Journal of Innovation & Knowledge 8 (2023) 100284

Journal of Innovation & Knowledge

https://www.journals.elsevier.com/journal-of-innovation-and-knowledge

The importance of digitalization in powering environmental innovation performance of European countries

Bui Quang Hung[a], Nguyen Thi Hong Nham[a], Le Thanh Ha[b,*]

[a] University of Economics, Ho Chi Minh City, Vietnam
[b] National Economics University, Vietnam

ARTICLE INFO

Article History:
Received 7 March 2022
Accepted 6 December 2022
Available online 13 December 2022

Keywords:
European countries
Digital public services
Digital business
Environmental innovation

JEL code:
C33
F21
O16

ABSTRACT

We empirically examine the influences of the digital business and digital public services on environmental innovation (EI) performance in the European region during the 2011-2019 period. We use four diverse measures to capture the performance of EIs of 24 European countries, including the percentage of enterprises implementing EI investment (% of surveyed firms); the percentage of enterprises implementing EI activities (e.g., implementation of resource efficiency actions, sustainable products, or ISO 14001 certificates) measured, a number of enterprises having new ISO 14001 registration and a number of EI related patents. There are four measures of e-Commerce, including online selling, e-Commerce sales, e-Commerce web sales, e-Commerce turnover, and two measures of e-Business, including CRM usage and cloud usage. Digital public service performance is captured by three indicators, including user centricity, business mobility and key enabler. Our study provides the theoretical framework to explain the link between digitalization and environmental performance. The nexus between digitalization and environmental innovations is empirically analyzed by using the panel corrected standard error (PCSE) model and the feasible generalized least squares (FGLS) model for the panel data featuring the cross-sectional dependency. Our estimation results highlight the importance of digital businesses, including e-commerce sales, e-commerce turnover, e-business (including CRP and cloud usage), in improving the EI investments, EI activities, EI related patents, and the number of enterprises with new ISO 14001 registration during the 2011-2019 period in the European region. Digital public services are less crucial in promoting EI performance as compared to digital businesses as these variables are not statistically significant in some cases. We also provide empirical evidence on the mechanism to explain the improvements in EI. Digitalization appears to have favorable impacts on EI investments of firms and government's financial support, and the public's awareness regarding the importance of EI.

Introduction

Environmental Innovation (EI) is believed as a long-term cure for environmental deterioration and climate change (Alam & Murad, 2020; Blok et al., 2015; Sarkodie et al., 2019). While energy-saving technologies help alleviate polluting emissions by enhancing energy efficiency during the production process (Wu et al., 2021), other advances in preventing pollution and good practices in environmental management work as the "end of pipe" treatment for pollutants (Huang & Liu, 2014). Moreover, waste recycling and renewable energy technologies could stabilize environmental degradation by providing either a feasible means of energy reuse or viable alternatives to fossil fuels (Du et al., 2019; Ganda, 2019). EI, therefore, provides an essential route to pollution control and sustainable development (Bolton & Hannon, 2016; Gu et al., 2019; Sarkodie et al., 2019). Fostering green innovation has become a crucial strategy across countries to breathe life back into the ecosystem.

Sustainable growth has become integral to modern economies (Ahmed et al., 2022; Chishti et al., 2022; Guang-Wen et al., 2022; Jackman & Moore, 2021; Manigandan et al., 2022; Shakib et al., 2022). Guang-Wen et al. (2022) use a database of the BRICS nations to explore the nexus between economic growth, environmental pollution, financial development, and renewable energy. Moreover, environmental sustainability plays a key role in the pursuit of sustainable development goals (Ahmed et al., 2022; Chishti et al., 2022; Guang-Wen et al., 2022). Energy security and environmental sustainability play a critical role in alleviating poverty (Taghizadeh-Hesary et al., 2022) and sustainable economic growth (Arslan et al., 2022). In the literature, there is a vast number of empirical studies on

* Corresponding author at: National Economics University, Vietnam.
E-mail address: halethanh.kt@gmail.com (L.T. Ha).

https://doi.org/10.1016/j.jik.2022.100284

determinants of environmental sustainability, such as the role of green innovation (Zakari, Khan, Tan, et al., 2022); abundant energy resources (Zakari, Li, Khan, et al., 2022) and alternative and nuclear energy (Khan, Tan, et al., 2022); economic growth, international trade, clean energy investment (Lyu et al., 2021). Recent studies impacts of investigate ICT trade on renewable energy transition and environmental sustainability (Murshed et al., 2020). Although scholars have given considerable attention to both the determinants and influences of environmental sustainability, many aspects still require further investigation, especially the effects of digitalization.

Nevertheless, EI is often underinvested. The main reason is that, different from conventional innovation, green innovation provides a double positive externality, from either the usual R&D spillover effects or the application and diffusions of environmental-related technologies (Oltra, 2008). There exist two contradicting perspectives about the motivations of EI. The "oligopoly" perspective contends that green innovation is merely firms' response to the policy pressures since this endangers their profits (de Jesus et al., 2018). Meanwhile, based on a more "optimistic" approach, Porter hypothesis (Porter & van der Linde, 1995) contends that green R&D is desirable since this not only enables firms to adapt environmental regulations and standards but also build strong competitive advantage by providing customers with superior value (given the rising green consumerism (Jové-Llopis & Segarra-Blasco, 2018). Correspondingly, firms may have different reactions to EI from different perspectives, either finding ways to avoid it or taking every opportunity and effort to do it. In this regard, conducting costly and risky green R&D activities is a strategic choice that internal resources and capabilities may influence.

In recent years, the term "digitalization" has been used with increasing frequency in public disclosure with many variants being used and often misunderstood (Khoreva et al., 2019).. In the European Union (EU), digitalization is a major driving force of economic and social change (Ha, 2022b). The impact of digitalization on the environment has been exhibited through different channels. According to the European Commission (2019), for example, technological advancement plays a role in the improved collection and subsequent recycling of electronic waste, and the reuse of used materials, which builds a circular economy[1]. Several environmental issues are being addressed digitally, including solid waste, e-waste, food waste, and agricultural waste. These systems are also the research focus of many authors; for example, see Ferrari et al. (2020), Genuino et al. (2017), Gu et al. (2019), Lu et al. (2016), Sharma et al. (2020), and Wen et al. (2018). In addition, digital technologies may contribute to the improvement of biodiversity in a variety of ways (Ha, 2022b; Ha et al., 2022). For instance, information and communication technology (ICT) can help increase the efficiency of policies and public awareness through visualizing and communicating biological data.

Further, business models can be developed through digitalization that helps prevent the degradation of biodiversity (Ha, 2022b; Ha & Thanh, 2022). In addition, there are other important channels, including environmental protection, sustainable agriculture, and urban sustainability. In more detail, heavy and chemical industries have caused problems of air and water pollution which are well-managed by digital technology. According to Abdul et al. (2021), digital technology can be used to effectively address environmental problems including air pollution, greenhouse gas emissions, wastewater treatment, and climate change. Other authors have agreed with this point, including Ha (2022b), Honarvar & Sami (2019) and Zhang et al., 2017).

Moreover, regarding sustainable production, with the support of digitalization a company can anticipate many beneficial impacts on the environment. For example, digital technology can be utilized to implement smart, sustainable manufacturing in the form of green energy, energy savings, or renewable energy consumption (Ha, 2022b; Ha & Thanh, 2022). By implementing cleaner and more sustainable processes, companies can reduce operating costs and increase worker safety (Zhang et al., 2017), and reduce resource use and degradation with the help of sustainable production (Roy & Singh, 2017). With the adoption of digital technologies, such as big data, cloud computing, and artificial intelligence, we can address the problems of resource shortages, traffic congestion, and air pollution (Lu et al., 2016; C.-H. Wu et al., 2021). Moreover,the relationship between digitalization and "conventional" innovation has been explored in the literature as well. The OECD Digital Economy Outlook 2020 reveals that information and communication technologies (ICTs) and cloud computing investment are recognized as facilitators of innovation. However, even for this conventional innovation, there have been contradicting findings over the effects of digitalization on innovation among scholars (Ezrachi & Stucke, 2020).

Based on two strands of discussion in the literature, we have evidence to believe that digitalization appears to have impacts on a specific type of innovation: EI. Unsurprisingly, the limitation in the data capturing the level of digitalization and EI prevents the prior scholar from exploiting this nexus. To our best knowledge, this is the first study examining the effect of digitalization on EI. Another contribution of this paper is the dynamics in using various indicators to reflect two key variables: digitalization and EI. In particular, we use four diverse measures to capture the performance of EIs of European countries, including the percentage of enterprises implementing EI investment (% of surveyed firms); the percentage of enterprises implementing EI activities (e.g., implementation of resource efficiency actions, sustainable products, or ISO 14001 certificates) measured, a number of enterprises having new ISO 14001 registration and a number of EI related patents. Regarding digitalization, it is addressed both in the context of digital business as well as digital public service. Specifically, there are four measures of e-Commerce, including online selling, e-Commerce sales, e-Commerce web sales, e-Commerce turnover, and two measures of e-Business, including CRM usage and cloud usage. More notably, the transmission mechanism through which the digital transformation process boosts EI implementation is also outlined in our theoretical framework. To confirm our findings, various econometric techniques are applied, including panel-corrected standard errors (PCSE) modelling and feasible generalized least squares (FGLS) estimation.

The remainder of this paper is organized as follows. In Section 2, we review relevant literature, while in Section 3, we describe the model, data, and estimation process. We report our empirical results in Section 4. Finally, we conclude the paper in Section 5.

Literature review

Theoretical underpinnings

This paper is based on the views of Schumpeterian (Schumpeter, 1934) and Arrowian (Arrow, 1962) to develop the theoretical framework to investigate a link between digitalization and EI. According to the Schumpeterian idea, internalization of benefits from innovation is possible due to market concentration (increased monopoly rents). As a result, this view encourages "creative destruction," or the dynamic procedure in which old technology is replaced by new ones. Competition and innovation have been thought to be negatively correlated according to this hypothesis. A more limited supposition, which claims that a level of market dominance is the essential incentive for innovation, instead of its cause, is attributed to the hypothesis. According to this viewpoint, market dominance in the digital world may be transient and hence has no impact on innovation motivations. Additionally, disruptive innovation, reversible network effects, new technologies, and the prospect of displacement, according to this viewpoint, put ongoing pressure on leading platforms and providers, ensuring sustained innovation investment (Sarkodie et al.,

[1] https://ec.europa.eu/environment/pdf/circular-economy/new_circular_economy_action_plan.pdf

2019). Moreover, a competitive push and investment in innovation across industries are kept consistent by rivalry and conglomerate growth (CPI, 2016).

The Arrowian theory, which proposes that innovation investment is mainly encouraged by intense competition while future innovation is discouraged by strong market power, is also noteworthy. In regard to this, because a monopoly would be unlikely to invest in innovative technology (or only invest if profits rise), competition is seen as an essential constraint. The empirical economic literature has demonstrated a wide range of outcomes (Bykova, 2017). The inverted U-shaped connection is emphasized, implying that as competition rises (from a low starting point), so does the rate of innovation, but that when the competition reaches a certain point, the rate of innovation will start to drop. Aghion et al. (2021) believe that competition is more likely to boost incremental profits from innovating (known as the "escape-competition impact") while lowering motivations to innovate for underperformers (known as the "Schumpeterian effect") (Aghion et al., 2005).

As revealed in Aghion et al. (2005), innovative activities can be promoted due to a greater product market competition, thus boosting the incremental profits from innovating and becoming prominent in neck-and-neck industries where the degree of technology adoption among firms' operation are equal. This effect is known as an 'escape-competition effect'. However, a negative 'Schumpeterian effect' on lagging businesses in unevolved sectors is forecasted in such models. Specifically, a higher competition results in a drop in laggard firms' post-innovation rents, discouraging them from keeping up with the leading businesses. Nonetheless, when this laggard firm has reached the present leader in the industry, an 'expected escape competition effect' (partially) counteracts this impact. The equilibrium ratio of neck-and-neck sectors is positively influenced by laggards' innovation drivers in unevolved sectors while negatively on neck-and-neck firms' innovation drivers in leveled sectors. This finding combined with the escape-competition and Schumpeterian effects suggests the 'composition effect' of competition. Particularly, in industries with the presence of neck-to-neck firms, the equilibrium fraction should decline with competition (Aghion et al., 2018).

Contextual features specific to particular sectors additionally complicate the link between innovation and market structure (Waller & Sag, 2014). Diverse industries have different levels and intensities of research and development, as well as varying levels of protection for innovation and share of rewards (De Bondt & Vandekerckhove, 2012). In these domains, inequalities in a range of operations (national or worldwide), cost levels, as well as dedication to innovation may also be evident. Firms then make the strategic decision to invest in new technologies with less zeal if they are uncertain about the outcome of innovation. Finally, since innovation investment is influenced by various economic activities, legal systems, and the accessibility of financial markets, a political/industrial aspect should be examined (Boone, 2001).

In addition to the Schumpeterian and Arrowian views, we also based on the view of stakeholders to explain the motivations behind EI implementations. In 1963, the Stanford Research Institute used the word stakeholder to describe "those groups without whose support an organization could not exist" (Friedman & Miles, 2006). The concept of stakeholders was introduced as part of a "strategic discipline" by Ackermann & Eden (2011), who distinguished stakeholders from shareholders and also included stakeholders in decision-making (Mitchell et al., 1997). Sulkowski et al. (2018) reveal that the stakeholder theory, as an academic perspective, offers a more detailed description of a company's structure and everyday operations (Sulkowski et al., 2018). As revealed by Co & Barro (2009), in accordance with stakeholder theory, which is based on four essential premises, firms have links to multiple processes but the outcomes are not satisfactory. Second, the firms' procedures and results are associated with the views of their stakeholders. Third, Co & Barro (2009) also contend that stakeholders cannot be allowed to override the safety of others because of a stakeholder's inherent value or comfort. Fourth, as a basis for numerous eco-scholarships, the stakeholder theory affects the sensitivity of companies to the environment (Crane & Livesey, 2003) as well as their environmental regulations (Salem et al., 2018). While implementation of EI has had mixed results and stakeholders' opinions have been difficult to predict. For instance, Jaaffar & Amran (2017) demonstrate that boards of directors of large business set policies and strategies for eco-friendly activities, but small businesses and their owners implement them (Huang et al., 2009). Further, Murillo-Luna et al. (2008) contend that stakeholders affect the firms' selection of environmental response strategies in German manufacturing organizations. Moreover, they lead to changes in unproven environmental impacts (Wagner, 2007). As a result, Belgian organizations did not match their environmental policies and stakeholder management perfectly (Buysse & Verbeke, 2003). It is more likely that stakeholders' views are more influential on EI practices (Seman et al., 2018).

Based on these three strands of views, we contend that a firm's internal capacity, government's financial support and the public's awareness about the importance of EI significantly motivate firms, enhance their internal capacity to implement EI and the level of public demands requiring them to perform it. The digital transformation process should have an effect on these channels in order to increase the prevalence of EIs among firms.

Digitalization, knowledge and innovation

Digitalization and knowledge

By digitalizing work, knowledge may be better utilized (Bouncken & Barwinski, 2021; Vuori et al., 2019), resulting in increased productivity (Chou et al., 2014; Ribeiro-Navarrete et al., 2021; Shujahat et al., 2018, 2019) and efficiency (Porter & Heppelmann, 2015). In short, digitalization should lead to improved performance, such as achieving set objectives or enhancing the expertise of individuals and organizations (Vuori et al., 2019).

In addition to the direction (sender and receiver) and content of knowledge flow, another important characteristic is the carrier (medium) by which knowledge passes from one individual to another (Vuori et al., 2019). Therefore, it is not surprising that digitalization is expected to enhance knowledge flows by providing effective tools to serve as media and enablers of knowledge. Production increases in direct proportion to the speed at which information flows within an organization (Schmenner, 2004). Therefore, the more effective and efficient the knowledge flow within an organization is, the more quickly knowledge workers are able to plan and execute their tasks (Wu et al., 2004). In support of knowledge work, technological tools and digital technologies are designed to achieve this. Franssila et al. (2016) indicate that tools are used in three domains in the digital workplace: (i) management and refinement of information by personal computers; (ii) acquisition and sharing of data and information in a networked work environment; and (iii) communication.

By making more information and knowledge readily available, digital tools provide better resources for knowledge work. However, Woods et al. (2002) contend that since human ability to interpret meaningful data has not improved, this may simultaneously lead to an information overload. Inefficiency and stress are a result of the feeling of losing control due to the abundance of information. In order to reap the benefits of digitalization, it is vital to identify and manage the information load associated with knowledge-intensive work. There is an urgent need to develop methods suited for different processes and conventions in order for individuals to be more resilient and more capable of coping with the demands of contemporary work (Vuori et al., 2019). While the digital revolution may enhance freedom, independence, and autonomy for knowledge workers by enabling mobility, flexibility, and asynchrony, it leads to a "always-on" lifestyle in which work intrudes into leisure time. Barber & Santuzzi (2015) have identified the expectation of availability and the

implicit pressure to respond immediately as being stressful factors. As a result of this situation, time management and workers' wellbeing are adversely affected if they perceive that they do not have enough time to recharge between working hours.

Digitalization and innovation

Digital innovation can be defined as "the creation of (and consequent change in) market offerings, business processes, or models that result from the use of digital technologies". As a result, management of digital innovation is linked to processes, principles, and practices that are required to orchestrate digital innovation effectively (Brock et al., 2020; Nambisan, 2018; Nambisan et al., 2019). Digital technologies are used and implemented by companies for a variety of purposes related to innovation and at different stages of the innovation process (Bartolacci et al., 2020). In this respect, studying the advantages, risks, and implications of using digital technologies is highly relevant, as well as identifying if and how innovation processes change as a result of the use and application of digital technologies. Additionally, it is necessary to determine whether firms must organize themselves differently internally in order to apply these technologies (Raguseo et al., 2016). As well as supporting knowledge management processes, digital technologies may also have implications for organizational structure and behaviors (Gressgård, 2011; Gressgård et al., 2014). The structural implications of these tools can include simplification of access to internal and external knowledge, and facilitation of knowledge dissemination among the members of an organization (Gastaldi et al., 2015). As regards the behavioral implications, digital technologies can be used to influence human interaction and aid in the development of knowledge and the creation of a shared understanding between the organization's members (Gressgård et al., 2014).

The use of digital technologies is challenging and dynamic (Appio et al., 2021; Pesch et al., 2021). A number of simultaneous adjustments must be made to organizational culture, decision-making, strategies, resources, and staffing (Gastaldi et al., 2015). For companies to rely on digital technologies, they must be prepared to change their approach to innovation on a continuous basis. As argued by Agostini et al. (2020), firms are likely to produce, assimilate, or exploit innovations if they see them as necessary and possess the requisite capabilities. On this point, research by Agostini & Filippini (2019), Huesig & Endres (2018) and Neirotti & Pesce (2018) all focus on how digital technologies influence organizational, technological and managerial factors that influence the innovation process. In addition to the perception that employees are becoming more and more focused on creative, innovative, and communicative tasks, which require continuous improvement and learning, digital technologies can spread this notion (Raguseo et al., 2016). Thus, the role of a company's employees in innovation is essential, requiring highly skilled personnel (Agostini & Filippini, 2019). The company should prepare suitable training for its employees and focus on the new core functions, such as how to manage and control digital systems. If the early stages of the transition towards digitalization are to be successful, the importance of employee training and professional development cannot be overstated. Moreover, individuals are embedded in a social context, and they must be capable of communicating, cooperating, and establishing social connections with others. Fully integrated and automated digital processes implicitly imply that employees will have a broader scope of responsibilities and need to understand the connection between processes and information flows. Simultaneously, they learn how to collaborate to develop ad hoc solutions to specific problems related to innovation. Managers must address these issues. Employee participation can be promoted by managers' support for organizational learning and innovation (Agostini & Filippini, 2019).

Technologically, managers can take advantage of advances in digital technology to improve the way they deploy resources during the innovation process, but they must identify and adopt the right digital tools. Huesig & Endres (2018) examine the factors influencing the adoption of Innovation Management Software (IMS) and how it can be applied. Their study contributes to a better understanding of the technological and organizational factors driving the transition from an innovation process to a digital process of innovation, particularly in the case of companies and innovation managers seeking to introduce and apply IMS to new product development (Agostini et al., 2020; Marion & Fixson, 2021). The authors suggest, therefore, that using digital tools as part of the innovation process can be a more nuanced process than the "more, the better" logic often advocated in previous literature in this area (Pesch et al., 2021).

Digitalization and EI implementation

In this paper, we believe that digitalization is the double-edged sword, which may promote or hinder the EI implementation. Having established a theoretical framework for innovation and market features, we turn our attention to the digital sector, which includes a more specific discussion of the drivers and barriers to EI.

The digital environment is characterized by the variety (scope) of personal data. Data can be more useful for future planning if more data points are obtained. Consider, for example, how digital personal assistants and online search results can be improved by combining personal data. The firms, in collecting personal information from the variety of services its users use beyond the search engine (such as e-mails, web browsers, texting, maps, and purchasing), can be able to build profiles of their users that will enable them to target them with more relevant organic and sponsored search results

Digital revolution may generate dynamic efficiency and enable both incremental and revolutionary innovation, which then lead to an improvement of various aspects of the economy. It is instructive to note that the digital transformation process includes various issues, which influence innovation and EI differently. Specifically, data is a vital contributor to the decision of innovation implementation, especially there is a prevalence of digitalization. A larger amount of data helps companies develop better algorithms, production, services, and organizational structures. By analyzing a rich source of data, government and business can learn how to use resources more efficiently and operate their company more effectively. Business strategies have been transformed by the data revolution. With the aim of gaining a competitive advantages over competitors, artificial intelligence (AI) and big data are increasingly being incorporated into strategic decision-making processes (The Economist, 2018). In addition, Big Data is a core economic asset capable of creating significant competitive advantages for businesses and driving innovation and growth (OECD, 2013).

The use of big data can boost innovation demand, but these efforts can be impeded by barriers to data. OECD (2019) noted that data-driven services offer significant improvements, along with a positive feedback loop that strengthens the strong while weakening the weak. As a valuable input, and as a result of its scope, data can contribute to the expansion and integration of a firm. Due to the value of data being determined by its volume, variety, and speed of collection and analysis, mergers allow companies to gain a data advantage. In the process of consolidation, valuable efficiencies can be created, while at the same time, data can be affected as a valuable resource for innovation and EI implementation.

Network effects are a characteristic of the digital economy that offers diverse economies of scale and efficiencies. In addition, network effects reduce pressure of competition, thereby limiting the implementation of EI (Haucap, 2019). For advertising- and marketing-based business models, personal data on users' weaknesses and strength as well as tastes and preferences is the valuable asset (Ezrachi & Stucke, 2016). The environment in which a person lives or the decisions he or she makes can be directly affected by big data analytics (Jain et al., 2016). Firms use sophisticated algorithms in a variety of activities, including data mining, data trade, online marketing,

recognition of pattern (Bishop, 2006), optimization of price, and estimation of demand, (Drechsler & Sánchez, 2018; Seele et al., 2021). Businesses' advertising-driven business models are fueled by this information. If a company has an advantage over rivals in terms of data, it can achieve scale economies that can drive its advantage in terms of data-and competitive balance. Consequently, leading companies compete on data collection and analysis, as well as on infrastructure and emerging markets.

As also revealed by (Osorio-Arjona & García-Palomares, 2019), when the Internet and mobile communications have grown exponentially, a huge variety of platforms has developed - ranging from social networks and video sharing to search engines and mobile apps. Platforms are more likely to serve as intermediaries to connect service suppliers to user. Access, communication and scale are facilitated by their ecosystem, which leads to greater transparency, competition, and innovation. Their platform generally serves both sides. More users generate a traditional spill-over effect, wherein more sellers, advertisers, or suppliers attract more customers, which can, in turn, produce more users. As opposed to traditional multisided markets (for example, newspapers, television, and radio), online platforms are able to gather personal information about their users, build profiles of them, target them with advertisements, and obtain endorsements from them.

The Internet and technology were once thought to decentralize power and foster inclusiveness. The use of high-end technology can give users direct access to many features and allow them to control them. Alternative news and entertainment sources could gain access to news and entertainment through this decentralizing vector, in turn eroding the traditional gatekeepers' power. Nevertheless, it is important to note that such platforms may function on a different vector - the control over the platform - which often resides centrally and may influence behavior.

Based on our discussion, a number of limitations have been identified in previous studies. First of all, no paper provides an in-depth analysis of digitalization's effects on the EI implementation. The association between digitization and conventional innovation has been explored thus far, but there is no work on the digitalization-EI linkage. A second issue is that scholars agree that cross-sectional dependence biases the results obtained using the conventional method (Canh et al., 2021; Ha et al., 2022; Le et al., 2022). Previous studies in this field have still not paid enough attention to this issue. Importantly, the previous studies have abstracted channels through which digitalization influences EI implementation. Our study aims at filling these gaps by contributing to the existing literature in several ways. First, our study is the first effort to analyze the effects of digital transformation on EI performance empirically. To provide a comprehensive analysis of this nexus, we utilize the various measures to reflect the EI performance. Second, the theoretical contribution of this paper is premised on the combination of the Schumpeterian, Arrowian, and stakeholder views to explain the motivations behind EI implementations. Based on the proposed theory, we demonstrate the mechanisms through which digitalization affects them to trigger EI activities. From an empirical approach, we apply the panel corrected standard errors (PCSE) model to a sample of 24 European countries from the period 2011-to 2019. For a robustness check, our study also applies the feasible generalized least squares (FGLS) model to examine our findings when we consider heteroscedasticity and fixed effects. For simulation purposes, we utilize the predictive margins analysis.

Model specification

We present the model used to examine the nexus of digitalization and EI performance (EIP) as follows:

$$EIP_{it} = \beta_0 + \beta_1 DG_{i,t} + \beta_2 EG_{i,t} + \beta_3 TS_{i,t} + \beta_5 FDI_{i,t} + \beta_5 EPI_{i,t} + \beta_6 NR_{i,t} + \beta_7 DM_{i,t} + \varphi_t + \omega_i + \varepsilon_{ijt,} \quad (1)$$

where i and t respectively represent country i and year t. φ_t and ω_i are added into the model to capture the country and year fixed effects, and $\varepsilon_{ijt,}$ is the error term.

EI performance (EIP)

Following Al-Ajlani et al. (2021), we use four diverse measures to capture the performance of EIs of European countries, including EI investments (*EI_ENTER*) measured as the percentage of enterprises implementing EI investment (% of surveyed firms); EI activities measured by the percentage of enterprises implementing EI activities (e.g., implementation of resource efficiency actions, sustainable products, or ISO 14001 certificates) measured as the share of certified firms among surveyed firms) (*EI_ACT*); a number of enterprises having new ISO 14001 registration (*EI_ISO*) measured as the share of surveyed firms; and a number of EI related patents (*EI_PATENT*). To shed light on this link, we further indicate the mechanism by studying the impacts of digitalization on the total investments (financial and human resources) aiming to trigger EI activities (*EI_INP*), including total R&D personnel and researchers (*EI_RD)* measured as a share of total employment; governments environmental and energy R&D appropriations and outlays (*EI_GOV*) measured as a share of GDP and total value of green early-stage investments per capita (*EI_GREEN*), and the level of public's EI awareness (*EI_ME*) measured as EI related media coverage (per min population). These variables are sources from the Organization for Economic Co-operation and Development (OECD) statistics (OECD.Stat) during the 2011-2019 period.

Digital business (DG_DB) and digital public services (DG_DPS)

- Digital business: this paper follows Ha (2022) and Ha & Thanh (2022) to use online selling (*DGDB_SO*), e-Commerce sales (*DGDB_ES*), e-Commerce web sales (*DGDB_ESWS*), e-Commerce turnover (*DGDB_TO*), and e-Business, including customer relation management (CRM) usage (*DGDB_CRM*) and cloud usage (*DGDB_CL*).
- Digital public services: Similarly, we based on the study of Ha (2020) to include three indicators to reflect the level of implementing digitalization in public sectors, including the extent to which (information about) a public service is provided online, how the online journey is supported and if public websites are mobile friendly (*DGDPS_UC*); the extent to which public services that are aimed at foreign businesses are available online, usable, and implement eID and eDocument capabilities. This indicator is calculated as a weighted average of business mobility online availability, usability, eID cross borders and eDocuments cross borders (*DGDPS_BM*) and the extent to which technical pre-conditions for eGovernment service provision are used (*DGDPS_KE*). These digitalization variables are available from eGovernment Benchmarking report and studies for digitalization by Capgemini. The dataset is available from 2011 to 2019.

Control variables

We follow the empirical studies in the literature to choose explanatory variables. Economic growth (*EG*), trade share (*TS*) are included in the explanatory variable list. We also add the proportion of net FDI inflows (*FDI*) in our theoretical model, as in Bu et al. (2019), Shahbaz et al. (2018), and Sun et al. (2017, 2019). In addition, we consider the impact of a country's industrialization level (*IND*) using the percentage of industrial value-added to GDP, following Fu et al. (2020) and Le & Hoang (2021). Following Le & Nguyen (2019), we consider the effects of natural rents (*NR*), while a level of democratization (*DM*) is also added as suggested by Le & Hoang (2021). These variables are available from World Development Indicators (WDI). The final

Table 1
Variable's description

Variable	Definition	Measure	Source	Obs	Mean	SD	Min	Max
EI_ENTER	EI investments	The percentage of enterprises implementing EI investment (% of surveyed firms)	OECD.Stat	216	78.86	38.93	0.00	155.00
EI_ACT	EI activities	The percentage of enterprises implementing EI activities (e.g., implementation of resource efficiency actions, sustainable products, or ISO 14001 certificates) (% of surveyed firms)	OECD.Stat	216	94.13	32.82	25.00	171.00
EI_ISO	Enterprises with new 14001 registration	Number of ISO 14001 certificates (per min population)	OECD.Stat	216	99.13	51.89	0.00	207.00
EI_PATENT	EI related patents	EI related patents (per min population)	OECD.Stat	216	129.38	64.95	0.00	322.00
EI_INP	Investments on environmental activities	Total investment on Financial and human resources directed towards triggering EI activities	OECD.Stat	216	79.01	46.30	1.00	214.00
EI_RD	Investments on R&D personnel and researchers	Total R&D personnel and researchers investments (% of total employment)	OECD.Stat	216	109.97	59.69	2.00	226.00
EI_GOV	Government environmental	Governments environmental and energy R&D appropriations and outlays (% of GDP)	OECD.Stat	216	53.89	37.65	0.00	140.00
EI_GREEN	Environmental early-stage investments	Total value of green early-stage investments (USD/capita)	OECD.Stat	216	97.01	106.18	0.00	422.00
EI_ME	Public's EI awareness	EI related media coverage (per min population)	OECD.Stat	216	137.39	52.40	40.00	287.00
DGDB_SO	Online selling	The proportion of individuals selling goods and services online.	Eurostat	216	14.76	8.91	1.00	48.00
DGDB _ES	e-Commerce sales	The proportion of firms with e-Commerce sales.	Eurostat	216	18.48	6.99	5.00	39.00
DGDB _TO	e-Commerce turnover	The proportion of firm with e-Commerce sales of at least 1% turnover.	Eurostat	216	14.84	5.62	5.00	32.00
DGDB _ESWS	e-Commerce web sales	The proportion of firms with web sales (via websites, apps or online marketplaces).	Eurostat	216	16.01	7.10	3.00	36.00
DGDB _B2C	e-Commerce web sales (B2C)	The proportion of firms with web sales in the form of Business to Customers.	Eurostat	167	11.90	4.31	5.00	28.00
DGDB _CRP	CRP usage	The proportion of firms with E-commerce, customer relation management (CRM) and secure transaction.	Eurostat	216	18.48	6.99	5.00	39.00
DGDB _CL	Cloud usage	The proportion of firms using Cloud computing services.	Eurostat	128	25.19	14.96	5.00	70.00
DGDPS_UC	User centricity	User centricity index as a weighted average of online availability, usability, and mobile friendliness.	eGBR	192	78.13	13.24	44.00	97.25
DGDPS _BM	Business mobility	Business mobility index as a weighted average of online availability, usability, eID cross borders and eDocuments cross border.	eGBR	192	63.36	17.39	9.00	100.00
DGDPS _KE	Key enablers	Key enablers index as a weighted average of eID, eDocument, digital post, eSafe and single sign on.	eGBR	192	54.35	25.57	0.00	99.00
EG	Economic growth	The real GDP per capital (constant 2010 US dollars).	WDI	216	33.64	23.50	1.02	111.15
TS	Trade share	The proportion of GDP.	WDI	216	1.30	0.66	0.55	4.08
FDI	Net inflow of foreign direct investment	The proportion of GDP.	WDI	216	0.02	0.26	-1.54	1.63
IND	Industrialization level	The value added to GDP.	WDI	216	0.22	0.06	0.10	0.38
EPI	Environmental performance index	The score is scaled between 0 and 100, where 0 and 100 mean worst and best performance, respectively.	YCELP	216	71.02	7.23	53.89	82.86
NR	Natural rents	The share of the sum of coal rents, mineral rents, natural gas rents, and forest rents to GDP (%).	WDI	216	0.44	0.47	0.00	2.58
DM	Level of democratization	The index of democratization	FSSDA	216	1.65	0.50	1.00	3.00

Note: WDI: World Development Indicator. OECD: Organization for economic co-operation and development. We take digitalization variables from multiple surveys, namely Eurostat - Community survey on ICT usage in Households and by Individual, Eurostat - ICT Enterprises survey, eGovernment Benchmarking Report. FSSDA: Finnish Social Science Data Archive; WBGI: World Bank Group Indicator. UMCES: University of Maryland Center for Environmental Science.

sample after dropping any countries that have missing observations consists of 24 European countries from 2011 to 2019. The detailed descriptions of included variables are summarized in Table 1. The correlation matrix between all variables is displayed in Table 2. Table 2 reveals that there is a positive association between digitalization and EI performance.

The following check on the data is cross-sectional dependence. The cross-sectional dependence (CD) tests proposed by Pesaran (2021), therefore the Im-Pesaran-Shin unit root test developed by Im et al. (2003) are used to check for stationarity of data presence of CD. We report the result in Table 3. According to Beck & Katz (1995), Ha (2022a), and Ha et al. (2021), along with proving the existence of CD as well as the stationarity of first-difference variables, we choose the panel corrected standard error (PCSE) and Feasible Generalized Least Squares (FGLS) model for our sample. All explanatory variables are lagged by one period as represented in Eq. (1) to resolve the endogeneity stemming from the simultaneous relationship between digitalization and EI performance. The predictive margins analysis is employed to display our findings. To shed more light on this link, we present the mechanism to explain the improvements of EI performance, including EI activities, investments on R&D personnel and researchers, government environmental and energy R&D appropriations and outlays, environmental early-stage investments and the public's EI awareness.

Empirical results

Digitalization and EI

EI activities

Table 4 demonstrates the impacts of digitalization on EI implementation investments by enterprises. Regarding digital business (*DB*), online selling (*DGDB_SO*), e-Commerce sales (*DGDB_ES*), e-Commerce web sales (*DGDB_ESWS*), e-Commerce turnover (*DGDB_TO*), and e-Business, including customer relation management (CRM) usage (*DGDB_CRM*) and cloud usage (*DGDB_CL*) are employed to measure this variable. The effect of e-commerce sales, e-commerce turnover, e-business (including CRP and cloud usage) on EI investments is statistically significant and positive. It is worth noting that our results highlight the importance of an application of e-commerce and benefits of this transformation process encourage firms to embark on these digital activities. The findings of this paper are consistent with those in other studies. Agan & Balcilar (2022) explore determinants of environmental technology diffusion and emphasize the

Table 2
Correlation coefficients

	EI_ENTER	EI_ACT	EI_ISO	EI_PATENT	EI_INP	EI_RD	EI_GOV	EI_GREEN	EI_ME	DGDB_OS	DGDB _ES	DGDB _ESWS	DGDB _TO	DGDB _B2C
EI_ENTER	1													
EI_ACT	0.828	1												
EI_ISO	0.721	0.801	1											
EI_PATENT	0.278	0.412	0.455	1										
EI_INP	0.379	0.473	0.580	0.603	1									
EI_RD	0.392	0.472	0.614	0.584	0.907	1								
EI_GOV	0.233	0.390	0.491	0.365	0.738	0.517	1							
EI_GREEN	0.297	0.289	0.302	0.528	0.801	0.691	0.285	1						
EI_ME	0.0163	0.0189	0.0994	0.511	0.288	0.314	-0.0213	0.418	1					
DGDB_SO	0.173	0.278	0.348	0.412	0.507	0.552	0.256	0.430	0.0464	1				
DGDB _ES	0.343	0.507	0.488	0.547	0.525	0.617	0.184	0.479	0.132	0.589	1	1		
DGDB _TO	0.254	0.408	0.404	0.521	0.497	0.606	0.133	0.472	0.181	0.539	0.980	1		
DGDB _ESWS	0.356	0.519	0.485	0.559	0.462	0.510	0.157	0.464	0.142	0.479	0.957	0.932	1	
DGDB _B2C	0.193	0.308	0.294	0.380	0.285	0.435	-0.0429	0.300	0.181	0.352	0.895	0.930	0.887	1
DGDB _CRP	0.343	0.507	0.488	0.547	0.525	0.617	0.184	0.479	0.132	0.589	1	0.980	0.957	0.895
DGDB _CL	0.187	0.410	0.373	0.586	0.577	0.638	0.269	0.500	0.445	0.607	0.718	0.722	0.662	0.604
DGDPS_UC	0.130	0.260	0.391	0.201	0.477	0.482	0.303	0.379	0.368	0.233	0.400	0.414	0.366	0.337
DGDPS _BM	0.0158	0.163	0.175	0.296	0.275	0.258	0.0201	0.402	0.549	0.0878	0.288	0.306	0.288	0.241
DGDPS _KE	-0.0175	0.159	0.246	0.214	0.334	0.266	0.258	0.297	0.331	0.198	0.239	0.241	0.226	0.137
EG	0.432	0.359	0.412	0.593	0.647	0.763	0.153	0.663	0.534	0.360	0.442	0.448	0.353	0.338
TS	-0.0613	-0.130	-0.224	-0.00664	-0.0729	0.0972	-0.414	0.139	0.199	0.0109	0.0825	0.128	0.00732	0.196
FDI	0.102	0.0600	0.101	0.0603	0.153	0.157	0.147	0.0668	0.00447	0.256	-0.00184	-0.0109	-0.0651	-0.0944
IND	0.0846	0.196	0.0343	-0.141	-0.0436	-0.00938	0.0236	-0.126	-0.509	0.121	0.346	0.319	0.335	0.359
EPI	0.443	0.511	0.608	0.483	0.819	0.838	0.523	0.636	0.326	0.538	0.566	0.550	0.497	0.370
NR	-0.419	-0.300	-0.287	-0.156	-0.172	-0.311	-0.0385	-0.0602	-0.117	0.180	-0.140	-0.154	-0.133	-0.220
DM	-0.453	-0.433	-0.579	-0.456	-0.731	-0.787	-0.327	-0.670	-0.241	-0.580	-0.604	-0.595	-0.519	-0.460

	DGDB _CRP	DGDB _CL	DGDPS _UC	DGDPS _BM	DGDPS _KE	EG	TS	FDI	IND	EPI	NR	DM
EI_ENTER												
EI_ACT												
EI_ISO												
EI_PATENT												
EI_INP												
EI_RD												
EI_GOV												
EI_GREEN												
EI_ME												
DGDB_SO												
DGDB _ES												
DGDB _TO												
DGDB _ESWS												
DGDB _B2C												
DGDB _CRP	1											
DGDB _CL	0.718	1										
DGDPS_UC	0.400	0.519	1									
DGDPS _BM	0.288	0.400	0.618	1								
DGDPS _KE	0.239	0.341	0.784	0.560	1							
EG	0.442	0.496	0.342	0.364	0.157	1						
TS	0.0825	-0.0552	-0.124	0.0272	-0.102	0.447	1					
FDI	-0.00184	0.0289	0.0634	-0.00675	0.156	0.115	-0.069	1				

(*continued on next page*)

Table 2 (*Continued*)

	DGDB_CRP	DGDB_CL	DGDPS_UC	DGDPS_BM	DGDPS_KE	EG	TS	FDI	IND	EPI	NR	DM
IND	0.346	0.0620	-0.0394	-0.202	-0.116	-0.22	0.0589	-0.328	1			
EPI	0.566	0.665	0.535	0.341	0.334	0.411	-0.232	0.293	-0.219	1		
NR	-0.140	-0.0522	0.0122	0.0492	0.143	-0.424	-0.129	-0.102	0.188	-0.297	1	
DM	-0.604	-0.602	-0.411	-0.256	-0.207	-0.672	-0.0487	-0.170	-0.0242	-0.470	0.173	1

significance of economic, social, political and environmental factors. The relationship between digitalization and innovation is indicated by (Agostini et al., 2020; Gobble, 2018; Yoo et al., 2010). The report of OECD (2019) highlights the impacts of digitalization on innovation through its effects on efficiencies and services. These studies reveal the critical findings that digitalization leads to an emergence of challenges in addition to an offer of new opportunities. However, digitalization generally brings about an increase in the level of innovation. It can be seen that the digitalization-innovation nexus has been exploited by many authors, but the impacts of the digital transformation process on the EI have still keep silent in the literature. Our paper is the first effort to embark on this association.

However, the role of digital public services is not evident in our sample of European countries. Although variables presenting the prevalence of digital public services are positive as we expect, they are all statistically insignificant. In the literature, there are very few studies on this relationship and scholars mostly pay their attention to roles of innovation in promoting the digital transformation in the public sector (Bertot et al., 2016). Mcloughlin et al. (2013) is among of very few papers that investigate the role of digital technology in providing the basis for changes in the way the governments operate and distribute their public services. However, there is no quantitative paper that provides empirical evidence on this issue.

The findings of our article are crucial since they suggest insightful lessons for economists and policy makers to promote the economic development towards the sustainable economy. The environmental degradation has become the global issue that is increasingly received an attention of scholars and policymakers. At the same time, the digital transformation process become an inevitable trend and take place on a global scale. It is vital that the publics, the governments and policymakers are aware of the importance of digitalization and its each type, including the digital transformation in the business and the public sector, in the EI implementation. Hence, resources will be prioritized for the type of digital transformation that is more effective. In our study, we highlight the more critical role of digital business.

In the following analysis, we investigate the impacts of digitalization on EI related patents, specifically, EI activities (*EI_ACT*). The results reported in Table 5 show that digitalization in the business and public sector have statistically significant and positive effects on EI activities EI activities as we expect. In this case, our study emphasizes the importance of both digital business and digital public services. We then examine the impacts of digitalization on EI captured by an implementation in enterprises with new ISO 14001 registration (*EI_ISO*). The results are outline in Table 6. Similarly, as we predict, the coefficients on digital business and digital public service variable are statistically significant and largely positive. Regarding digital public services, three indicators affect the number of new ISO 14001 registration positively.

In Table 7, we report the relationship of digitalization and EI implementation captured by EI related patents. Almost indicators of digital business and digital public service have statistically significant and positive effects on EI related patents. However, the impacts of digital public services indicators are only statistically significant at 5% and 10% significance level compared to the significant at a 1% of digital business. The marginal effects of digital business and digital public services on EI implementation are portraited in Fig. 1.

The findings suggest the integration of digitalization into the firms' operation, production, selling and management process as well the benefits and advantages from digital public services promote firms to implement the EI. Hence, digitalization, especially implemented by the firms themselves, is a key driver of EI implementation. The sustainable development requires firms to comply with environmental standards and implement innovations promoting the environmental protection. When the sustainability becomes the top priority goal of countries, the governments of these countries should

Table 3
Cross sectional dependence tests and stationary tests

Variable (in level)	CD-test, Pesaran (2004)	Im-Pesaran-Shin test (Z-bar)	Variable (in difference)	Im-Pesaran-Shin test (Z-bar)
EI_ENTER	7.712***	4.135	DEI_ENTER	-2.524***
EI_ACT	4.561***	-0.453	DEI_ACT	-4.251***
EI_ISO	0.56	5.055	DEI_ISO	-4.224***
EI_PATENT	19.481***	-0.376	DEI_PATENT	-5.212***
EI_INP	0.184	-0.068	DEI_INP	-5.050***
EI_RD	8.126***	0.871	DEI_RD	-3.483***
EI_GOV	2.261**	-1.694**	DEI_GOV	-5.360***
EI_GREEN	0.454	9.812	DEI_GREEN	-2.015**
EI_ME	37.513***	-0.387	DEI_ME	-4.252***
DGDB_SO	5.672***	-0.237	DDGDB_SO	-4.722***
DGDB _ES	20.739***	-1.559**	DDGDB _ES	-5.225***
DGDB _TO	23.545***	-2.239**	DDGDB _TO	-5.606***
DGDB _ESWS	21.001***	-1.957**	DDGDB _ESWS	-4.702***
DGDB _B2C	26.777***	-3.063***	DDGDB _B2C	-3.845***
DGDB _CRP	20.739***	-1.559**	DDGDB _CRP	-5.225***
DGDPS_UC	31.737***	-2.834***	DDGDPS_UC	-4.793***
DGDPS _BM	16.161***	-2.249**	DDGDPS _BM	-3.437***
DGDPS _KE	16.364***	-3.042***	DDGDPS _KE	-4.513***
EG	42.070***	3.007	DEG	-3.698***
TS	14.973***	0.463	DTS	-3.241***
FDI	0.103	-4.056***	DFDI	-4.653***
IND	7.381***	0.247	DIND	-3.663***
EPI	12.463***	1.136	DEPI	-3.219***
NR	32.791***	4.124***	DNR	-2.238***
DM	0.034	9.771	DDM	-3.370***

Note: Regarding CD test, the null hypothesis is that the cross-section is independent. P-value is closed to zero, implying that data are correlated across panel groups. Regarding CIPS (Pesaran Panel Unit Root Test with cross-sectional and first difference mean), the null hypothesis is "panels are homogeneous non-stationary".

propose policies to accelerate the digital transformation process, especially to support firms to integrate the digital technologies in their activities.

Mechanism

It is essential to discover the existence of the relationship between digitalization and EI. But the urgency becomes even more intense in finding the transmission mechanism through which the digital transformation process has a favorable impact on the implementation of EI. These channels consist of specific investments (financialization and human resources) to trigger environmental activities (*EI_INP*); specific investments in R&D personnel and researchers (*EI_RD*); government environmental and energy R&D appropriations and outlays (*EI_GOV*); total value of green early-investments (*EI_GREEN*); and EI related media coverage (*EI_ME*). Our study highlights that a firm's own investments in EI, government's financial support and the public's awareness about the importance of EI significantly motivate firms, enhance their internal capacity to implement EI and the level of public's demands requiring them to perform it. To promote the prevalence of EIs among firms, the digital transformation process should have effects on these channels.

The analyses regarding impacts of digitalization on these channels are outlined in Tables A.2-A.6 in Appendix, respectively. Specifically, Table A.2 investigates the impacts of digitalization on investments to trigger EI activities. Regarding seven indicators of digital business, most of them have positive effects on investments to trigger EI activities, but only the impact of Cloud usage is statistically significant at 1% significance level. Similarly, regarding digital public services, only key enablers (*DGDPS _KE*) is statistically significant and substantially positive at a 1% significance level. We then examine the impacts of digitalization on investments on R&D personnel and researchers and report the results in Table A.3. All aspects of digital business have statistically significant impacts on investments on R&D personnel and researchers, except for e-Commerce Web Sales and e-Commerce Turnover. By contrast, e-Business, Cloud usage, is reported to statistically significant and negatively affect R&D personnel and researchers. This result implies that an increase in Cloud usage results in a drop of investments on R&D personnel and researchers. In terms of digital public services, the influence of Business Mobility is statistically significant at 1% significance level and negative, opposite to that of User Centricity and Key Enablers. Our study reveals that only key enablers play a critical role in enhancing investments on R&D personnel and researchers in our sample of European countries.

The next channel is the government environmental, and the results are reported in Table A.4. Notably, digital business is found to have statistically insignificant effects on government environmental and energy R&D appropriations and outlays. Meanwhile, regarding digital public services indicators, only the impact of key enablers is statistically significant and positive, while the remaining variables are statistically insignificant. Following up, the research investigates the impacts of digitalization on environmental early-stage investments. The results reported in Table A.5 show that most digital business indicators have statistically significant and positive effects on *EI_GREEN*, except for Online Sellings. Similarly, digital public services have statistically and positive influence on *EI_GREEN*. Notably, the effect of User Centricity is the largest, followed by Key Enablers and Business Mobility. The finding implies that the digital public services play an essential to promote environmental early-stage investments, especially the public feeling about the friendliness of the digital procedure as captured by User Centricity. Finally, we report our findings about impacts of digitalization on the public's EI awareness. As displayed in Table A.6, digital business and digital public services both have statistically significant and positive impacts on this variable. Visually, the effects of digitalization on these variables are displayed in Fig. 2.

Discussions

Our study is a comprehensive analysis of the nexus between digitalization and EI performance. We provide the theoretical framework to explain the link between digitalization and environmental performance. Our estimation results highlight the importance of digital businesses, including e-commerce sales, e-commerce turnover, e-

Table 4
Impacts of digitalization on EI implementation: Enterprises with EIs

—	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Enterprises with EI: EI_Enter									
	Digital Business							**Digital Public Services**		
VARIABLES	Online Sellings	e-Commerce Sales	e-Commerce Web Sales	e-Commerce Turnover	e-Commerce B2C Sales	e-Business: CRP	e-Business: iCloud	eGOV: User Centricity	eGOV: Business Mobility	eGOV: Key Enablers
—	—	—	—	—	—	—	—	—	—	—
L.DG_DB	-0.34	1.12***	0.53	1.18***	0.23	1.12***	0.37**			
	(0.269)	(0.318)	(0.377)	(0.223)	(0.449)	(0.318)	(0.187)			
L.DG_DPS								0.24	0.07	0.05
								(0.176)	(0.098)	(0.051)
L.EG	0.77***	0.77***	0.79***	0.77***	0.72***	0.77***	0.89***	0.74***	0.74***	0.75***
	(0.093)	(0.095)	(0.092)	(0.096)	(0.118)	(0.095)	(0.124)	(0.102)	(0.107)	(0.101)
L.TS	-18.05***	-20.03***	-19.66***	-19.59***	-21.51***	-20.03***	-23.92***	-19.10***	-19.44***	-19.33***
	(3.078)	(2.957)	(2.853)	(2.611)	(3.208)	(2.957)	(2.859)	(2.555)	(2.416)	(2.520)
L.FDI	5.02	5.72	4.83	8.33	10.43*	5.72	17.92**	4.39	4.51	3.91
	(5.750)	(6.232)	(5.910)	(6.677)	(5.396)	(6.232)	(8.299)	(5.981)	(5.672)	(5.853)
L.IND	188.84***	127.19***	164.65***	124.74***	148.57***	127.19***	206.59***	159.50***	165.91***	166.24***
	(25.528)	(29.916)	(26.485)	(26.347)	(23.811)	(29.916)	(29.705)	(18.921)	(19.438)	(20.410)
L.EPI	-0.30	-0.91*	-0.66	-0.91**	-0.83*	-0.91*	-0.15	-0.88	-0.66	-0.69
	(0.482)	(0.499)	(0.453)	(0.457)	(0.484)	(0.499)	(0.428)	(0.553)	(0.448)	(0.464)
L.NR	-28.94***	-31.31***	-30.97***	-30.60***	-38.35***	-31.31***	-31.79***	-35.39***	-35.21***	-35.11***
	(3.798)	(3.854)	(3.864)	(3.747)	(4.468)	(3.854)	(3.108)	(4.492)	(4.385)	(4.178)
L.DM	-12.73*	-7.09	-9.51	-7.85	-17.13**	-7.09	-11.47	-14.24*	-14.21*	-14.22*
	(7.059)	(7.666)	(7.468)	(7.706)	(8.116)	(7.666)	(7.776)	(7.859)	(8.094)	(7.918)
Observations	192	192	192	192	143	192	104	168	168	168
Number of countries	24	24	24	24	24	24	24	24	24	24

Standard errors in parentheses
*** p<0.01
** p<0.05
* p<0.1

Table 5
Impacts of digitalization on EI implementation: EI activities

—	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	EI activities: EI_ACT									
	Digital Business							**Digital Public Services**		
VARIABLES	Online Sellings	e-Commerce Sales	e-Commerce Web Sales	e-Commerce Turnover	e-Commerce B2C Sales	e-Business: CRP	e-Business: iCloud	eGOV: User Centricity	eGOV: Business Mobility	eGOV: Key Enablers
—	—	—	—	—	—	—	—	—	—	—
L.DG_DB	-0.16	1.81***	1.29***	1.86***	0.58	1.81***	0.36**			
	(0.139)	(0.261)	(0.289)	(0.196)	(0.401)	(0.261)	(0.156)			
L.DG_DPS								0.30*	0.35***	0.18***
								(0.152)	(0.097)	(0.033)
L.EG	0.59***	0.57***	0.60***	0.57***	0.53***	0.57***	0.50***	0.57***	0.51***	0.59***
	(0.099)	(0.095)	(0.098)	(0.102)	(0.115)	(0.095)	(0.137)	(0.104)	(0.121)	(0.097)
L.TS	-15.31***	-17.46***	-17.42***	-16.73***	-14.32***	-17.46***	-14.43***	-14.85***	-15.26***	-14.89***
	(1.992)	(2.178)	(2.268)	(1.912)	(2.390)	(2.178)	(2.413)	(1.966)	(2.255)	(1.923)
L.FDI	6.48*	8.89**	8.22*	12.94***	6.50	8.89**	11.97	5.48	7.33*	4.60
	(3.833)	(4.392)	(4.209)	(4.846)	(4.089)	(4.392)	(9.638)	(3.548)	(4.033)	(3.270)
L.IND	255.19***	163.47***	209.69***	161.68***	214.87***	163.47***	224.34***	229.53***	245.31***	243.60***
	(20.216)	(20.676)	(18.902)	(19.039)	(18.504)	(20.676)	(26.866)	(16.376)	(17.052)	(13.979)
L.EPI	1.36***	0.62	0.89**	0.63*	1.34***	0.62	0.99***	0.95**	1.05***	1.01***
	(0.357)	(0.412)	(0.403)	(0.339)	(0.350)	(0.412)	(0.299)	(0.461)	(0.403)	(0.350)
L.NR	-15.76***	-17.78***	-17.60***	-16.64***	-18.53***	-17.78***	-21.76***	-19.28***	-22.33***	-20.80***
	(2.155)	(2.337)	(2.287)	(2.084)	(2.882)	(2.337)	(2.322)	(2.919)	(3.155)	(2.509)
L.DM	5.86	13.32***	10.86**	11.95**	8.95	13.32***	10.44	6.81	6.71	6.72
	(5.081)	(4.963)	(4.855)	(5.173)	(5.647)	(4.963)	(7.029)	(5.139)	(5.964)	(5.252)
Observations	192	192	192	192	143	192	104	168	168	168
Number of countries	24	24	24	24	24	24	24	24	24	24

Standard errors in parentheses
*** p<0.01
** p<0.05
* p<0.1

Table 6
Impacts of digitalization on EI implementation: Enterprises with new 14001 registration

—	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Enterprises with new ISO 14001 registrations: EI_ISO									
	Digital Business							**Digital Public Services**		
VARIABLES	Online Sellings	e-Commerce Sales	e-Commerce Web Sales	e-Commerce Turnover	e-Commerce B2C Sales	e-Business: CRP	e-Business: iCloud	eGOV: User Centricity	eGOV: Business Mobility	eGOV: Key Enablers
—	—	—	—	—	—	—	—	—	—	—
L.DG_DB	0.41	2.59***	1.68***	2.52***	1.28	2.59***	0.58			
	(0.269)	(0.361)	(0.369)	(0.256)	(0.829)	(0.361)	(0.366)			
L.DG_DPS								0.60***	0.32**	0.30***
								(0.199)	(0.131)	(0.070)
L.EG	0.42	0.37	0.41	0.37	0.54*	0.37	0.84*	0.45	0.40	0.49
	(0.288)	(0.285)	(0.288)	(0.291)	(0.324)	(0.285)	(0.444)	(0.319)	(0.328)	(0.307)
L.TS	-37.36***	-38.65***	-38.38***	-37.54***	-36.70***	-38.65***	-31.91***	-35.06***	-35.90***	-35.24***
	(2.471)	(2.714)	(2.596)	(2.380)	(3.362)	(2.714)	(3.441)	(2.813)	(2.891)	(2.727)
L.FDI	9.71	15.33	14.08	20.59*	10.64	15.33	4.87	12.32	13.54	10.68
	(11.440)	(10.715)	(10.683)	(10.950)	(13.076)	(10.715)	(15.012)	(11.160)	(11.629)	(11.243)
L.IND	129.67***	12.29	83.57**	16.29	106.55*	12.29	206.02***	129.56***	149.69***	155.35***
	(32.133)	(40.727)	(37.489)	(40.732)	(58.756)	(40.727)	(66.023)	(38.317)	(36.709)	(34.614)
L.EPI	-0.97	-1.62**	-1.18*	-1.55***	-0.49	-1.62**	1.35*	-1.23	-0.79	-1.03
	(0.622)	(0.653)	(0.619)	(0.577)	(0.758)	(0.653)	(0.781)	(0.815)	(0.726)	(0.700)
L.NR	-26.88***	-26.67***	-26.28***	-25.04***	-28.20***	-26.67***	-21.72***	-30.40***	-31.75***	-32.64***
	(5.362)	(3.752)	(3.874)	(3.609)	(4.840)	(3.752)	(6.171)	(5.391)	(5.360)	(5.463)
L.DM	-53.39***	-45.58***	-49.63***	-47.92***	-42.15**	-45.58***	-26.35	-51.08***	-51.09***	-51.21***
	(14.642)	(13.910)	(14.051)	(14.379)	(17.137)	(13.910)	(19.500)	(16.778)	(16.583)	(16.583)
Observations	192	192	192	192	143	192	104	168	168	168
Number of countries	24	24	24	24	24	24	24	24	24	24

Standard errors in parentheses
*** p<0.01
** p<0.05
* p<0.1

Table 7
Impacts of digitalization on EI implementation: EI related patents

—	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	EI related patents: EI_Patent									
	Digital Business							**Digital Public Services**		
VARIABLES	Online Sellings	e-Commerce Sales	e-Commerce Web Sales	e-Commerce Turnover	e-Commerce B2C Sales	e-Business: CRP	e-Business: iCloud	eGOV: User Centricity	eGOV: Business Mobility	eGOV: Key Enablers
—	—	—	—	—	—	—	—	—	—	—
L.DG_DB	1.60***	5.82***	6.71***	5.43***	8.29***	5.82***	2.42***			
	(0.409)	(0.824)	(0.999)	(0.462)	(1.663)	(0.824)	(0.376)			
L.DG_DPS								0.81**	0.19*	0.05
								(0.342)	(0.095)	(0.103)
L.EG	3.10***	2.95***	3.04***	2.95***	3.41***	2.95***	2.57***	3.10***	3.05***	3.09***
	(0.258)	(0.315)	(0.335)	(0.300)	(0.439)	(0.315)	(0.278)	(0.266)	(0.272)	(0.273)
L.TS	-54.34***	-55.39***	-58.52***	-52.75***	-64.22***	-55.39***	-42.90***	-49.58***	-48.43***	-48.33***
	(5.940)	(8.425)	(9.284)	(6.930)	(10.435)	(8.425)	(5.321)	(5.541)	(6.149)	(6.155)
L.FDI	-7.46	7.42	9.80	18.35	11.70	7.42	-14.89	-5.13	-2.73	-4.07
	(11.644)	(11.049)	(11.435)	(12.077)	(13.299)	(11.049)	(18.780)	(10.643)	(11.165)	(11.039)
L.IND	101.23**	-148.73***	-83.51*	-128.03***	-130.79***	-148.73***	-71.61	135.30***	126.90***	123.85***
	(46.220)	(47.590)	(47.889)	(40.759)	(36.775)	(47.590)	(85.636)	(49.044)	(46.928)	(47.197)
L.EPI	-2.96***	-3.98***	-3.82***	-3.76***	-3.44***	-3.98***	-3.70***	-0.81	-1.80*	-1.76**
	(0.860)	(1.192)	(1.228)	(0.891)	(1.107)	(1.192)	(0.760)	(1.045)	(0.925)	(0.843)
L.NR	4.83*	8.50*	6.99	12.18**	35.00***	8.50*	5.43	20.51***	14.62***	16.12***
	(2.571)	(5.092)	(5.159)	(5.275)	(10.349)	(5.092)	(6.962)	(6.073)	(4.549)	(4.559)
L.DM	10.44	25.06***	25.66***	19.11***	30.08**	25.06***	14.46	9.12	8.83	8.87
	(11.041)	(7.558)	(7.920)	(7.192)	(12.171)	(7.558)	(11.265)	(11.160)	(9.994)	(10.479)
Observations	192	192	192	192	143	192	104	168	168	168
Number of countries	24	24	24	24	24	24	24	24	24	24

Standard errors in parentheses
*** p<0.01
** p<0.05
* p<0.1

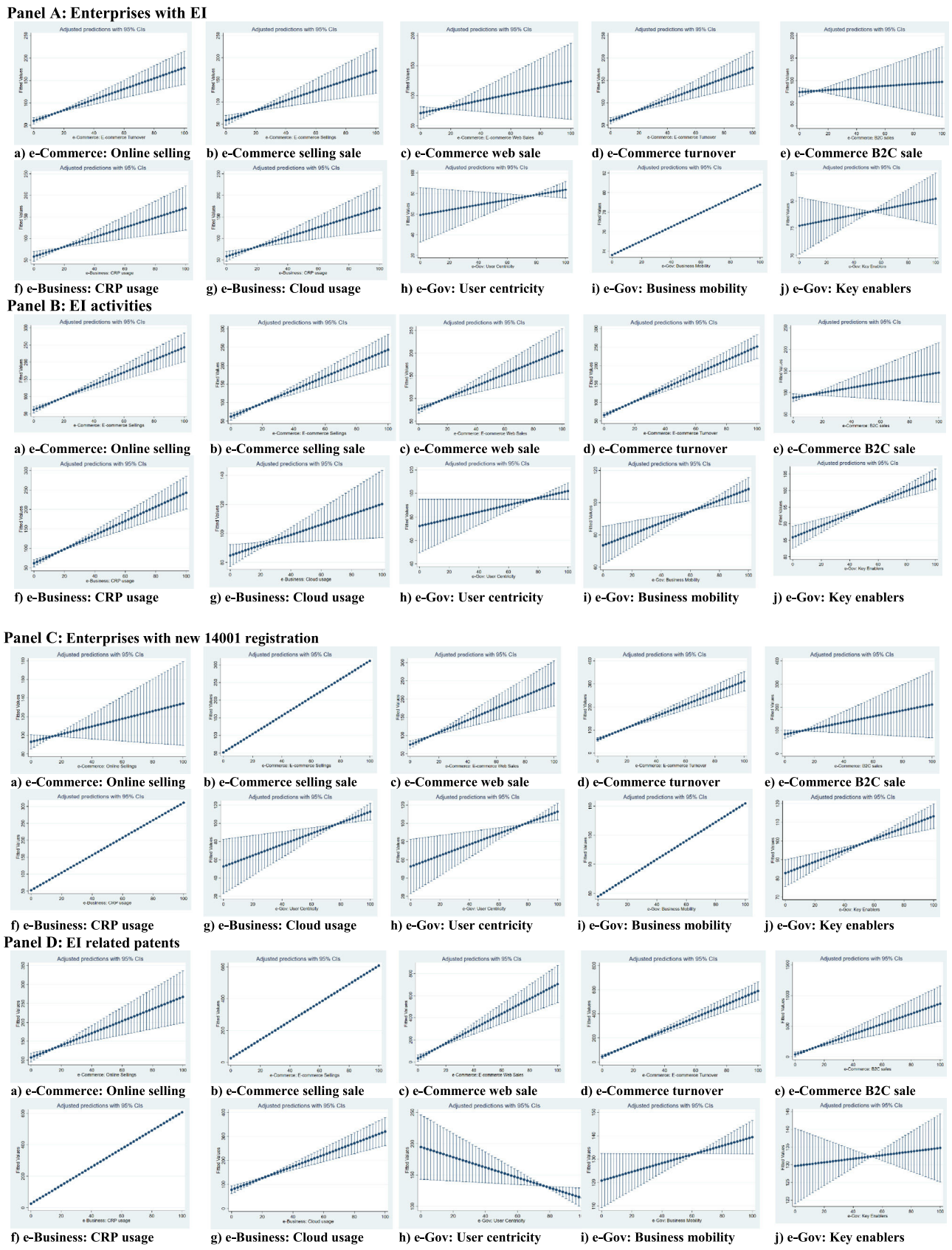

Fig. 1. Predictive margin of digitalization, Panel A: Enterprises with EI, Panel B: EI activities, Panel C: Enterprises with new 14001 registration, Panel D: EI related patents

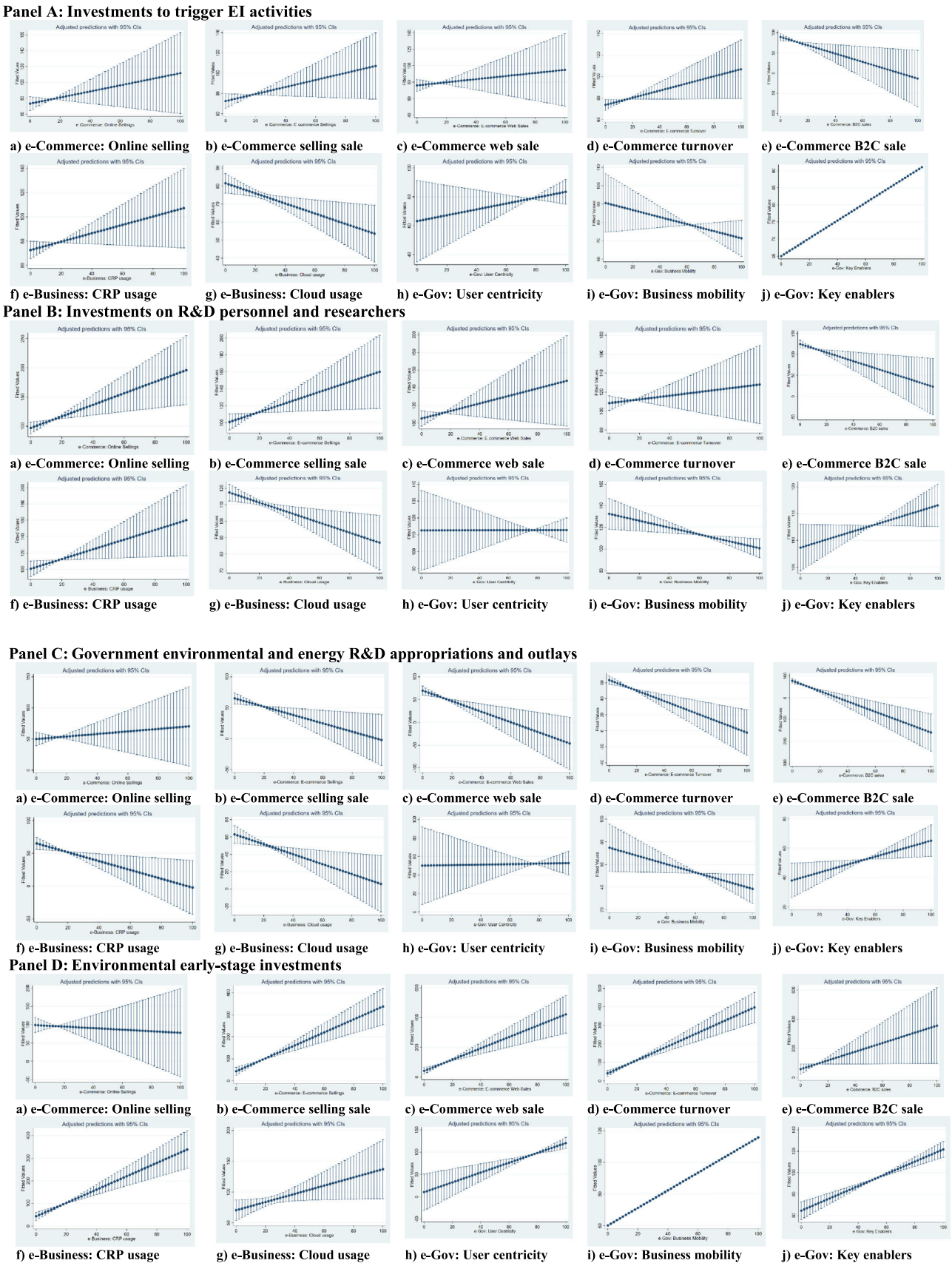

Fig. 2. Predictive margin of digitalization: Mechanisms, Panel A: Investments to trigger EI activities, Panel B: Investments on R&D personnel and researchers, Panel C: Government environmental and energy R&D appropriations and outlays, Panel D: Environmental early-stage investments, Panel E: EI awareness

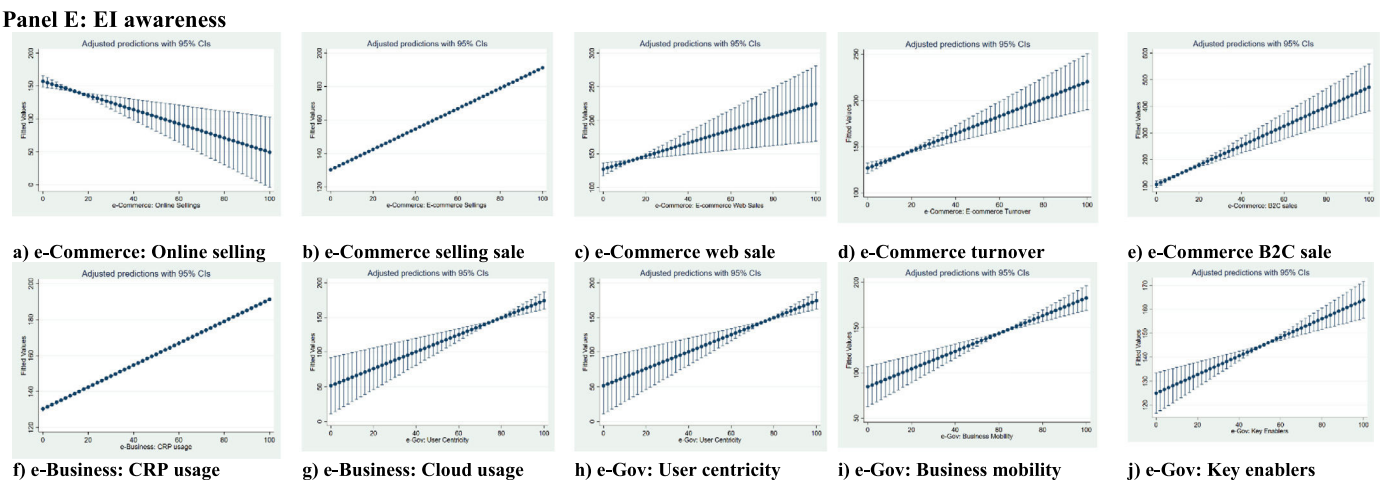

Fig. 2. Continued.

business (including CRP and cloud usage) in improving the EI investments, EI activities, EI related patents, and the number of enterprises with new ISO 14001 registration during the 2011-2019 period in the European region. Digital public services are less crucial in promoting EI performance as compared to digital businesses as these variables are not statistically significant in some cases. We also provide empirical evidence on the mechanism to explain the improvements in EI. Digitalization appears to have favorable impacts on EI investments of firms and government's financial support, and the public's awareness regarding the importance of EI. Our findings provide empirical evidence to support the view of Schumpeterian, Arrowian, and stakeholders to explain the motivations behind EI implementations. These views make us believe that a firm's internal capacity, government's financial support, and the public's awareness of the importance of EI significantly motivate firms and enhance their internal capacity to implement EI and the level of public demands requiring them to perform it. The digital transformation process considerably influences these channels in order to enhance the prevalence of EIs among firms. Like many previous studies, digitalization leads to the use of knowledge (Bouncken & Barwinski, 2021; Vuori et al., 2019), resulting in increased productivity (Chou et al., 2014; Ribeiro-Navarrete et al., 2021; Shujahat et al., 2018, 2019) and efficiency (Porter & Heppelmann, 2015), and then environmental sustainability (Alam & Murad, 2020; Blok et al., 2015; Sarkodie et al., 2019). Digitalization is an essential route to pollution control and sustainable development (Bolton & Hannon, 2016; Gu et al., 2019; Sarkodie et al., 2019).

Conclusions

This article investigates the effects of the digital transformation process on the performance of EIs in the private and public sectors. To capture the performance of EIs in 24 European countries, four different measures, including the percentage of enterprises investing in EI (percent of surveyed firms), the percentage of enterprises implementing EI activities (resource efficiency actions, sustainable products, or ISO 14001 certificates) measured, and the number of enterprises with new ISO 14001 certificates are employed. We have four measures of e-Commerce, including online selling, e-Commerce sales, e-Commerce web sales, and e-Commerce turnover. We also have two measures of e-Business, including CRM use and cloud use. Indicators of digital public service performance include user centricity, business mobility, and key enablers. We have developed a theoretical framework to explain the relationship between digitalization and environmental performance. Both the panel corrected standard error (PCSE) model, and the feasible generalized least squares (FGLS) model for the panel data featuring the cross-sectional dependency are employed to empirically investigate this linkage. The relevance of both digital enterprises and digital public services in enhancing EI performance in the European area from 2011 to 2019 is highlighted by our estimation results. In particular, our study emphasizes the significance of digital businesses, including e-commerce sales, e-commerce turnover, e-business (including CRP and cloud usage) in improving the EI investments, EI activities, EI related patents, and the number of enterprises with new ISO 14001 registration during the 2011-2019 period in the European region. The role of digital public services in promoting EI performance is relatively less important than that of digital businesses since these variables are not statistically significant in some cases. We also find a positive relationship of digitalization on EI investments by enterprises and governments, as well as public awareness of the relevance of EIs.

Our research findings suggest that European countries should accelerate the digital economy, strengthen the construction of digital infrastructure, and promote digital implementation. Governments should recognize and seize the opportunities presented by digital technology to establish a more effective legislative framework for increasing company technology investment and public attention to environmental improvements.

Some of the other policies that will likely be discussed are how the government can utilize existing innovation and technology most efficiently, change consumption patterns, and improve production processes. The following are additional recommendations for European Union governments. As a first step, climate and environmental data management should be optimized and standardized. Secondly, information barriers must be removed in order to build a circular or green economy. Thirdly, governments in Europe should support and accelerate the development of a green economy and society by developing digital solutions that will raise public awareness of the importance of digitalization.

Several limitations should be considered when interpreting the findings of our research. To begin with, we utilized archival data gathered exclusively for the European Union. It is essential to consider the role of digitalization in improving the environmental issues in developing countries, where there have been warnings about environmental degradation and the necessity of EI (Ha, Nam, et al., 2021). There are, however, no surveys that follow stringent guidelines for collecting information about the digital transformation process in developing economies (Ha, 2022). Furthermore, due to external factors, digitalization may adversely affect the implementation of EI. In assessing the effectiveness of government policies, it is important to consider economic development and complexity. This study is

expected to provide insights to economists and policymakers in designing policies that promote digital transformation and enhance the implementation of EI. In a future study, we may explore the available data sources so as to collect more information on digitalization in developing countries as well as examine the role of digitalization in this area.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Compliance with Ethical Standards

- Disclosure of potential conflicts of interest
- Research involving Human Participants and/or Animals
- Informed consent

Contributions

Le Thanh Ha, Bui Quang Hung and Nguyen Thi Hong Nhung, equally contributed to all stages of preparing, drafting, writing and revising this review article. Bui Quang Hung have made a substantial, direct, and intellectual contribution to the work during different preparation stages. Nguyen Thi Hong Nhung read, revised and approved the final version of this manuscript.

Data availability statement

Data available on request due to privacy/ethical restrictions

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Table A.1, Table A.2, Table A.3, Table A.4, Table A.5, Table A.6

Table A.1
Countries in the sample

EU countries		
Austria	Hungary	Portugal
Belgium	Iceland	Slovak Republic
Bulgaria	Ireland	Slovenia
Czech Republic	Italy	Sweden
Denmark	Lithuania	
Spain	Luxembourg	
Estonia	Latvia	
United Kingdom	Malta	
Greece	Netherlands	
Croatia	Poland	

Table A.2
Impacts of digitalization on investments to trigger EI activities

—	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	EI investments: EI_INP									
	Digital Business							Digital Public Services		
VARIABLES	Online Sellings	e-Commerce Sales	e-Commerce Web Sales	e-Commerce Turnover	e-Commerce B2C Sales	e-Business: CRP	e-Business: iCloud	eGOV: User Centricity	eGOV: Business Mobility	eGOV: Key Enablers
—	—	—	—	—	—	—	—	—	—	—
L.DG_DB	0.38	0.35*	0.19	0.33**	-1.03	0.35*	0.28***			
	(0.305)	(0.204)	(0.263)	(0.165)	(0.401)	(0.204)	(0.106)			
L.DG_DPS								0.20	-0.19	0.26***
								(0.188)	(0.132)	(0.074)
L.EG	1.00***	0.98***	0.98***	0.98***	0.81***	0.98***	0.78***	0.90***	0.95***	0.93***
	(0.148)	(0.151)	(0.151)	(0.151)	(0.179)	(0.151)	(0.189)	(0.160)	(0.163)	(0.159)
L.TS	-6.95**	-6.22**	-6.14*	-6.07*	-0.97	-6.22**	-4.10	-4.44	-4.73	-4.15
	(3.306)	(3.170)	(3.285)	(3.108)	(4.292)	(3.170)	(5.964)	(3.448)	(3.599)	(3.472)
L.FDI	-22.82***	-20.96**	-21.19**	-20.28**	-20.25**	-20.96**	-15.03	-19.57**	-21.13**	-20.51**
	(8.712)	(8.626)	(8.608)	(8.553)	(10.074)	(8.626)	(12.973)	(8.680)	(8.778)	(8.416)
L.IND	89.83***	80.98***	91.71***	81.82***	133.80***	80.98***	125.69***	98.78***	96.41***	115.49***
	(17.351)	(21.359)	(21.304)	(20.199)	(18.430)	(21.359)	(25.585)	(20.783)	(17.947)	(19.865)
L.EPI	3.43***	3.55***	3.62***	3.56***	4.39***	3.55***	4.75***	3.60***	3.94***	3.44***
	(0.599)	(0.561)	(0.576)	(0.536)	(0.510)	(0.561)	(0.751)	(0.538)	(0.554)	(0.456)
L.NR	18.14***	19.74***	19.82***	19.95***	16.74***	19.74***	21.54**	18.59***	21.90***	15.29***
	(4.230)	(3.454)	(3.480)	(3.458)	(5.298)	(3.454)	(8.630)	(3.954)	(4.066)	(3.523)
L.DM	3.34	2.95	2.29	2.62	6.16	2.95	7.34	2.82	2.96	2.63
	(6.824)	(6.484)	(6.287)	(6.639)	(6.836)	(6.484)	(9.068)	(6.807)	(6.945)	(6.731)
Observations	192	192	192	192	143	192	104	168	168	168
Number of countries	24	24	24	24	24	24	24	24	24	24

Standard errors in parentheses
*** p<0.01
** p<0.05
* p<0.1

Table A.3
Impacts of digitalization on investments on R&D personnel and researchers

—	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Investments on R&D personnel and researchers: EI_RD									
	Digital Business							**Digital Public Services**		
VARIABLES	Online Sellings	e-Commerce Sales	e-Commerce Web Sales	e-Commerce Turnover	e-Commerce B2C Sales	e-Business: CRP	e-Business: iCloud	eGOV: User Centricity	eGOV: Business Mobility	eGOV: Key Enablers
—	—	—	—	—	—	—	—	—	—	—
L.DG_DB	0.99***	0.59**	0.43	0.20	1.02***	0.59**	-0.30***			
	(0.352)	(0.269)	(0.304)	(0.250)	(0.389)	(0.269)	(0.109)			
L.DG_DPS								0.00	-0.32***	0.08*
								(0.158)	(0.117)	(0.042)
L.EG	1.12***	1.07***	1.08***	1.08***	0.84***	1.07***	0.85***	0.97***	1.03***	0.97***
	(0.138)	(0.142)	(0.145)	(0.144)	(0.112)	(0.142)	(0.107)	(0.129)	(0.129)	(0.127)
L.TS	1.52	3.70	3.71	4.15	11.37***	3.70	8.85***	6.36**	6.35**	6.53**
	(3.532)	(3.412)	(3.539)	(3.507)	(2.367)	(3.412)	(2.636)	(2.945)	(3.189)	(2.918)
L.FDI	-13.78**	-9.49*	-9.70*	-9.72*	-12.27***	-9.49*	-23.58***	-9.88**	-11.97**	-10.08**
	(6.556)	(5.542)	(5.544)	(5.409)	(4.294)	(5.542)	(8.137)	(4.643)	(4.721)	(4.543)
L.IND	153.57***	145.36***	160.41***	164.77***	198.87***	145.36***	165.89***	175.32***	165.69***	179.34***
	(17.992)	(25.869)	(25.245)	(25.447)	(25.038)	(25.869)	(30.723)	(22.260)	(20.182)	(20.825)
L.EPI	3.66***	4.08***	4.17***	4.23***	5.48***	4.08***	5.86***	4.76***	4.96***	4.65***
	(0.653)	(0.608)	(0.623)	(0.612)	(0.362)	(0.608)	(0.460)	(0.571)	(0.552)	(0.506)
L.NR	0.90	5.22**	5.28**	5.62**	-0.04	5.22**	2.55	3.61	7.60***	2.36
	(2.800)	(2.334)	(2.343)	(2.380)	(3.074)	(2.334)	(3.070)	(2.712)	(2.782)	(2.457)
L.DM	-9.74*	-11.87**	-12.67**	-13.51**	-10.02**	-11.87**	-11.96*	-12.27**	-12.12**	-12.34**
	(5.781)	(5.520)	(5.215)	(5.514)	(4.626)	(5.520)	(6.857)	(4.984)	(4.737)	(4.957)
Observations	192	192	192	192	143	192	104	168	168	168
Number of countries	24	24	24	24	24	24	24	24	24	24

Standard errors in parentheses
*** p<0.01
** p<0.05
* p<0.1

Table A.4
Impacts of digitalization on government environmental and energy R&D appropriations and outlays

—	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Government environmental and energy R&D appropriations and outlays: EI_GOV									
	Digital Business							**Digital Public Services**		
VARIABLES	Online Sellings	e-Commerce Sales	e-Commerce Web Sales	e-Commerce Turnover	e-Commerce B2C Sales	e-Business: CRP	e-Business: iCloud	eGOV: User Centricity	eGOV: Business Mobility	eGOV: Key Enablers
—	—	—	—	—	—	—	—	—	—	—
L.DG_DB	0.20	-0.67	-1.16	-0.65	-2.36	-0.67	-0.57			
	(0.380)	(0.256)	(0.344)	(0.172)	(0.488)	(0.256)	(0.218)			
L.DG_DPS								0.03	-0.36	0.27**
								(0.278)	(0.172)	(0.114)
L.EG	0.44***	0.44***	0.43***	0.44***	0.27**	0.44***	0.41**	0.40**	0.47***	0.42***
	(0.151)	(0.146)	(0.144)	(0.146)	(0.133)	(0.146)	(0.176)	(0.162)	(0.178)	(0.154)
L.TS	-17.93***	-16.74***	-15.89***	-17.03***	-11.64**	-16.74***	-16.16**	-17.04***	-17.09***	-16.49***
	(3.972)	(3.769)	(3.827)	(3.713)	(5.101)	(3.769)	(6.949)	(4.401)	(4.536)	(4.563)
L.FDI	-5.05	-5.46	-6.41	-6.82	-7.21	-5.46	-7.82	-3.45	-5.88	-4.17
	(5.777)	(5.391)	(5.246)	(5.569)	(5.647)	(5.391)	(6.643)	(5.956)	(5.220)	(5.995)
L.IND	107.46***	144.44***	149.40***	143.39***	179.83***	144.44***	140.12***	111.44***	100.87***	125.62***
	(20.792)	(28.224)	(28.703)	(24.405)	(24.992)	(28.224)	(31.997)	(23.823)	(22.740)	(27.882)
L.EPI	2.67***	3.04***	3.13***	3.02***	3.45***	3.04***	3.67***	2.64***	2.89***	2.27***
	(0.620)	(0.591)	(0.602)	(0.563)	(0.638)	(0.591)	(1.028)	(0.559)	(0.584)	(0.488)
L.NR	15.76**	17.19***	17.68***	16.77***	5.76	17.19***	13.38	13.75**	18.42***	9.53
	(6.952)	(5.991)	(6.140)	(5.889)	(9.310)	(5.991)	(14.232)	(6.643)	(5.936)	(6.245)
L.DM	15.82**	12.43**	11.09**	13.03**	16.72**,*	12.43**	22.64***	15.43**	15.61**	15.19**
	(6.371)	(5.621)	(5.512)	(5.478)	(4.044)	(5.621)	(8.196)	(6.119)	(6.376)	(5.997)
Observations	192	192	192	192	143	192	104	168	168	168
Number of countries	24	24	24	24	24	24	24	24	24	24

Standard errors in parentheses
*** p<0.01
** p<0.05
* p<0.1

Table A.5
Impacts of digitalization on environmental early-stage investments

—	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Environmental early-stage investments: EI_GREEN									
	Digital Business							**Digital Public Services**		
VARIABLES	Online Sellings	e-Commerce Sales	e-Commerce Web Sales	e-Commerce Turnover	e-Commerce B2C Sales	e-Business: CRP	e-Business: iCloud	eGOV: User Centricity	eGOV: Business Mobility	eGOV: Key Enablers
—	—	—	—	—	—	—	—	—	—	—
L.DG_DB	-0.21	2.95***	3.80***	3.56***	2.97**	2.95***	0.67**			
	(0.717)	(0.517)	(0.754)	(0.497)	(1.494)	(0.517)	(0.320)			
L.DG_DPS								1.10***	0.56**	0.57***
								(0.273)	(0.225)	(0.080)
L.EG	2.44***	2.41***	2.45***	2.40***	2.41***	2.41***	1.79*	2.30***	2.22***	2.38***
	(0.639)	(0.660)	(0.660)	(0.651)	(0.866)	(0.660)	(1.071)	(0.698)	(0.717)	(0.716)
L.TS	10.83	7.48	5.38	8.40	8.59	7.48	8.93	13.87	12.34	13.59
	(10.432)	(10.094)	(10.057)	(9.943)	(15.929)	(10.094)	(18.305)	(11.172)	(11.097)	(11.296)
L.FDI	-93.67***	-89.56**	-87.65**	-80.98**	-75.29	-89.56**	-22.66	-86.76**	-84.72**	-89.80**
	(35.987)	(36.205)	(36.240)	(35.385)	(47.221)	(36.205)	(60.189)	(38.194)	(38.225)	(37.519)
L.IND	-83.65	-231.82***	-211.60***	-260.29***	-128.82	-231.82***	2.35	-84.80	-48.91	-36.81
	(60.272)	(60.733)	(62.207)	(55.510)	(78.569)	(60.733)	(97.206)	(69.342)	(70.571)	(68.272)
L.EPI	5.29***	4.11***	4.09***	3.96***	5.20***	4.11***	6.01***	4.36***	5.19***	4.70***
	(1.216)	(0.956)	(0.953)	(1.017)	(1.336)	(0.956)	(1.634)	(1.098)	(1.113)	(1.018)
L.NR	57.28***	54.26***	53.18***	56.09***	80.65***	54.26***	81.04***	60.85***	58.73***	56.47***
	(11.568)	(10.538)	(10.522)	(10.735)	(13.873)	(10.538)	(10.661)	(10.074)	(11.375)	(10.052)
L.DM	-9.55	2.35	3.96	1.65	4.51	2.35	-2.24	-6.92	-6.91	-7.17
	(19.830)	(21.486)	(21.413)	(21.615)	(28.433)	(21.486)	(28.463)	(21.696)	(22.684)	(22.279)
Observations	192	192	192	192	143	192	104	168	168	168
Number of countries	24	24	24	24	24	24	24	24	24	24

Standard errors in parentheses
*** p<0.01
** p<0.05
* p<0.1

Table A.6
Impacts of digitalization on the public's EI awareness

—	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Environmental early-stage investments: EI_ME									
	Digital Business							**Digital Public Services**		
VARIABLES	Online Sellings	e-Commerce Sales	e-Commerce Web Sales	e-Commerce Turnover	e-Commerce B2C Sales	e-Business: CRP	e-Business: iCloud	eGOV: User Centricity	eGOV: Business Mobility	eGOV: Key Enablers
—	—	—	—	—	—	—	—	—	—	—
L.DG_DB	1.08***	0.61**	0.98***	0.93***	3.65***	0.61**	1.73***			
	(0.319)	(0.250)	(0.335)	(0.183)	(0.514)	(0.250)	(0.194)			
L.DG_DPS								1.23***	0.98***	0.39***
								(0.271)	(0.182)	(0.082)
L.EG	0.87***	0.90***	0.91***	0.90***	1.33***	0.90***	1.07***	1.06***	0.90***	1.13***
	(0.177)	(0.181)	(0.179)	(0.178)	(0.177)	(0.181)	(0.169)	(0.147)	(0.147)	(0.161)
L.TS	11.53***	7.99***	7.31***	8.07***	2.73	7.99***	9.95*	9.40***	7.70**	8.53***
	(2.770)	(2.509)	(2.502)	(2.432)	(2.939)	(2.509)	(5.319)	(2.579)	(3.886)	(2.553)
L.FDI	-21.97*	-24.60*	-23.86*	-22.08*	-21.89*	-24.60*	-56.65***	-26.13**	-21.51*	-28.90**
	(12.277)	(13.393)	(13.246)	(13.156)	(11.617)	(13.393)	(17.822)	(11.824)	(11.270)	(13.318)
L.IND	-354.31***	-406.42***	-408.54***	-422.00***	-491.93***	-406.42***	-527.57***	-405.94***	-354.98***	-365.03***
	(29.426)	(38.567)	(36.835)	(35.141)	(37.924)	(38.567)	(44.606)	(36.398)	(32.118)	(40.082)
L.EPI	0.77	-0.14	-0.20	-0.24	-0.54	-0.14	-1.44***	-1.39**	-0.68	-0.64
	(0.570)	(0.539)	(0.517)	(0.496)	(0.428)	(0.539)	(0.540)	(0.649)	(0.567)	(0.538)
L.NR	16.89**	11.34*	10.96*	11.70**	33.71***	11.34*	20.19***	10.91*	4.07	10.04
	(7.249)	(5.957)	(6.007)	(5.931)	(8.326)	(5.957)	(7.648)	(6.401)	(6.139)	(6.499)
L.DM	-5.47	1.50	2.47	1.94	20.18**	1.50	8.72	3.03	2.86	2.98
	(10.447)	(9.586)	(9.617)	(9.507)	(9.328)	(9.586)	(8.970)	(10.847)	(8.320)	(10.522)
Observations	192	192	192	192	143	192	104	168	168	168
Number of countries	24	24	24	24	24	24	24	24	24	24

Standard errors in parentheses
*** p<0.01,
** p<0.05,
* p<0.1

References

Abdul K, Hangjung Z, Ananth C. (2021). Digital transformation and environmental sustainability. MDPI Sustainability 13:1530. https://www.mdpi.com/2071-1050/13/3/1530

Ackermann, F., & Eden, C. (2011). Strategic Management of stakeholders: Theory and practice. *Long Range Planning*, *44*(3), 179–196. doi:10.1016/j.lrp.2010.08.001.

Agan, B., & Balcilar, M. (2022). On the determinants of green technology diffusion: An empirical analysis of economic, social, political, and environmental factors. *Sustainability*, *14*(4). doi:10.3390/su14042008 Art. 4.

Aghion, P., Bechtold, S., Cassar, L., & Herz, H. (2018). The causal effects of competition on innovation: Experimental evidence. *The Journal of Law, Economics, and Organization*, *34*(2), 162–195. doi:10.1093/jleo/ewy004.

Aghion, P., Bergeaud, A., & Van Reenen, J. (2021). The impact of regulation on innovation. *National Bureau of Economic Research*.

Aghion, P., Bloom, N., Blundell, R., Griffith, R., & Howitt, P. (2005). Competition and Innovation: An Inverted-U Relationship*. *The Quarterly Journal of Economics*, *120*(2), 701–728. doi:10.1093/qje/120.2.701.

Agostini, L., & Filippini, R. (2019). Organizational and managerial challenges in the path toward Industry 4.0. *European Journal of Innovation Management*, *22*(3), 406–421. doi:10.1108/EJIM-02-2018-0030.

Agostini, L., Galati, F., & Gastaldi, L. (2020). The digitalization of the innovation process: Challenges and opportunities from a management perspective. *European Journal of Innovation Management*, *23*(1), 1–12. doi:10.1108/EJIM-11-2019-0330.

Ahmed, Z., Caglar, A. E., & Murshed, M. (2022). A path towards environmental sustainability: The role of clean energy and democracy in ecological footprint of Pakistan. *Journal of Cleaner Production*, *358*, 132007. doi:10.1016/j.jclepro.2022.132007.

Al-Ajlani, H., Cvijanović, V., Es-Sadki, N., & Müller, V. (2021). *EU Eco-Innovation Index 2021 Policy brief.*

Alam, M. M., & Murad, M. W. (2020). The impacts of economic growth, trade openness and technological progress on renewable energy use in organization for economic co-operation and development countries. *Renewable Energy*, *145*, 382–390. doi:10.1016/j.renene.2019.06.054.

Appio, F. P., Frattini, F., Petruzzelli, A. M., & Neirotti, P. (2021). Digital transformation and innovation management: A synthesis of existing research and an agenda for future studies. *Journal of Product Innovation Management*, *38*(1), 4–20. doi:10.1111/jpim.12562.

Arrow, K. J. (1962). The economic implications of learning by doing. *The Review of Economic Studies*, *29*(3), 155–173. doi:10.2307/2295952.

Arslan, H. M., Khan, I., Latif, M. I., Komal, B., & Chen, S. (2022). Understanding the dynamics of natural resources rents, environmental sustainability, and sustainable economic growth: New insights from China. *Environmental Science and Pollution Research*, *29*(39), 58746–58761. doi:10.1007/s11356-022-19952-y.

Barber, L. K., & Santuzzi, A. M. (2015). Please respond ASAP: Workplace telepressure and employee recovery. *Journal of Occupational Health Psychology*, *20*(2), 172–189. doi:10.1037/a0038278.

Bartolacci, F., Caputo, A., & Soverchia, M. (2020). Sustainability and financial performance of small and medium sized enterprises: A bibliometric and systematic literature review. *Business Strategy and the Environment*, *29*(3), 1297–1309. doi:10.1002/bse.2434.

Beck, N., & Katz, J. N. (1995). What to do (and not to do) with Time-Series Cross-Section Data. *The American Political Science Review*, *89*(3), 634–647. doi:10.2307/2082979.

Bertot, J. C., Estevez, E., & Janowski, T. (2016). Digital Public Service Innovation: Framework Proposal. In *Proceedings of the 9th International Conference on Theory and Practice of Electronic Governance* (pp. 113–122). doi:10.1145/2910019.2910108.

Bishop, C. M. (2006). *Pattern Recognition and Machine Learning (Information Science and Statistics)*. Springer-Verlag.

Blok, V., Wesselink, R., Studynka, O., & Kemp, R. (2015). Encouraging sustainability in the workplace: A survey on the pro-environmental behaviour of university employees. *Journal of Cleaner Production*, *106*, 55–67. doi:10.1016/j.jclepro.2014.07.063.

Bolton, R., & Hannon, M. (2016). Governing sustainability transitions through business model innovation: Towards a systems understanding. *Research Policy*, *45*(9), 1731–1742. doi:10.1016/j.respol.2016.05.003.

Boone, J. (2001). Intensity of competition and the incentive to innovate. *International Journal of Industrial Organization*, *19*(5), 705–726. doi:10.1016/S0167-7187(00)00090-4.

Bouncken, R., & Barwinski, R. (2021). Shared digital identity and rich knowledge ties in global 3D printing—A drizzle in the clouds? *Global Strategy Journal*, *11*(1), 81–108. doi:10.1002/gsj.1370.

Brock, K., den Ouden, E., Langerak, F., & Podoynitsyna, K. (2020). Front end transfers of digital innovations in a hybrid agile-stage-gate setting. *Journal of Product Innovation Management*, *37*(6), 506–527. doi:10.1111/jpim.12556.

Bu, M., Li, S., & Jiang, L. (2019). Foreign direct investment and energy intensity in China: Firm-level evidence. *Energy Economics*, *80*, 366–376. doi:10.1016/j.eneco.2019.01.003.

Buysse, K., & Verbeke, A. (2003). Proactive environmental strategies: A stakeholder management perspective. *Strategic Management Journal*, *24*(5), 453–470. doi:10.1002/smj.299.

Bykova, A. (2017). The impact of industry's concentration on innovation: Evidence from Russia. *Journal of Corporate Finance Research /Корпоративные Финансы | ISSN: 2073-0438*, *11*(1). doi:10.17323/j.jcfr.2073-0438.11.1.2017.37-49 Art. 1..

Canh, N. P., Schinckus, C., Thanh, S. D., & Chong, F. H. L. (2021). The determinants of the energy consumption: A shadow economy-based perspective. *Energy*, *225*, 120210.

Chishti, M. Z., Alam, N., Murshed, M., Rehman, A., & Balsalobre-Lorente, D. (2022). Pathways towards environmental sustainability: Exploring the influence of aggregate domestic consumption spending on carbon dioxide emissions in Pakistan. *Environmental Science and Pollution Research*, *29*(29), 45013–45030. doi:10.1007/s11356-022-18919-3.

Chou, Y.-C., Hao-Chun Chuang, H., & Shao, B. B. M (2014). The impacts of information technology on total factor productivity: A look at externalities and innovations. *International Journal of Production Economics*, *158*, 290–299. doi:10.1016/j.ijpe.2014.08.003.

Co, H. C., & Barro, F. (2009). Stakeholder theory and dynamics in supply chain collaboration. *International Journal of Operations & Production Management*, *29*(6), 591–611. doi:10.1108/01443570910957573.

CPI. (2016). Technology giants, the moligopoly hypothezis and holistic competition: A Primer. *Competition Policy International. https://www.competitionpolicyinternational.com/technology-giants-the-moligopoly-hypothezis-and-holistic-competition-a-primer/.*

Crane, A., & Livesey, S. (2003). Are You Talking to Me?: Stakeholder communication and the risks and rewards of dialogue. *Unfolding Stakeholder Thinking: 2*Routledge.

De Bondt, R., & Vandekerckhove, J. (2012). Reflections on the relation between competition and innovation. *Journal of Industry, Competition and Trade*, *12*(1), 7–19. doi:10.1007/s10842-010-0084-z.

de Jesus, A., Antunes, P., Santos, R., & Mendonça, S. (2018). Eco-innovation in the transition to a circular economy: An analytical literature review. *Journal of Cleaner Production*, *172*, 2999–3018. doi:10.1016/j.jclepro.2017.11.111.

Drechsler, L., & Sánchez, J. C. B. (2018). The Price Is (Not) Right: Data protection and discrimination in the age of pricing algorithms. *European Journal of Law and Technology*, *9*(3). https://ejlt.org/index.php/ejlt/article/view/631.

Du, K., Li, P., & Yan, Z. (2019). Do green technology innovations contribute to carbon dioxide emission reduction? Empirical evidence from patent data. *Technological Forecasting and Social Change*, *146*, 297–303. doi:10.1016/j.techfore.2019.06.010.

European Commission. (2019). *Digitalisation and Its Impact on Innovation.* Retrieved March 6, 2022, from https://ec.europa.eu/info/publications/digitalisation-and-its-impact-innovation_en.

Ezrachi. A., & Stucke. M. E (2020). *Virtual Competition—Ariel Ezrachi, Maurice E. Stucke. (n.d.).* Retrieved March 7, 2022, from: https://www.hup.harvard.edu/catalog.php?isbn=9780674545472.

Ferrari, F., Striani, R., Minosi, S., De Fazio, R., Visconti, P., Patrono, L., Catarinucci, L., Esposito Corcione, C., & Greco, A. (2020). An innovative IoT-oriented prototype platform for the management and valorisation of the organic fraction of municipal solid waste. *Journal of Cleaner Production*, *247*, 119618. doi:10.1016/j.jclepro.2019.119618.

Franssila, H., Okkonen, J., & Savolainen, R. (2016). Developing measures for information ergonomics in knowledge work. *Ergonomics*, *59*(3), 435–448. doi:10.1080/00140139.2015.1073795.

Friedman, A., & Miles, S. (2006). *Stakeholders: Theory and Practice*. Oxford University Press.

Fu, Q., Chen, Y. E., Jang, C.-L., & Chang, C.-P. (2020). The impact of international sanctions on environmental performance. *Science of The Total Environment*, *745*, 141007. doi:10.1016/j.scitotenv.2020.141007.

Ganda, F. (2019). The impact of innovation and technology investments on carbon emissions in selected organisation for economic Co-operation and development countries. *Journal of Cleaner Production*, *217*, 469–483. doi:10.1016/j.jclepro.2019.01.235.

Gastaldi, L., Appio, F. P., Martini, A., & Corso, M. (2015). Academics as orchestrators of continuous innovation ecosystems: Towards a fourth generation of CI initiatives. *International Journal of Technology Management*, *68*(1−2), 1–20. doi:10.1504/IJTM.2015.068784.

Genuino, D. A. D., Bataller, B. G., Capareda, S. C., & de Luna, M. D. G. (2017). Application of artificial neural network in the modeling and optimization of humic acid extraction from municipal solid waste biochar. *Journal of Environmental Chemical Engineering*, *5*(4), 4101–4107. doi:10.1016/j.jece.2017.07.071.

Gobble, M. M. (2018). Digitalization, digitization, and innovation. *Research-Technology Management*, *61*(4), 56–59. doi:10.1080/08956308.2018.1471280.

Gu, W., Zhao, X., Yan, X., Wang, C., & Li, Q. (2019). Energy technological progress, energy consumption, and CO2 emissions: Empirical evidence from China. *Journal of Cleaner Production*, *236*, 117666. doi:10.1016/j.jclepro.2019.117666.

Guang-Wen, Z., Murshed, M., Siddik, A.B., Alam, M.S., Balsalobre-Lorente, D., & Mahmood, H. (n.d.). Achieving the objectives of the 2030 sustainable development goals agenda: Causalities between economic growth, environmental sustainability, financial development, and renewable energy consumption. *Sustainable Development, n/a*(n/a). doi:10.1002/sd.2411.

Ha, L. T. (2022). Effects of digitalization on financialization: Empirical evidence from European countries. *Technology in Society*, *68*, 101851. doi:10.1016/j.techsoc.2021.101851.

Ha, L. T. (2022). Socioeconomic and resource efficiency impacts of digital public services. *Environmental Science and Pollution Research.* https://doi.org/10.1007/s11356-022-21408-2.

Ha, L. T. (2022). Are digital business and digital public services a driver for better energy security? Evidence from a European sample. *Environmental Science and Pollution Research*. doi:10.1007/s11356-021-17843-2.

Ha, L. T., Dung, H. P., & Thanh, T. T. (2021). Economic complexity and shadow economy: A multi-dimensional analysis. *Economic Analysis and Policy*, *72*, 408–422. doi:10.1016/j.eap.2021.09.011.

Ha, L. T., Huong, T. T. L., & Thanh, T. T. (2022). Is digitalization a driver to enhance environmental performance? An empirical investigation of European countries. *Sustainable Production and Consumption*. doi:10.1016/j.spc.2022.04.002.

Ha, L. T., Nam, P. X., & Thanh, T. T. (2021). Effects of bribery on firms' environmental innovation adoption in Vietnam: Mediating roles of firms' bargaining power and credit and institutional constraints. *Ecological Economics*, *185*, 107042. doi:10.1016/j.ecolecon.2021.107042.

Ha, L. T., & Thanh, T. T. (2022). Effects of digital public services on trades in green goods: Does institutional quality matter? *Journal of Innovation & Knowledge*, *7*,(1) 100168. doi:10.1016/j.jik.2022.100168.

Haucap, J. (2019). Competition and competition policy in a data-driven economy. *Intereconomics*, *2019*(4), 201–208.

Honarvar, A. R., & Sami, A. (2019). Towards sustainable smart city by particulate matter prediction using urban big data, excluding expensive air pollution infrastructures. *Big Data Research*, *17*, 56–65. doi:10.1016/j.bdr.2018.05.006.

Huang, Y., & Liu, L. (2014). Fighting corruption: A long-standing challenge for environmental regulation in China. *Environmental Development*, *12*, 47–49. doi:10.1016/j.envdev.2014.06.001.

Huang, Y.-C., Ding, H.-B., & Kao, M.-R. (2009). Salient stakeholder voices: Family business and green innovation adoption. *Journal of Management & Organization*, *15*(3), 309–326. doi:10.5172/jmo.2009.15.3.309.

Huesig, S., & Endres, H. (2018). Exploring the digital innovation process: The role of functionality for the adoption of innovation management software by innovation managers. *European Journal of Innovation Management*, *22*(2), 302–314. doi:10.1108/EJIM-02-2018-0051.

Im, K. S., Pesaran, M. H., & Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *Journal of Econometrics*, *115*(1), 53–74. doi:10.1016/S0304-4076(03)00092-7.

Jaaffar, A. H., & Amran, A. A. (2017). The influence of leaders' past environmental-related experiences and positive deviance behaviour in green management practices. *Jurnal Pengurusan (UKM Journal of Management)*, *51*(0). Art. 0 http://ejournals.ukm.my/pengurusan/article/view/22781.

Jackman, M., & Moore, W. (2021). Does it pay to be green? An exploratory analysis of wage differentials between green and non-green industries. *Journal of Economics and Development*, *23*(3), 284–298. doi:10.1108/JED-08-2020-0099.

Jain, P., Gyanchandani, M., & Khare, N. (2016). Big data privacy: A technological perspective and review. *Journal of Big Data*, *3*(1), 25. doi:10.1186/s40537-016-0059-y.

Jarle Gressgård, L. (2011). Virtual team collaboration and innovation in organizations. *Team Performance Management: An International Journal*, *17*(1/2), 102–119. doi:10.1108/13527591111114738.

Jarle Gressgård, L., Amundsen, O., Merethe Aasen, T., & Hansen, K. (2014). Use of information and communication technology to support employee-driven innovation in organizations: A knowledge management perspective. *Journal of Knowledge Management*, *18*(4), 633–650. doi:10.1108/JKM-01-2014-0013.

Jové-Llopis, E., & Segarra-Blasco, A. (2018). Eco-innovation strategies: A panel data analysis of Spanish manufacturing firms. *Business Strategy and the Environment*, *27*(8), 1209–1220. doi:10.1002/bse.2063.

Khan, I., Tan, D., Hassan, S. T., & Bilal (2022). Role of alternative and nuclear energy in stimulating environmental sustainability: Impact of government expenditures. *Environmental Science and Pollution Research*, *29*(25), 37894–37905. doi:10.1007/s11356-021-18306-4.

Khoreva, V., Vaiman, V., Bondarouk, T., & Salojärvi, S. (2019). Exploring the influence of digitalization on global talent management. *Academy of Management Proceedings*, *2019*(1), 10238. doi:10.5465/AMBPP.2019.18.

Le, H. T., & Hoang, D. P. (2021). Economic sanctions and environmental performance: The moderating roles of financial market development and institutional quality. *Environmental Science and Pollution Research*. doi:10.1007/s11356-021-17103-3.

Le, T. H., Hoang, P. D., & To, T. T. (2022). Is product proximity a driver for better energy security? Global evidence of nonlinear relationships between product proximity and energy security. *International Journal of Sustainable Development & World Ecology*, *0*(0), 1–21. doi:10.1080/13504509.2022.2025500.

Le, T.-H., & Nguyen, C. P. (2019). Is energy security a driver for economic growth? Evidence from a global sample. *Energy Policy*, *129*, 436–451. doi:10.1016/j.enpol.2019.02.038.

Lu, W., Chen, X., Ho, D. C. W., & Wang, H. (2016). Analysis of the construction waste management performance in Hong Kong: The public and private sectors compared using big data. *Journal of Cleaner Production*, *112*, 521–531. doi:10.1016/j.jclepro.2015.06.106.

Lyu, L., Khan, I., Zakari, A., & Bilal (2021). A study of energy investment and environmental sustainability nexus in China: A bootstrap replications analysis. *Environmental Science and Pollution Research*. doi:10.1007/s11356-021-16254-7.

Manigandan, P., Alam, M. S., Alagirisamy, K., Pachiyappan, D., Murshed, M., & Mahmood, H. (2022). Realizing the Sustainable Development Goals through technological innovation: Juxtaposing the economic and environmental effects of financial development and energy use. *Environmental Science and Pollution Research*. doi:10.1007/s11356-022-22692-8.

Marion, T. J., & Fixson, S. K. (2021). The transformation of the innovation process: How digital tools are changing work, collaboration, and organizations in new product development*. *Journal of Product Innovation Management*, *38*(1), 192–215. doi:10.1111/jpim.12547.

Mcloughlin, I., Wilson, R., & Martin, M. (2013). Digital Government and Public Service Innovation. *Digital Government at Work*. Oxford University Press. doi:10.1093/acprof:oso/9780199557721.003.0002.

Mitchell, R. K., Agle, B. R., & Wood, D. J. (1997). Toward a theory of stakeholder identification and salience: Defining the principle of who and what really counts. *The Academy of Management Review*, *22*(4), 853–886. doi:10.2307/259247.

Murillo-Luna, J. L., Garcés-Ayerbe, C., & Rivera-Torres, P. (2008). Why do patterns of environmental response differ? A stakeholders' pressure approach. *Strategic Management Journal*, *29*(11), 1225–1240. doi:10.1002/smj.711.

Murshed, M., Chadni, M. H., & Ferdaus, J. (2020). Does ICT trade facilitate renewable energy transition and environmental sustainability? Evidence from Bangladesh, India, Pakistan, Sri Lanka, Nepal and Maldives. *Energy, Ecology and Environment*, *5*(6), 470–495. doi:10.1007/s40974-020-00190-2.

Nambisan, S. (2018). Architecture vs. ecosystem perspectives: Reflections on digital innovation. *Information and Organization*, *28*(2), 104–106. doi:10.1016/j.infoandorg.2018.04.003.

Nambisan, S., Zahra, S. A., & Luo, Y. (2019). Global platforms and ecosystems: Implications for international business theories. *Journal of International Business Studies*, *50*(9), 1464–1486. doi:10.1057/s41267-019-00262-4.

Neirotti, P., & Pesce, D. (2018). ICT-based innovation and its competitive outcome: The role of information intensity. *European Journal of Innovation Management*, *22*(2), 383–404. doi:10.1108/EJIM-02-2018-0039.

OECD. (2019). *How's Life in the Digital Age?: Opportunities and Risks of the Digital Transformation for People's Well-being*. OECD. https://doi.org/10.1787/9789264311800-en

OECD. (2013). *Exploring data-driven innovation as a new source of growth: Mapping the policy issues raised by "big data.* (pp. 319–356). OECD. doi:10.1787/9789264193307-12-en.

Oltra, V. (2008). Environmental innovation and industrial dynamics: The contributions of evolutionary economics. Cahiers du GREThA (2007-2019) *(No. 2008–28; Cahiers Du GREThA (2007-2019))*. Groupe de Recherche en Economie Théorique et Appliquée (GREThA). https://ideas.repec.org/p/grt/wpegrt/2008-28.html.

Osorio-Arjona, J., & García-Palomares, J. C. (2019). Social media and urban mobility: Using twitter to calculate home-work travel matrices. *Cities*, *89*, 268–280. https://doi.org/10.1016/j.cities.2019.03.006

Pesaran, M. H. (2021). General diagnostic tests for cross-sectional dependence in panels. *Empirical Economics*, *60*(1), 13–50. doi:10.1007/s00181-020-01875-7.

Pesch, R., Endres, H., & Bouncken, R. B. (2021). Digital product innovation management: Balancing stability and fluidity through formalization. *Journal of Product Innovation Management*, *38*(6), 726–744. doi:10.1111/jpim.12609.

Porter, M. E., & Heppelmann, J. E. (2015). How Smart, Connected Products Are Transforming Companies. *Harvard Business Review*. *https://hbr.org/2015/10/how-smart-connected-products-are-transforming-companies*.

Porter, M. E., & van der Linde, C. (1995). Toward a New Conception of the Environment-Competitiveness Relationship. *Journal of Economic Perspectives*, *9*(4), 97–118. doi:10.1257/jep.9.4.97.

Raguseo, E., Gastaldi, L., & Neirotti, P. (2016). Smart work: Supporting employees' flexibility through ICT, HR practices and office layout. *Evidence-Based HRM: A Global Forum for Empirical Scholarship*, *4*(3), 240–256. doi:10.1108/EBHRM-01-2016-0004.

Ribeiro-Navarrete, S., Botella-Carrubi, D., Palacios-Marqués, D., & Orero-Blat, M. (2021). The effect of digitalization on business performance: An applied study of KIBS. *Journal of Business Research*, *126*, 319–326. doi:10.1016/j.jbusres.2020.12.065.

Roy, V., & Singh, S. (2017). Mapping the business focus in sustainable production and consumption literature: Review and research framework. *Journal of Cleaner Production*, *150*, 224–236. doi:10.1016/j.jclepro.2017.03.040.

Salem, M. A., Shawtari, F., Shamsudin, M. F., & Hussain, H. B. I. (2018). The Consequences of Integrating Stakeholder Engagement in Sustainable Development (Environmental Perspectives). *Sustainable Development*, *26*(3), 255–268. doi:10.1002/sd.1699.

Sarkodie, S. A., Strezov, V., Jiang, Y., & Evans, T. (2019). Proximate determinants of particulate matter (PM2.5) emission, mortality and life expectancy in Europe, Central Asia, Australia, Canada and the US. *Science of The Total Environment*, *683*, 489–497. doi:10.1016/j.scitotenv.2019.05.278.

Schmenner, R. W. (2004). Service Businesses and Productivity*. *Decision Sciences*, *35*(3), 333–347. doi:10.1111/j.0011-7315.2004.02558.x.

Schumpeter, J. A. (1934). *The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle* (SSRN Scholarly Paper ID 1496199). *Social Science Research Network*. *https://papers.ssrn.com/abstract=1496199*.

Seele, P., Dierksmeier, C., Hofstetter, R., & Schultz, M. D. (2021). Mapping the Ethicality of Algorithmic Pricing: A Review of Dynamic and Personalized Pricing. *Journal of Business Ethics*, *170*(4), 697–719. doi:10.1007/s10551-019-04371-w.

Seman, N. A. A., Zakuan, N., Rashid, U. K., Nasuredin, J., & Ahmad, N. (2018). Understanding stakeholder pressures in adopting environmental management practices based on stakeholder theory: A review. *International Journal of Research*, *5*(20) Art. 20.

Shahbaz, M., Nasir, M. A., & Roubaud, D. (2018). Environmental degradation in France: The effects of FDI, financial development, and energy innovations. *Energy Economics*, *74*, 843–857. doi:10.1016/j.eneco.2018.07.020.

Shakib, M., Yumei, H., Rauf, A., Alam, M., Murshed, M., & Mahmood, H. (2022). Revisiting the energy-economy-environment relationships for attaining environmental sustainability: Evidence from Belt and Road Initiative countries. *Environmental Science and Pollution Research*, *29*(3), 3808–3825. doi:10.1007/s11356-021-15860-9.

Sharma, G. D., Yadav, A., & Chopra, R. (2020). Artificial intelligence and effective governance: A review, critique and research agenda. *Sustainable Futures*, *2*, 100004. doi:10.1016/j.sftr.2019.100004.

Shujahat, M., Ali, B., Nawaz, F., Durst, S., & Kianto, A. (2018). Translating the impact of knowledge management into knowledge-based innovation: The neglected and mediating role of knowledge-worker satisfaction. *Human Factors and Ergonomics in Manufacturing & Service Industries*, *28*(4), 200–212. doi:10.1002/hfm.20735.

Shujahat, M., Sousa, M. J., Hussain, S., Nawaz, F., Wang, M., & Umer, M. (2019). Translating the impact of knowledge management processes into knowledge-based innovation: The neglected and mediating role of knowledge-worker productivity. *Journal of Business Research*, *94*, 442–450. doi:10.1016/j.jbusres.2017.11.001.

Sulkowski, A. J., Edwards, M., & Freeman, R. E. (2018). Shake your stakeholder: Firms leading engagement to cocreate sustainable value. *Organization & Environment*, *31*(3), 223–241. doi:10.1177/1086026617722129.

Sun, C., Li, Z., Ma, T., & He, R. (2019). Carbon efficiency and international specialization position: Evidence from global value chain position index of manufacture. *Energy Policy*, *128*, 235–242. doi:10.1016/j.enpol.2018.12.058.

Sun, C., Zhang, F., & Xu, M. (2017). Investigation of pollution haven hypothesis for China: An ARDL approach with breakpoint unit root tests. *Journal of Cleaner Production*, *161*, 153–164. doi:10.1016/j.jclepro.2017.05.119.

Taghizadeh-Hesary, F., Zakari, A., Yoshino, N., & Khan, I. (2022). Leveraging on energy security to alleviate poverty in Asian economies. *The Singapore Economic Review*, 1–28. doi:10.1142/S0217590822440015.

The Economist. (2018). *The sunny and the dark side of AI*. March 28) https://www.economist.com/special-report/2018/03/28/the-sunny-and-the-dark-side-of-ai.

Vuori, V., Helander, N., & Okkonen, J. (2019). Digitalization in knowledge work: The dream of enhanced performance. *Cognition, Technology & Work*, *21*(2), 237–252. doi:10.1007/s10111-018-0501-3.

Wagner, M. (2007). Integration of Environmental Management with Other Managerial Functions of the Firm: Empirical Effects on Drivers of Economic Performance. *Long Range Planning, 40*(6), 611−628. https://doi.org/10.1016/j.lrp.2007.08.001

Waller, S. W., & Sag, M. (2014). *Promoting Innovation* (SSRN Scholarly Paper ID 2479569). *Social Science Research Network*. doi:10.2139/ssrn.2479569.

Wen, Z., Hu, S., De Clercq, D., Beck, M. B., Zhang, H., Zhang, H., Fei, F., & Liu, J. (2018). Design, implementation, and evaluation of an Internet of Things (IoT) network system for restaurant food waste management. *Waste Management*, *73*, 26–38. doi:10.1016/j.wasman.2017.11.054.

Woods, D. D., Patterson, E. S., & Roth, E. M. (2002). Can We Ever Escape from Data Overload? A Cognitive Systems Diagnosis. *Cognition, Technology & Work*, *4*(1), 22–36. doi:10.1007/s101110200002.

Wu, C.-H., Tsai, S.-B., Liu, W., Shao, X.-F., Sun, R., & Wacławek, M. (2021). Eco-Technology and Eco-Innovation for Green Sustainable Growth. *Ecological Chemistry and Engineering S*, *28*(1), 7–10. doi:10.2478/eces-2021-0001.

Wu, F., Huberman, B. A., Adamic, L. A., & Tyler, J. R. (2004). Information flow in social groups. *Physica A: Statistical Mechanics and Its Applications*, *337*(1), 327–335. doi:10.1016/j.physa.2004.01.030.

Yoo, Y., Henfridsson, O., & Lyytinen, K. (2010). Research commentary—the new organizing logic of digital innovation: An agenda for information systems research. *Information Systems Research*, *21*(4), 724–735. doi:10.1287/isre.1100.0322.

Zakari, A., Khan, I., Tan, D., Alvarado, R., & Dagar, V. (2022). Energy efficiency and sustainable development goals (SDGs). *Energy*, *239*, 122365. doi:10.1016/j.energy.2021.122365.

Zakari, A., Li, G., Khan, I., Jindal, A., Tawiah, V., & Alvarado, R. (2022). Are abundant energy resources and Chinese business a solution to environmental prosperity in Africa? *Energy Policy*, *163*, 112829. doi:10.1016/j.enpol.2022.112829.

Zhang, Y., Ren, S., Liu, Y., & Si, S. (2017). A big data analytics architecture for cleaner manufacturing and maintenance processes of complex products. *Journal of Cleaner Production*, *142*, 626–641. doi:10.1016/j.jclepro.2016.07.123.