7

Innovative Foreign Direct Investments and the Knowledge Sources for Green and Digital Inventions: A Patent-Based Analysis

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1 Introduction

The COVID-19 pandemic and the socio-economic crisis that it has generated on a worldwide scale are asking policymakers to adopt recovery and resilient plans that could lead their countries and regions to move along different growth patterns than pre-crisis ones. The consequences that the Russia-Ukraine war, along with the interventions taken by third countries to curb it, are having on prices and availability of energy,

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agricultural and raw materials are making this structural change possibly more urgent. Following an evolutionary approach to resilience, this has brought to the front the opportunity of combining the green and the digital transitions in a "twin-transition", which is capable to make economies evolve along smart, sustainable and inclusive patterns of growth. On the one hand, greenhouse gas emissions and the entailed raise of global temperatures make the green transition necessary to "act forward". On the other hand, the digital transition towards more powerful and empowering digital technologies poses serious environmental threats—spanning from the depletion of rare materials to high energy consumption—and opportunities—from improving green efficiency to facilitating the development of new green technologies for that to happen. The interlinking of the green and the digital transition has been accordingly receiving increasing attention.

In Europe, this policy target was already at the core of the 2020 Industrial Strategy for a green and digital Europe, aimed at strengthening the competitiveness of European companies in global markets and to improve their innovative performance, especially in the green and digital technological fields (European Commission, 2020). Such a strategy, which is strongly integrated with other major European initiatives, like the European Green Deal and the European Digital Strategy, has been recently updated in the National Recovery and Resilience Plans of the

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NextGenerationEU. Indeed, several of its missions refer to the combined unfolding of the green and the digital transitions (Pilati, 2021). Also outside Europe, an increasing number of countries are approaching an integrated green and digital recovery. In the US, for example, a US$2.3 trillion plan[1] has been approved also to accelerate the green transition through infrastructural, innovation and skill investments, which are digital too. Similar initiatives have been taken in Asia. The recovery plan of South Korea, for example, included US$63 billion in green funding for smart grids and infrastructure for electric vehicles, and supporting new green digital solutions is also a key part of Singapore's Green Plan 2030.[2]

The above-described policy background refers to a scenario in which, as the COVID-19 crisis has shown, European and non-European countries are increasingly more globally integrated and in which global value chains make of the green and the digital transitions two interlinked processes that unfold within interdependent economies. In such a scenario, foreign direct investments (FDIs), in their well-recognised role of means of knowledge exchange across locations (Castellani & Zanfei, 2006), emerge as a pivotal leverage through which economies can source the knowledge necessary to develop and adopt green and digital technologies. Indeed, the ability to foster and sustain the digital and green transitions rests on the successful development and deployment of relevant technologies, which in turn depend on the capacity of firms to source relevant knowledge within and outside their resident location.

Taking the above-described scenario as a starting point, we study the role of foreign direct investment (FDI) flows in facilitating access to the knowledge base relevant for the development of green and digital technologies of European Union (EU) countries and regions. More precisely, we investigate the extent to which inward and outward innovative FDIs—that is, both greenfield foreign investments and cross-border mergers and acquisitions (M&As) with an innovative content—can constitute a channel through which European countries and regions are exposed to the external knowledge sources that can be combined with

[1] https://www.whitehouse.gov/briefing-room/statements-releases/2021/03/31/fact-sheet-the-american-jobs-plan/.

[2] https://www.greenplan.gov.sg.

local knowledge in the development of green and digital technologies. Technological knowledge sourcing is in fact an important channel for the enrichment of the knowledge base already available in European regions. FDIs lead to knowledge flows regarding combinations of management practices, work organizations and, especially for innovative FDIs, technological expertise.

In dealing with this research question, we refer and contribute to the geography of innovation literature, positioning in a still thin stream of studies on the role of extra-regional linkages for the local development of new technologies (Balland & Boschma, 2021). In this stream, FDIs have already received attention as one of the most important channels through which regions entertain relationships with the outer environment that can increase their innovation capacity (Zhu et al., 2017; He et al., 2018; Crescenzi et al., 2015; Castellani et al., 2022). In particular, recent studies have shown the role that FDIs have, though with important nuances, in facilitating the green (Castellani et al., 2022) and the digital transition (Zanfei et al., 2019). However, this role of FDIs has been so far recognized mainly indirectly, by generically assuming and alluding to, rather than measuring, their capacity of bringing foreign knowledge in the hosting regions. As an added value to this literature, we look at the knowledge-conveying role of FDIs more directly, by claiming that the regional occurrence of innovative FDIs, both inward and outward, could facilitate a specific mechanism of local knowledge accumulation: the actual use of foreign produced knowledge in the development of local inventions. As we will argue, this requires extending and refining our theoretical knowledge of the mechanisms through which FDIs affect regional innovation, also and above all in the digital and green domain.

In order to support our theoretical arguments, we compile a novel dataset and carry out an empirical investigation of the role of FDIs in shaping the knowledge base used in green and digital inventions in EU countries and regions. This analysis proceeds in two steps. We first identify EU green and digital patents, and analyse their evolution over time and geography. In doing so, we show how the distribution of the two technologies across EU countries changes in recent years, as well as the location of the knowledge base—captured by the country of the patents that EU green and digital patents cite—relevant for their development.

In the second step of our analysis, we rely on a gravity-modelling framework to understand whether the knowledge base of green and digital technologies developed in EU metropolitan and NUTS 3 regions correlate with innovative FDIs—namely EU innovative inward and outward greenfield FDIs and cross-border M&As.

The results of the analysis indicate that, after a period of continued increase in the 2000s, the development of green technologies stagnated. By contrast, EU digital patenting showed marked increases after 2012. EU green and digital technologies concentrate in France and, even more markedly, in Germany. The technological knowledge base used for their development is nevertheless to a large extent located outside the EU, and in particular in the United States (US). Results of our econometric analysis show that inward innovative FDIs are significantly and positively associated with the backward citations of EU green and digital patents to foreign knowledge bases. This positive association, which is driven by the more recent EU patent activities and it is stronger for digital than for green innovation, suggests that foreign MNEs carrying out innovative activities in the EU create pipelines that allow EU territories to access knowledge developed in the parent R&D labs of such MNEs. By contrast, innovative outward FDIs are not associated with access to the foreign knowledge base used in the development of EU digital or green technologies. This result suggests the limited importance for the development of digital and green technologies of reverse knowledge transfer from the destination countries of EU FDIs to the home locations.

The rest of the chapter is structured as follows: Sect. 2 provides the theoretical background of our study and our contribution to it; Sect. 3 illustrates the data alongside the empirical analysis and discusses the results and Sect. 4 concludes.

2 Theoretical Background

Our analysis of the local development of new green and digital technologies positions in the economic geography literature, which in fact provides a picture of the globalized world economy as a set of locations with "local buzz" (Storper & Venables, 2004) connected by "global pipelines"

(Bathelt et al., 2004). Companies and multinational enterprises in particular are the key actors shaping such connections, serving as conduits for multidirectional knowledge flows between places (e.g. Cano-Kollmann et al., 2016; Crescenzi & Iammarino, 2017; Iammarino & McCann, 2013; Song, 2014). Indeed, while most interactions take place between agents within geographically delimited areas, creating in some cases clusters (or buzz) with especially dense activity, cross-local and cross-national connections (or pipelines) are key to allow combinations of different knowledge inputs and avoid cognitive lock-in (Balland & Boschma, 2021; Boschma, 2005; Giuliani & Bell, 2005; Zhu et al., 2017).

The tension between local and global forces has also been remarked by the literature about regional technological specialization and diversification, in which the latter has emerged to depend on the interlink between indigenous (related) capabilities and a wide set of extra-regional linkages, consisting of regional inflows of non-local actors and non-regional linkages of local actors (Balland & Boschma, 2021). Among the former, most of the attention has been attracted by FDIs, which have been argued to bring novel knowledge in the hosting region, which can spur the development of either more unrelated or related new technologies (He et al., 2018; Zhu et al., 2017). Indeed, this depends on the strategy (e.g. kind of FDI) pursued by MNEs and by the domain (e.g. green vs. non-green) of the relevant technologies (Crescenzi et al., 2015; Castellani et al., 2022).

FDIs are in fact an important tool for building pipelines and, eventually, promoting processes of mutual learning, technological transfer and innovation. The international business literature has shown that FDIs have a twofold innovation effect at the local level. The first one is direct and accrues from the capacity of MNC subsidiaries to innovate in the hosting region, usually exploiting a superior set of assets and thus to a higher extent than indigenous companies (Cantwell, 1989; Castellani & Zanfei, 2006; Guadalupe et al., 2012; Stiebale, 2016). The second effect is instead indirect and derives from the spillovers that the innovative activities of foreign subsidiaries have on local firms. These in turn innovate more benefiting from knowledge inputs of both disembodied nature (pure knowledge spillovers), for example, through research cooperation with MNCs, and embodied nature (rent spillovers), for example, through human capital mobility and supply-chain relationships with foreign subsidiaries (Castellani et al., 2015; Crescenzi et al., 2015; Papanastassiou et al., 2020). In dealing with both mechanisms, it is generally claimed that regional innovation benefits from incoming FDIs (i.e. inward), thanks to the additional knowledge these are assumed to convey in the host region and of which local actors are expected to take stock. This is a reasonable assumption, which however does not make explicit the inner mechanism through which FDIs render foreign knowledge available at the local level and does lack a direct empirical testing of it, at least on a systematic (i.e. cross-country and cross-industry) basis.

As a way to contribute filling this gap, we extend the theoretical analysis of the FDI impact on regional innovation by maintaining that an important part of it passes through the extent to which FDIs of an innovative nature increase the knowledge base on which local inventions can draw. Following the Schumpeterian theory of recombinant innovations (Frenken et al., 2012; Weitzman, 1998), we posit that FDIs in activities with an innovation content—for example, greenfield FDIs in R&D and/or M&As of innovative companies—represent an important channel through which regional inventors can increase their exposure to novel external knowledge, which they can combine and recombine with the local one in their inventing activities. In turn, this is an exposure that local inventors can be expected to exploit by inserting in the prior art of their inventions the knowledge generated in the country where the MNC home-base is located. In the case of patented inventions, this would materialize in a higher propensity of local inventors to cite patents that have been applied in the country of the relevant MNC. Just to make an example, we could expect that innovative FDIs from US-based MNCs, which are directed to European regions, could increase the extent to which European regional patents cite US ones (i.e. filled in the US). Furthermore, and this is an additional extension of the standard theoretical background of the impact of FDI on local innovation, a similar argument can be put forward with respect to outward FDIs. Looking at inward FDIs, we may expect that foreign MNCs carrying out innovative activities in EU regions rely also on knowledge developed in their parent R&D labs and that translates into inventive outcomes of their home countries, on which they can be expected to draw (by citing them) for innovating in their hosting places. Conversely, outward innovative FDIs by firms based in EU regions might serve to put them in contact with host countries' knowledge sources and with the relative inventive outcomes. Previous empirical studies showed that the offshoring of innovative greenfield FDI are positively associated with productivity and innovation growth at home (Belderbos et al., 2016; Castellani & Pieri, 2013). These outcomes could also rely (still by citing) for innovating in their home locations, for example, via reverse knowledge transfer (Branstetter, 2006; Criscuolo et al., 2005).

The previous arguments have a general expected validity, as they can apply to the effect of innovative FDIs on the development of any kind of technology at the regional level. However, given their distinguishing characteristics, we can expect them to hold true to a possibly larger extent with respect to our two focal technologies, that is, green and digital ones. On the one hand, green technologies have been found to be comparatively more "complex" than non-green ones (Barbieri et al., 2020), mainly due to the wider set of knowledge domains on which their inventions draw and on their more dispersed knowledge base. This is a peculiar aspect, which renders the role of innovative FDIs in extending the access to additional (foreign) knowledge important to retain. On the other hand, the new wave of digital technologies does also have special features, being "enabling" of structural transformations at the firm level and having, though to a different extent, the features of "General Purpose Technologies" (GPT) (Bianchini, Damioli, & Ghisetti, 2022; Martinelli et al., 2021). Because of these features, in the development of these technologies, the cross-fertilization of ideas across different knowledge domains is very pervasive and this also makes the FDI mechanism we are investigating of crucial relevance.

3 Empirical Application

3.1 Data and Definitions

We perform our analysis by combining the European Patent Office (EPO) Worldwide Patent Statistical (PATSTAT), the Financial Times' fDi Markets and the Bureau van Dijk's Zephyr datasets.

We measure green technologies by identifying *green patent applications* to the European Patent Office (EPO) through the OECD Envtech classification of environment-related technologies, in turn based on the Cooperative Patent Classification (CPC) and the International Patent Classification (IPC). As an established classification of digital technological fields does not yet exist,[3] digital patents are selected through a search query on titles and abstracts based on a list of keywords. This list coincides with that developed by Bianchini, Müller, and Pelletier (2022) building on the taxonomy and dimensions of the digital technology ecosystem identified by the OECD (2019), as well as on recent contributions on the patent mapping of AI (Baruffaldi et al., 2020) and of Industry 4.0 technologies (Martinelli et al., 2021). Accordingly, the keywords were selected to map the following categories of technologies: artificial intelligence, big data, Internet of Things, computing infrastructures, robotics and additive manufacturing.

Patent data are used to map the knowledge flows that represent our main dependent variable. More precisely, we use the *backward citations* of a focal green or digital patent as a measure of the knowledge base on which the relative green or digital invention draws. In order to do that, we allocate both citing and cited patents to the NUTS3 region and country of residence of the inventor. The address of the inventors is used in place of that of the assignees because the former is a better proxy of the location where the focal technology was developed. Patents developed in a specific location could be assigned, for internal strategies, to the headquarter of the company or to the ultimate owner.

As far as our main regressors are concerned, we investigate the extent to which innovative FDIs can be retained conducive of the knowledge flows at the basis of green and digital inventions. Following an established practice (Belderbos et al., 2016; Castellani & Pieri, 2013; Damioli & Marin, 2020), we define *innovative greenfield FDIs* as the investment

[3] Recent contributions that have relied on hierarchical patent classification systems (e.g. IPC, CPC) include Ardito et al., 2018; Fujii & Managi, 2018 and Corradini et al., 2021. Other scholars have adopted keyword inclusion/exclusion criteria applied to the text fields of patents or publications (Webb et al., 2018; Van Roy et al., 2020; Bianchini, Damioli, & Ghisetti, 2022), whereas recent contributions have used a combination of both methods (Baruffaldi et al., 2020; EPO, 2020; Martinelli et al., 2021; WIPO, 2019). However, the lists of keywords and technological classes adopted in these works are often heterogeneous and not always exhaustive.

projects MNE make for establishing foreign new activities or expanding existing ones in research and development (R&D) and design, development and testing (DDT). *Innovative foreign M&As* are instead the acquisitions of a foreign target company that made one or more patent applications in the 20 years before the deal completion (Aquaro et al., 2021; Damioli & Marin, 2020).

3.2 Descriptive Evidence

Digital and Green Inventions in the EU

While the urgency of the digital transformation and of the green transition recurs frequently in EU policy documents, the pace at which their underlying technologies are developed is different. As Fig. 7.1 shows, the number of EU applications in digital technologies has increased over the period 2003—2016, though with an irregular but smooth trend, marked by two consistent jumps in 2014 and 2016, in the latter case by

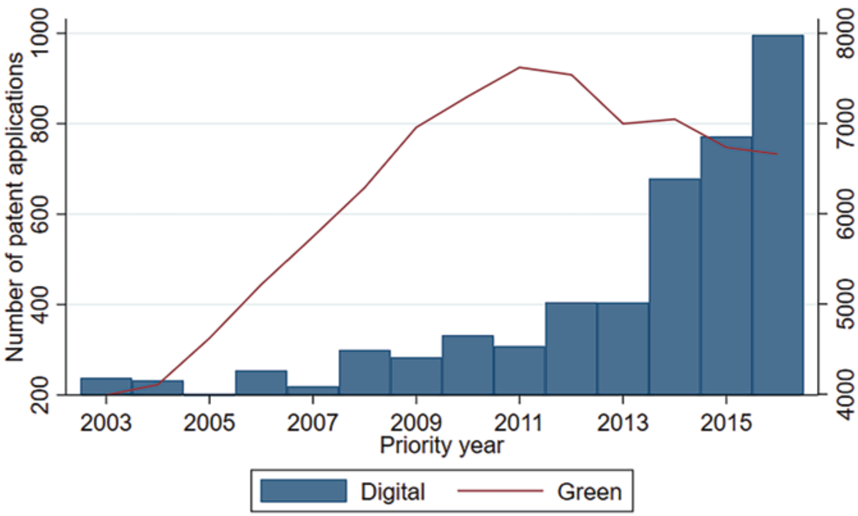

Fig. 7.1 Upward trend in the development of green and digital technologies in the EU, 2003–2016. (*Note*: Green patents on the secondary axis)

recovering from the decrease of 2015. A pattern of marked increases in the development of digital technologies is consistent with what has been detected worldwide in other studies (Van Roy et al., 2020; WIPO, 2019). The development of green technologies in the EU over the same period has increased more sharply until the last financial crisis (2011), following which it has embarked along a continuous slow down up to the latest years, which has been documented by other recent studies (Dechezleprêtre & Kruse, 2022; Kruse et al., 2022). As evoked by these studies, private incentives to develop new clean technologies might have decreased and, quite worryingly, this has been happening while the level of technology support policies to the green transition has also declined until 2016, for then experiencing a scattered increase, but without reaching the 2011-peak (Kruse & Atkinson, 2022).

The general European trend in digital and green technologies is the result of an interesting heterogeneity of patent application patterns across the EU countries (Table 7.1). Germany accounts for nearly half of green and digital patents in period 2003–2009, but its share declines significantly in the more recent period (2010–2016). This is particularly marked in digital technologies where the share of German patents drops from

Table 7.1 Green and digital EPO patent applications by EU country, 2003–2016

Country	Green		Digital	
	2003–2009	2010–2016	2003–2009	2010–2016
	(Number of applications)			
EU	36,932	49,908	1727	3897
	(% over total EU)			
DE	47.6	43.2	52.9	37.5
FR	16.7	17.7	13.0	18.5
IT	8.1	7.2	7.6	7.8
SE	4.4	5.6	8.5	10.8
NL	5.5	5.3	8.3	6.7
ES	2.9	3.4	3.4	5.5
DK	3.7	4.9	1.2	2.0
AT	3.1	3.6	3.0	2.0
BE	3.1	2.7	1.1	3.0
FI	2.4	3.1	0.9	3.1
Other EU	2.6	3.3	0.2	3.1

Note: Percentages may not total 100 due to rounding

52.9% to 37.5%. This reveals a process of catching-up in other EU countries, with national shares in 2010–2016 being similar in green and digital patent applications in most of them. Particularly strong increases in the share of digital patent applications are observed in France, which moved from a share of digital patent of 13% to 18.5%. In 2010–2016, Germany contributes relatively more (by 5.7 percentage points) to green than digital patenting. Conversely, Sweden's shares are larger in digital than green patent applications (by 5.2 percentage points in 2010–2016), making the Nordic country the third most important EU innovator in digital technologies.

The Geography of the Knowledge Sources of Green and Digital Inventions

Both digital and green technologies are developed through the interaction of actors (like firms, universities and research organizations) that are embedded in places marked by specific socio-economic and institutional features. A pivotal one is their constitutive knowledge sources, which geography of innovation studies have shown to vary across countries and, within them, across regional systems of innovation. In turn, both national and regional innovation systems are open ones, and their boundaries are crossed by external knowledge flows through which the local buzz can be combined with their participation to global pipelines.

If we consider backward citations of a focal patent as a proxy of the knowledge inputs that are searched and combined to obtain an invention, the location of the patents that are cited by digital and green EU applications reveal an interesting geography of their knowledge sources. Table 7.2 shows that for both kinds of technologies, these knowledge sources are mainly located outside of the EU. The percentage of non-EU patents cited in EU green innovations is above 50% in all EU countries, ranging from 52% in Germany to 70.7% in Belgium. A similar pattern emerges in digital patents where the percentage of non-EU patents cited ranges from 47% in Austria to 83% in Finland.

Tables 7.3 and 7.4 reveal that the percentage of non-EU cited patents is larger for digital (58.8%) than for green (56.3%) patent applications.

Table 7.2 Knowledge sources of EU green and digital inventions by area, 2003–2016

Country	Area cited in green patents			Area cited in digital patents		
	Domestic	Foreign, EU	Foreign, non-EU	Domestic	Foreign, EU	Foreign, non-EU
	%					
AT	8.2	37.7	54.0	10.6	42.2	47.1
BE	7.7	21.7	70.7	1.3	24.7	74.0
DE	38.7	9.2	52.2	38.8	8.6	52.7
DK	15.2	29.3	55.5	0.0	25.8	74.2
ES	7.8	31.2	61.1	6.3	23.9	69.8
FI	11.6	24.2	64.2	0.0	16.5	83.5
FR	20.2	21.3	58.5	28.2	9.3	62.5
IT	11.5	30.4	58.2	14.6	28.3	57.1
NL	10.0	25.7	64.2	8.2	27.4	64.5
SE	6.5	28.6	64.9	9.2	20.9	69.9
Other EU	7.3	27.8	64.9	0.0	18.3	81.7

Note: Percentages may not total 100 due to rounding

The US is the most important sources of knowledge for EU inventors in both green and digital technologies. In particular, the US account for 27.5% of the patents cited by green EU patent applications and 32.3% of the patents cited by EU digital ones. This pattern could be due to the mass of US patents susceptible of being cited as well as to their superior quality. However, irrespectively from that, it signals that the knowledge generated in the US innovation system is pivotal for the development of the two technologies at stake and that geographical distance is not a crucial impediment to benefit from knowledge inputs via citations.

Germany and Japan are other two important sources of knowledge for the development of digital and green technologies in the EU. German patents, in particular, are similarly important for both technologies, accounting for 27.9% of green and 27.1% of digital patents cited by EU patent applications. By contrast, Japanese patents are more important for green (15.6% of patents cited by EU patent applications) than for digital (11.1%) technologies.

Within-country citations also account for relevant shares of backward patent citations. Particularly high shares are detected in Germany (which record about 39% of domestic citations in both green and digital

Table 7.3 Knowledge sources of EU green inventions, by country, 2003–2016

Citing country	EU cited country												Non-EU cited country							
	AT	BE	DE	DK	ES	FI	FR	IT	NL	SE	Other	Total	CA	CH	CN	JP	UK	US	Other	Total
	%												%							
EU	1.1	0.8	27.9	1.2	0.7	0.7	6.2	2.1	1.3	1.0	0.5	**43.4**	1.3	1.8	1.2	15.6	3.7	27.5	5.5	**56.3**
AT	8.2	0.4	28.1	0.4	0.2	0.8	3.9	1.5	1.1	0.9	0.4	**46.0**	1.5	2.5	1.6	16.3	2.8	24.1	5.3	**54.0**
BE	0.4	7.7	11.6	0.4	0.3	0.5	4.6	1.3	1.5	0.5	0.4	**29.3**	1.2	1.0	0.7	12.0	4.9	40.6	10.3	**70.7**
DE	1.0	0.4	38.7	0.6	0.4	0.3	3.8	1.1	0.8	0.6	0.2	**47.8**	1.1	2.2	1.0	15.6	3.3	24.4	4.7	**52.2**
DK	0.5	0.4	18.4	15.2	2.0	0.6	3.4	0.7	2.0	1.0	0.3	**44.5**	1.4	1.2	1.9	12.4	4.1	28.4	6.1	**55.5**
ES	0.5	0.7	16.3	2.5	7.8	0.4	5.7	1.9	1.6	0.9	0.6	**38.9**	1.3	1.2	2.6	13.5	3.6	31.7	7.2	**61.1**
FI	1.0	0.4	12.3	1.2	0.1	11.6	4.0	1.2	1.4	2.3	0.3	**35.8**	2.4	1.4	2.1	15.3	3.0	31.8	8.1	**64.2**
FR	0.8	0.5	15.8	0.5	0.4	0.4	20.2	1.2	0.8	0.7	0.3	**41.5**	1.3	1.3	1.0	16.9	4.0	28.7	5.4	**58.5**
IT	0.8	0.8	20.1	0.4	0.5	0.3	5.6	11.5	0.9	0.6	0.3	**41.8**	1.3	1.6	1.2	16.2	3.8	28.0	6.1	**58.2**
NL	0.6	0.9	14.9	1.1	0.5	0.5	4.6	1.4	10.0	1.0	0.2	**35.8**	1.6	1.8	1.4	13.9	4.4	34.4	6.7	**64.2**
SE	1.0	0.3	19.0	0.8	0.2	0.8	4.2	1.2	0.8	6.5	0.3	**35.1**	1.7	1.3	1.2	20.7	4.0	31.3	4.8	**64.9**
Other EU	1.0	0.3	15.6	0.5	0.9	0.7	4.5	1.7	0.9	0.8	8.0	**35.1**	2.0	1.4	3.4	15.3	4.5	31.2	7.1	**64.9**

Note: Percentages may not total 100 due to rounding

Table 7.4 Knowledge sources of EU digital inventions, by cited country, 2003–2016

Country	EU cited country												non-EU cited country							
	AT	BE	DE	DK	ES	FI	FR	IT	NL	SE	Other	Total	CA	CH	CN	JP	UK	US	Other	Total
	%												%							
EU	0.8	0.4	27.1	0.5	0.6	0.7	5.0	2.0	1.0	2.4	0.1	**40.5**	1.2	2.8	2.1	11.1	3.8	32.3	6.2	**58.8**
AT	10.6	0.0	26.7	0.0	0.0	14.3	0.6	0.0	0.6	0.0	0.0	**52.9**	2.8	0.6	5.5	11.7	0.4	22.5	3.5	**47.1**
BE	0.6	1.3	17.8	0.0	0.0	1.3	2.5	1.3	1.3	0.0	0.0	**26.0**	1.3	4.4	5.0	11.4	5.7	42.5	3.8	**74.0**
DE	0.2	0.3	38.8	0.9	0.2	0.0	3.1	0.8	0.7	1.9	0.3	**47.3**	1.2	3.3	1.4	10.7	4.3	26.6	5.2	**52.7**
DK	0.0	0.0	15.7	0.0	0.4	0.0	3.5	0.0	0.0	6.2	0.0	**25.8**	0.0	3.1	4.1	13.8	2.6	44.5	6.0	**74.2**
ES	1.2	0.0	13.7	0.0	6.3	3.5	2.4	1.2	1.9	0.0	0.1	**30.2**	1.3	1.2	1.6	17.8	4.6	36.4	6.9	**69.8**
FI	0.0	0.0	9.4	0.0	0.0	0.0	4.7	0.0	0.0	2.4	0.0	**16.5**	4.7	4.7	0.0	7.1	0.0	59.8	7.1	**83.5**
FR	0.6	0.0	6.4	0.0	0.4	0.0	28.2	0.6	0.0	1.3	0.0	**37.5**	0.0	1.9	2.2	8.6	0.7	43.3	5.7	**62.5**
IT	0.7	1.6	21.6	0.0	0.7	0.0	1.5	14.6	1.4	0.7	0.0	**42.9**	1.3	4.3	2.1	6.0	4.6	30.0	8.9	**57.1**
NL	0.0	1.6	19.2	0.0	0.0	0.0	3.3	3.3	8.2	0.0	0.0	**35.5**	1.6	3.3	4.1	13.1	2.0	33.3	7.0	**64.5**
SE	1.0	0.0	15.5	0.0	0.5	0.0	2.1	1.3	0.5	9.2	0.0	**30.1**	0.8	1.0	0.7	14.6	5.2	39.7	7.8	**69.9**
Other EU	3.1	0.0	8.5	2.1	1.6	0.0	1.5	1.5	0.0	0.0	0.0	**18.3**	3.2	2.5	9.0	11.1	0.2	40.5	15.2	**81.7**

Note: Percentages may not total 100 due to rounding

technologies) and France (20% in green and 28% in digital technologies). Other countries, in general, play a relatively minor role in the development of both green and digital technologies in the EU.

Innovative FDI Patterns in the EU

Among the channels through which external knowledge can reach and be absorbed by systems of innovation across places (both national and regional), FDIs are of upmost importance. Indeed, through FDIs, MNCs can transfer knowledge and competencies of which host or home locations could be missing. And these could be crucial for their capacity of developing new technologies also in the digital and in the green domains.

As Fig. 7.2 shows, the flows of innovative FDIs have grown substantially in the EU over the period 2003–2016. The financial crisis that burst in 2009 has inevitably created a deep negative shock, which has reduced substantially the number of innovative foreign greenfield and, even more abruptly, innovative foreign M&As in and from the EU. Still, the shock has been completely reabsorbed afterwards and the same number has grown above the pre-crisis period both in outward and inward terms. In this last respect, Fig. 7.2 confirms that EU countries are more involved in inward than in outward flows, with the gap increasing over the period for innovative greenfield FDIs and remaining broadly unchanged for innovative foreign M&As. In 2016, inward greenfield FDIs have nearly reached the number of inward M&As, while outward greenfield ones remain detached along the flatter trend since 2003.

Tables 7.5 and 7.6 show origin and destination countries of innovative FDIs towards and from the EU. The EU receives more innovative greenfield FDIs from extra-EU countries (1743) than those it directs in extra-EU countries (1486). Similarly, the number of innovative foreign acquisitions of EU target companies made by extra-EU acquirers (1682) is larger than those of extra-EU target companies made by EU acquirers (1127).

Intra-EU greenfield FDIs are proportionally less (28% of total inward and 32% of total outward greenfield FDIs) than intra-EU foreign M&As (43% of total inward and 53% of total outward foreign M&As).

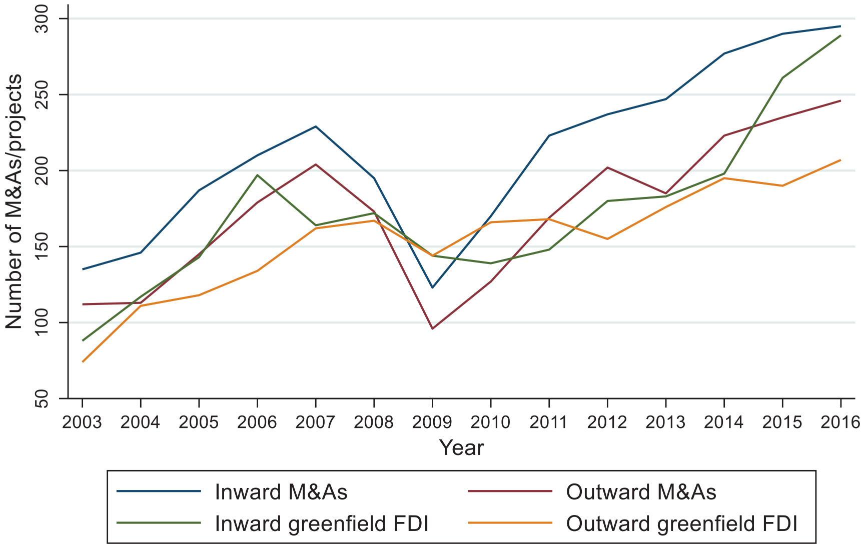

Fig. 7.2 Upward trend in innovative FDIs in the EU, 2003–2016

Relatively large fractions of inward greenfield FDIs into the EU are directed to Germany (17.4% of total inward FDIs), France (12.8%), Ireland (11.1%) and Spain (10.1%). Looking at the distribution of destination countries of foreign acquisitions of EU companies, companies located in Germany (31.6% of total inward M&As) are by far the favourite country of foreign acquirers, followed at large distance by France (12%), Italy (9%) and the Netherlands (7.6%). As for destinations, greenfield outward FDIs of EU countries are predominantly directed to non-EU countries (68.4%, or 1486 out of 2173), especially to the US (17.8%) and to emerging economies like China (16.8%) and India (14.3%). Destinations of foreign outward M&As show a different pattern, as target companies of foreign M&As made by EU acquirers are broadly balanced between EU (53.2%) and non-EU (46.8%) countries. The most prevalent target countries are the US (15.8%), Germany (14.3%) and China (11.7%).

Table 7.5 Innovative greenfield FDIs by destination and source country, 2003–2016

	Destination																			
Origin	DE	FR	IE	ES	PL	RO	BE	CZ	IT	NL	HU	Other EU	**Total EU**	US	CN	IN	UK	CA	Other non-EU	**Total non-EU**	**Total**
DE	.	3.3	1.5	5.1	1.9	2.7	0.7	2.3	0.7	0.6	3.1	7.8	**29.7**	18.8	19.1	15.2	5.0	1.3	10.9	**70.3**	**100.0**
FR	3.9	.	1.2	7.5	2.4	2.7	3.4	0.5	1.0	0.5	1.5	2.7	**27.2**	13.3	15.8	13.8	9.0	9.2	11.7	**72.8**	**100.0**
NL	7.4	3.9	1.5	4.4	3.9	2.5	3.0	1.5	0.0	.	0.0	4.4	**32.5**	20.2	16.7	15.3	11.8	1.0	2.5	**67.5**	**100.0**
SE	4.7	5.3	3.3	2.0	3.3	4.0	0.7	0.7	2.7	1.3	1.3	8.0	**37.3**	11.3	17.3	16.0	7.3	4.0	6.7	**62.7**	**100.0**
DK	5.3	5.3	2.6	2.6	5.3	1.3	0.0	2.6	1.3	1.3	0.0	11.8	**39.5**	23.7	14.5	15.8	1.3	2.6	2.6	**60.5**	**100.0**
IT	9.8	9.8	3.3	11.5	1.6	0.0	3.3	0.0	.	0.0	0.0	6.6	**45.9**	16.4	13.1	9.8	9.8	0.0	4.9	**54.1**	**100.0**
FI	5.1	3.1	1.0	1.0	6.1	1.0	0.0	1.0	0.0	0.0	4.1	8.2	**30.6**	15.3	24.5	16.3	7.1	1.0	5.1	**69.4**	**100.0**
BE	9.0	10.4	1.5	3.0	0.0	4.5	.	0.0	0.0	3.0	0.0	4.5	**35.8**	13.4	13.4	16.4	6.0	7.5	7.5	**64.2**	**100.0**
IE	1.3	2.6	.	5.1	3.8	1.3	0.0	2.6	3.8	1.3	2.6	3.8	**28.2**	30.8	3.8	9.0	20.5	2.6	5.1	**71.8**	**100.0**
Other EU	15.9	7.1	0.9	4.4	5.3	4.4	0.0	1.8	0.0	0.9	0.9	12.4	**54.0**	20.4	3.5	8.0	8.0	3.5	2.7	**46.0**	**100.0**
Total EU	**3.7**	**3.6**	**1.5**	**4.9**	**2.7**	**2.6**	**1.3**	**1.5**	**0.8**	**0.6**	**1.9**	**6.4**	31.6	**17.8**	**16.8**	**14.2**	**7.4**	**3.3**	**8.9**	68.4	100.0
US	15.0	13.9	18.7	7.4	7.5	3.7	4.6	4.0	3.5	3.3	2.6	15.9	**100.0**								
UK	13.7	12.3	11.3	12.7	9.8	5.4	2.5	3.9	2.9	2.5	2.0	21.1	**100.0**								
JP	35.8	19.2	4.2	9.2	0.0	0.0	10.0	2.5	4.2	4.2	0.8	10.0	**100.0**								
CH	24.0	20.2	9.6	6.7	3.8	0.0	2.9	2.9	5.8	3.8	1.9	18.3	**100.0**								
CN	30.3	11.1	4.0	2.0	3.0	2.0	3.0	2.0	11.1	7.1	1.0	23.2	**100.0**								
Other non-EU	28.1	7.9	6.7	8.2	8.6	3.0	3.0	1.5	2.6	5.6	2.6	22.1	**100.0**								
Total non-EU	**19.7**	**13.4**	**13.6**	**7.9**	**6.9**	**3.2**	**4.3**	**3.3**	**3.9**	**3.8**	**2.3**	**17.6**	100.0								
Total	**17.4**	**12.8**	**11.1**	**10.1**	**7.4**	**4.6**	**4.3**	**3.7**	**3.5**	**3.3**	**3.3**	**18.4**	100.0								

Table 7.6 Innovative foreign M&As by target and acquiring country, 2003–2016

	Target																	
Acquirer	DE	FR	IT	NL	SE	FI	ES	DK	BE	Other EU	**Total EU**	US	UK	CH	RU	Other non-EU	**Total non-EU**	**Total**
DE	.	8.3	7.1	6.9	2.8	2.8	3.1	3.1	2.4	9.2	**45.6**	19.9	11.6	10.2	0.2	12.5	**54.4**	**100.0**
FR	13.9	.	7.8	2.5	2.2	1.7	8.6	1.9	4.5	6.1	**49.3**	18.9	11.4	4.2	0.6	15.6	**50.7**	**100.0**
NL	17.7	6.1	5.8	.	3.2	2.3	2.3	1.9	5.5	10.3	**55.0**	15.8	11.9	1.9	1.9	13.5	**45.0**	**100.0**
SE	15.7	2.6	4.9	4.1	.	10.4	0.7	8.6	1.1	4.1	**52.2**	14.6	16.0	3.4	0.4	13.4	**47.8**	**100.0**
IT	19.5	11.7	.	2.6	4.5	3.9	8.4	0.6	0.0	9.1	**60.4**	18.2	7.8	4.5	0.0	9.1	**39.6**	**100.0**
BE	19.2	16.0	4.8	16.8	0.8	4.0	0.8	1.6	.	4.8	**68.8**	8.0	12.0	2.4	0.0	8.8	**31.2**	**100.0**
AT	50.0	6.7	0.8	2.5	0.8	1.7	0.8	2.5	0.8	9.2	**75.8**	4.2	5.8	6.7	0.8	6.7	**24.2**	**100.0**
IE	7.6	2.5	3.4	1.7	0.8	1.7	1.7	0.0	3.4	0.8	**23.7**	39.8	26.3	0.8	0.0	9.3	**76.3**	**100.0**
Other EU	14.1	7.3	4.9	2.3	6.0	2.8	1.3	1.5	1.3	15.4	**57.1**	9.6	8.9	1.7	8.3	14.5	**42.9**	**100.0**
Total EU	**14.3**	**6.2**	**5.2**	**3.8**	**3.0**	**3.4**	**3.2**	**2.6**	**2.4**	**9.0**	**53.2**	**15.8**	**11.7**	**4.2**	**2.3**	**12.8**	**46.8**	**100.0**
US	33.6	13.8	8.6	8.6	8.5	3.9	4.4	4.8	4.0	9.8	**100.0**							
UK	29.2	12.8	8.2	10.0	8.2	3.7	4.1	6.8	2.3	14.6	**100.0**							
CH	46.7	7.8	7.8	4.8	5.4	3.6	4.8	5.4	3.6	10.2	**100.0**							
JP	36.1	13.9	12.5	9.7	8.3	4.2	2.8	0.0	5.6	6.9	**100.0**							
CA	39.0	18.6	6.8	6.8	5.1	5.1	0.0	3.4	5.1	10.2	**100.0**							
CN	50.8	8.5	6.8	8.5	5.1	1.7	3.4	0.0	1.7	13.6	**100.0**							
NO	15.7	5.9	0.0	11.8	35.3	5.9	2.0	19.6	0.0	3.9	**100.0**							
Other non-EU	37.3	10.6	9.5	5.3	2.7	3.4	8.4	6.8	4.6	11.4	**100.0**							
Total non-EU	**35.3**	**12.3**	**8.4**	**8.0**	**7.8**	**3.8**	**4.7**	**5.5**	**3.7**	**10.6**	100.0							
Total	**31.6**	**12.0**	**9.0**	**7.6**	**6.8**	**5.0**	**5.3**	**5.2**	**4.1**	**13.4**	100.0							

3.3 Innovative FDIs and the Knowledge Sources for Green and Digital Inventions: Econometric Analysis

According to the rationale that we have proposed in the theoretical background (Sect. 2), inward and outward FDIs (either as greenfield or M&As) could act as pipelines conveying in EU regions knowledge inputs that are produced in other countries. In so doing, they can be expected to facilitate the use (i.e. citation) of foreign inventive outcomes as prior art knowledge for the development of local green and digital technologies.

To estimate the relationship between innovative FDIs and the knowledge sources of green and digital inventions, we estimate the following gravity equation:

$$\begin{aligned} \text{backcit}^{c}_{i,j,t} = {} & \alpha + \beta_0 IgFDI_{i,j,t-1} + \beta_1 OgFDI_{i,j,t-1} \\ & + \beta_2 IM\,\&\,A_{i,j,t-1} + \beta_3 OM\,\&\,A_{i,j,t-1} + \beta_4 X'_{i,t-1} \\ & + \beta_5 C'_{j,t-1} + \beta_6 DIST_{i,j} + \gamma_t + \varepsilon_{i,j,t} \end{aligned} \tag{7.1}$$

where $\text{backcit}^{c}_{i,j,t}$ stands for the number of citations in technology c (either digital or green) that patents of EU region i make to patents filed in the foreign country j in year t. $X'_{i,t}$ and $C'_{j,t}$ are control variables referring to EU region i and country j, respectively, namely their *GDP*[4] and the stock of patents filed by them under the Patent Co-operation Treaty (PCT). $DIST_{i,j,t-1}$ is a dyadic variable referring to the geographical distance between foreign country j and EU region i,[5] and γ_t are year fixed effects. Innovative FDIs are defined by four dummy variables: $IgFDI_{i,j,t-1}$, which is equal to one if the number of inward greenfield FDI projects in EU region i and originating from foreign country j is greater than 0, and 0 otherwise; $OgFDI_{i,j,t-1}$, equal to 1 if the number of outward greenfield FDI projects in foreign country j originating from EU region i is greater than 0, and 0 otherwise; $IM\,\&\,A_{i,j,t}$, which is equal to 1 if the number of inward M&As targeting a company based in EU

[4] We retrieve data on GDP at the EU regional level from the Cambridge Econometrics database and at country level from the World Development Indicators database.

[5] Data by country pairs on distance were obtained from the CEPII database. Data for region-country pairs were manually computed.

region i and originating from foreign country j is greater than 0, and 0 otherwise; $OM\ \&\ A_{i,\ j,\ t}$, which is equal to 1 if the number of outward M&As targeting a company based in foreign country and originating from EU region i is greater than 0, and 0 otherwise.

We estimate our equation by means of the Pseudo-Poisson Maximum Likelihood estimator separately for digital and green patents. We run our regressions for the period 2003–2016, for which we have data on both patent applications and citations and on FDIs. Furthermore, in order to explore our focal relationship over time, we split our sample into two temporal windows, namely 2003–2009 and 2010–2016.

Table 7.7 reports our regression results for the estimates of Eq. (7.1). Model estimates show that in the period 2010–2016, conditional on GDP and patent stocks of citing regions and cited countries and on their geographical distance,[6] inward innovative greenfield FDIs are significantly and positively associated with backward foreign citations in digital and green EPO patents made by EU-based inventors. This relationship appears stronger and more robust in the case of digital technologies. In this case, inward innovative M&As are also correlated with backward citations. Furthermore, despite a non-significant relation between inward FDI and backward citations in the first half of the period (2003–2009), the association is overall significant across the 2003–2016 period. In the case of backward citations of green patents, beside a lower elasticity, our findings support a statistically significant association only with greenfield investments limited to the more recent period (2010–2016). Conversely, outward FDIs are not statistically significant for the backward citations of both green and digital technologies.

Overall, our econometric evidence supports the view that inward FDIs act as important pipelines allowing regions in the EU to access sources of knowledge abroad. Conversely, results do not support the hypothesis that innovative outward FDI act as pipelines to access foreign knowledge sources and stimulate reverse knowledge transfers.

[6] For what concerns the control variables, model estimates suggest the expected associations, that is, a positive association of foreign backward citations with GDP of origin regions, GDP of country destinations (only for green patents) and patent stocks of origin regions and destination countries, as well as a negative association with geographical distance.

Table 7.7 Innovative FDIs and knowledge sources for green and digital inventions—regression estimation

	Backward citations of digital patents			Backward citations of green patents		
	2003–2016	2003–2009	2010–2016	2003–2016	2003–2009	2010–2016
	(1)	(2)	(3)	(4)	(5)	(6)
Inward innovative greenfield FDIs	0.257**	0.147	0.304**	0.010	–0.096	0.113**
	(0.027)	(0.449)	(0.023)	(0.813)	(0.176)	(0.026)
Outward innovative greenfield FDIs	–0.018	–0.562**	0.097	–0.015	0.026	–0.025
	(0.889)	(0.025)	(0.494)	(0.762)	(0.742)	(0.678)
Inward innovative M&As	0.215*	–0.162	0.334**	–0.019	–0.121	0.050
	(0.090)	(0.532)	(0.022)	(0.662)	(0.110)	(0.296)
Outward innovative M&As	0.129	0.240	0.085	0.034	0.032	0.017
	(0.348)	(0.385)	(0.582)	(0.462)	(0.658)	(0.757)
Regional GDP (Location i, in log)	1.313***	1.134***	1.331***	1.329***	1.387***	1.277***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Country GDP (Location j, in log)	–0.001	–0.058	0.044	0.338***	0.430***	0.249***
	(0.981)	(0.520)	(0.551)	(0.000)	(0.000)	(0.000)
Geographical distance (in log)	–0.499***	–0.301***	–0.567***	–0.461***	–0.401***	–0.511***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Regional patent stocks (Location i, in log)	0.214***	0.163*	0.210***	0.583***	0.537***	0.633***
	(0.000)	(0.052)	(0.000)	(0.000)	(0.000)	(0.000)
Country patent stocks (Location j, in log)	0.110***	0.272**	0.080***	0.122***	0.107***	0.135***
	(0.000)	(0.012)	(0.003)	(0.000)	(0.000)	(0.000)
Observations	70,052	26,200	43,852	795,743	376,931	418,812
Pseudo R-squared	0.487	0.498	0.488	0.717	0.738	0.698

Note: Time dummies included in all regressions. P-values in parentheses: $*p < 0.1$, $**p < 0.05$, $***p < 0.01$

4 Conclusions

Several policy initiatives in and beyond Europe are pushing for the design of new patterns of development to cope with major shocks and challenges the humankind has to deal with nowadays. The development and interlinkage of environmental and digital technologies are the core of these efforts. By shaping knowledge linkages between places, FDIs constitute a leverage of primary interest through which economies can source the knowledge required to develop, adopt and combine green and digital technologies.

In this study we provide evidence of EU green and digital technological trajectories, and assess whether innovative FDIs contribute to them. In particular, we first show how the distribution of the two technologies across countries changes in recent years, as well as the location of the knowledge sources relevant for their development, which we capture using the patent citations of EU green and digital patent applications. We then rely on a gravity-modelling framework to understand whether the foreign knowledge base of green and digital technologies developed in EU metropolitan and NUTS 3 regions correlate with EU innovative FDIs—namely innovative inward and outward greenfield FDIs and cross-border M&As.

EU digital and green technologies show contrasting levels and growth, while geographical patterns are more similar. On the one side, in 2003–2016 for each digital patent application to the EPO there were about 15 (15.4) green ones. Moreover, after a period of steady increase in the 2000s, the development of green technologies shows clear signs of stagnation. By contrast, EU digital patents showed no or moderate increases up to 2012, and a marked increase thereafter. On the other side, Germany and, to a lower extent, France are by far the countries with more patent applications in both technological domains, with a relative specialization of the former in green technologies and of the latter in digital technologies. There are nevertheless signs of recent catching-up of other EU countries, especially in digital technologies, with Germany share of total EU patent applications falling by about 15 percentage points from 2003–09 to 2010–2016 and other countries, namely France and Sweden, increasing their share. Overall, the evidence is consistent with green technologies being (on average) more mature than digital ones.

The knowledge base for the development of both green and digital technologies, which we measure through the patents cited by EU patent applications, is mainly located outside of the EU. Non-EU patent citations account for about 59% EU digital patent applications and about 56% of the green ones. We also find strong geographic concentration of technological knowledge sourcing, with the United States, Germany and Japan accounting alone for about 70% of citations of both EU digital patent applications (32% US, 27% Germany, 11% Japan) and EU green ones (28% Germany, 27% US, 16% Japan).

Preliminary findings of gravity models show that inward innovative FDIs, both inward greenfield FDIs and inward M&As, are significantly and positively associated with the knowledge base of digital technologies. This positive association, which is driven by more recent EU digital patent activities, suggests that foreign MNEs carrying out innovative activities in the EU act as pipelines allowing the EU to access sources of knowledge abroad. This association is strongest in the last decade and in digital rather than green patent activities. These findings are consistent with a relative weakness of the EU in the development of the more advanced digital technologies that have picked up in the last decade. Innovative inward FDIs can facilitate access to foreign digital technologies that can help catching-up of the EU in these technologies. Finally, outward FDIs from EU regions are not associated with citations to technologies developed in the host countries. This result suggests the limited importance for the development of digital and green technologies of reverse knowledge transfer from the destination countries of EU FDIs.

These findings provide valuable new evidence on the role of innovative FDIs for the achievement of the objectives of the new industrial strategy, the European Green Deal and the European Digital Agenda, and provide new insights into the potential leverage that foreign sources of knowledge can have on the development of digital and green technologies in the EU, as well as into the issues of technological vulnerability due to foreign dependency. While the primary focus of the study is on Europe, the results of the analysis aim to have a broader impact by providing novel empirical evidence on an issue of general interest as it emerges, for example, in the 2030 Agenda for Sustainable Development (UN, 2015)—a "Roadmap for redefining sustainable development as a people and planet agenda: A prosperous and fair world within the planetary boundaries" (TWI2050, 2019, p. 7).

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