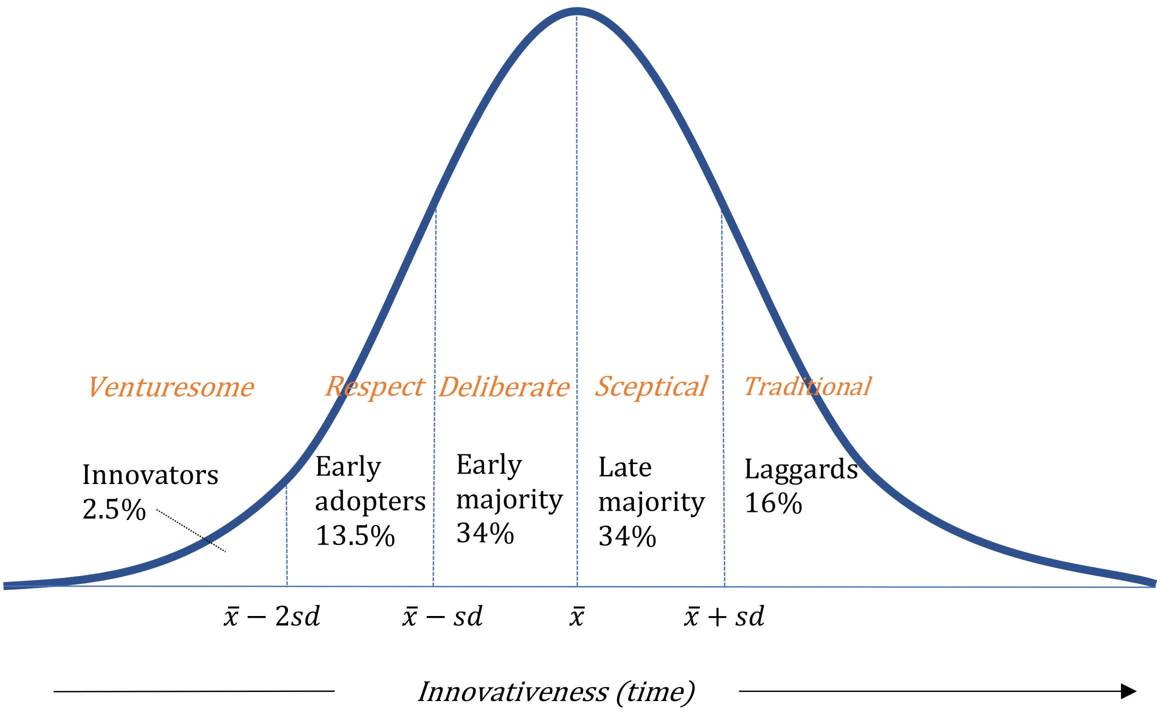

Fig. A1. Adopter categories based on innovativeness measured by time.

Source: Rogers (2003)