ISSN 1831-9424

European Commission

JRC TECHNICAL REPORT

The role of inward innovative foreign direct investments in the acquisition of foreign knowledge: the case of EU green and digital inventions

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2023

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EUR 31562 EN

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EU Science Hub
https://joint-research-centre.ec.europa.eu

JRC133591

EUR 31562 EN

PDF	ISBN 978-92-68-04639-5	ISSN 1831-9424	doi:10.2760/387171	KJ-NA-31-562-EN-N

Luxembourg: Publications Office of the European Union, 2023

How to cite this report: Bello, M., Castellani, D., Damioli, G., Marin, G., Montresor, S., *The role of inward innovative foreign direct investments in the acquisition of foreign knowledge: the case of EU green and digital inventions*, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/387171, JRC133591

Contents

Abstract

This paper aims to investigate the role of foreign direct investments (FDIs) in developing the local knowledge base of green and digital inventions in the European Union (EU). By drawing on recent research on the green and the digital transition, we investigate the extent to which inward innovative FDIs – i.e., both greenfield foreign investments and cross-border mergers and acquisitions (M&As) with an innovative content – can constitute a channel through which European regions are exposed to the external knowledge they need for the development of green and digital technologies. Our analysis relies on citation data about green and digital patent applications in the EU and uses this information in a gravity-modelling framework. We find that the knowledge base of green and digital technologies developed in EU metropolitan and NUTS 3 regions positively correlates with innovative inward FDIs. This positive correlation, which appears stronger with respect to greenfield FDIs, is driven by innovative investments originating from outside the EU in the case of digital technologies. By contrast, FDIs from both the EU and outside the EU affect the technological development of green technologies. These findings are consistent with the relative strength of the EU in the development of green technologies, and conversely with its relative weakness in the development of the more advanced digital technologies that have picked up in the last decade.

Acknowledgements

This report benefitted from suggestions and feedback from Valentina Di Girolamo, Athina Karvounaraki, Alessio Mitra and Tiago Pereira (DG Research and Innovation). The authors are also grateful from the comments received from participants at the INNOVA MEASURE V intermediate and final workshops (October 2022 and April 2023). The report is a deliverable of the INNOVA MEASURE V project (Horizon Europe 101052304).

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1 Introduction

The green and the digital transitions are both high on agenda of policy makers to facilitate smart, sustainable and inclusive patterns of growth in countries worldwide. On the one hand, the green transition is needed to curb greenhouse gas emissions and the rise of global temperatures in facing the challenges posed by climate change. On the other hand, the transition towards more advanced and empowering digital technologies provides a range of important opportunities to increase the efficiency of production processes in the era of the Industry 4.0, as well as that of innovation processes that can rely on new General Purpose Technologies and new methods of inventing. Furthermore, despite their non-negligible environmental impact, new digital technologies can also improve green efficiency.

The European Commission had already set the two transitions as a policy target of the 2020 Industrial Strategy for a green and digital Europe, and of other major initiatives, like the European Green Deal and the European Digital Strategy. This overall strategy, aimed at improving the innovative performance of European companies and strengthening their overall competitiveness with special reference to the green and digital technological domains (European Commission, 2020), has been recently updated in the National Recovery and Resilience Plans of the NextGenerationEU. Indeed, the green and the digital transitions recur frequently in the missions of these Plans (Pilati, 2021). The two transitions at stake have fallen under the policy radar also outside Europe. In the US, for example, first a US$2.3 trillion plan has been devoted to the green transition through different actions, including a range of digital initiatives. Then Inflation Reduction Act of 2022 became the most significant legislation in US history offering funding to accelerate the transition to clean energy. Similar initiatives have been taken elsewhere, like in South Korea, with a US$63 billion plan for the development of smart grids and infrastructures for electric vehicles, and in Singapore, with its Green Plan for 2030, where new green digital solutions play a key role.

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 and 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 innovative FDIs – i.e., 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 external knowledge sources that can be combined with 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 organisations 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 and 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 recognised 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. We claim that the regional occurrence of inward innovative FDIs 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 domains.

In order to support our theoretical arguments, we compile a novel dataset combining data on patent applications filed in the metropolitan and NUTS 3 regions of the EU27 and the United Kingdom (which we refer to as EU in the rest of the study), with details on their backward citations and information on inward FDI. We carry out an empirical investigation of the role of FDIs in shaping the knowledge base used in green and digital inventions in EU regions. After identifying EU green and digital patents, we rely on a gravity-modelling framework to understand whether the number of backward citations of green and digital technologies developed in EU regions correlate with inward innovative FDIs – namely EU inward innovative greenfield FDIs and cross-border M&As.

The analysis shows 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 inward greenfield FDI, suggests that foreign multinational enterprises (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. This positive association is driven by innovative foreign investments originating outside the EU in the case of digital technologies. In the case of green technologies, by contrast, FDIs from both the EU and outside the EU affect their technological development.

The rest of the document is structured as follow. Section 2 provides the theoretical background of our study and our contribution to it. Section 3 illustrates the data alongside basic descriptive statistics. Section 4 presents our empirical strategy, whereas Section 5 discusses the results. Section 6 concludes.

2 Theoretical background

This work is positioned in the economic geography literature, which provides a picture of the globalised world economy as a set of locations with 'local buzz' (Storper and Venables 2004) connected by 'global pipelines' (Bathelt et al. 2004). In this scenario, companies and multinational enterprises, in particular, are the key actors shaping external connections of local places, and serving as conduits for multidirectional knowledge flows between them (e.g., Cano-Kollmann et al. 2016, Crescenzi and Iammarino 2017, Iammarino and McCann 2013, Song 2014). Indeed, while most interactions take place between agents within geographically delimited areas, often creating clusters (or buzz) with especially dense activities, cross-local and cross-national connections (or pipelines) are key to allow combinations of different knowledge inputs and avoid cognitive lock-in situations (Balland and Boschma, 2021; Boschma 2005, Giuliani and Bell 2005; Zhu et al., 2017).

The tension between local and global forces has also been remarked by the literature about regional technological specialisation 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 and 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 (Zhu et al., 2017; He al., 2018). 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 MNE 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 and 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 can in fact benefit from knowledge inputs from the MNEs of both disembodied nature (pure knowledge spillovers), for example through research cooperation with MNEs, and of 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 focus on the relationship between regional green and digital inventions and inward FDI and look at the knowledge-conveying role of the latter more directly. 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 local knowledge base on which inventions can draw. Following the Schumpeterian theory of recombinant innovations (Weitzman, 1998; Frenken et al., 2012), we posit that FDIs in activities with an innovation content – e.g., 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 MNE 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 MNE. Just to make an example, we could expect that innovative FDIs from US-based MNEs, which are directed to a European region, could increase the extent to which patents from that region cite patents from US-based inventors.

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) (Martinelli et al., 2021; Bianchini et al., 2022a). Because of these features, in the development of these technologies, the cross-fertilisation of ideas across different knowledge domains is very pervasive and this also makes the FDI mechanism we are investigating of crucial relevance and an additional important contribution to the literature

3 Data and descriptive analysis

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 Env-tech 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, 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 et al., (2022b) 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.[1]

Following a consolidated stream of research (see Thompson and Fox-Kean, 2005), citations contained in patent data are used to map the knowledge flows that represent our main dependent variable. More precisely, we use the backward patent citations of a green or digital patent as a measure of the knowledge base on which the relative green or digital invention draws. In order to do so, we georeferenced the citing patents at the EU metropolitan and NUTS 3 region-level[2] based on the residence of the inventor. The cited patent are instead georeferenced at the country-level as information on the region of residence of inventors cannot be consistently collected for cited patents filed at non-EPO patent offices. 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 in fact be assigned, for internal strategies, to the headquarter of the company or to the ultimate owner, in a different place than that of the relative invention[3].

This study investigates the extent to which innovative inward FDIs can be retained conducive of the knowledge flows at the basis of green and digital inventions filed in EU metropolitan and NUTS 3 regions. Following an established practice (Castellani and Pieri, 2013; Belderbos et al. 2016; Damioli and Marin, 2020), we define innovative greenfield FDIs as the investment 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 retained as the acquisitions of a foreign target company that made one or more patent applications in the 20 years before the deal completion (Damioli and Marin, 2020; Aquaro et al. 2021).

Finally, in investigating the role of FDIs, we control for a vector of variables that could influence the total number of backward citations of green and digital patents. These include: number of digital and green patents in the FDI hosting location, its GDP, total patent stocks and a vector of dyadic variables between FDI origin country and FDI hosting location, such as their geographical contiguity, geographical distance, differences in time zones, commonality of language spoken, and commonality of religion. We retrieve data on GDP at the EU regional level from the ARDECO database (Cambridge Econometrics) and at country level from the World Development Indicators database (World Bank). Figures on patent stocks are derived from the OECD REGPAT Database (perpetual inventory method, 20% annual depreciation), whereas data for the dyadic variables were derived from the CEPII database and own calculation (e.g. region-by-country distances). Our analysis focuses on the period 2003-2017. The choice of this time period is dictated by the time lag required for patent applications filing date at the time when we retrieved digital patents in PATSTAT. Basic descriptive statistics for our focal and control variables are provided in Table A.1 in Annex 1.

As shown in Bello et al. (2023), the numbers of EU applications in digital and green technologies have increased in the last two decades, with, digital patents reporting more marked increases in the most recent

[1] See Bello et al. (2023) for a more comprehensive description of these categories and the overall methodology.

[2] The metropolitan regions correspond to NUTS 3 regions or combinations of NUTS 3 regions constituting agglomerations of at least 250,000 inhabitants. These agglomerations were identified using the Eurostat and European Commission DG REGIO classification based on Urban Audit's Functional Urban Area (FUA), which are 'functional economic units' based on density and commuting patterns of the smallest administrative units for which national commuting data are available (NUTS 3 level in Europe). NUTS 3 regions with more than 50% of the population living within a given agglomeration are aggregated in a metropolitan region.

[3] We use fractional counting of patents by region for those patents with inventors from multiple regions. The same applies for citations count where the inventors of the cited patent reside in different countries.

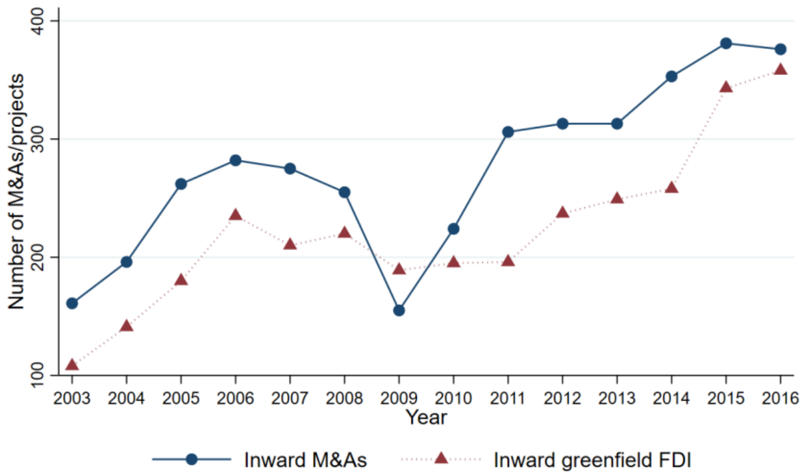
years, reflecting the unprecedented widespread application to a growing number of industries and business functions (Clark 2015, McKinsey 2018). The development of digital and green technologies is driven by a relatively small number of European regions concentrated in Continental Europe and Sweden, with green patents being slightly more geographically dispersed than digital ones. As for the location of the related technological knowledge base, extra-EU patent citations account for nearly 60% of all patent citations found in EU digital and green patents, with the United States and Japan accounting alone for the largest shares. Within the EU, Germany is the most important source of knowledge for green and digital technologies.

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, MNEs 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 Figure 1 shows, the flows of innovative FDIs have grown substantially in the EU over the period 2003 – 2017. The financial crisis that burst in 2009 has inevitably created a deep negative shock, which has reduced substantially the number of innovative inward foreign greenfield and, even more abruptly, innovative foreign M&As in the EU. Still, the shock has been completely reabsorbed afterwards and the same number has grown above the pre-crisis period. In 2017, inward greenfield FDIs have nearly reached the number of inward M&As. In terms of origin countries of innovative FDIs, the EU receives more innovative greenfield FDIs from extra-EU countries (66%) than innovative brownfield FDIs (54%). A very large fraction of inward FDIs originate from the US (42% and 32% for greenfield and M&As, respectively) (

Table 1).

Figure 1. Trend in inward innovative FDI, EU28, 2003-2017



Source: Authors' calculation based on fDi Markets and Zephyr datasets

Table 1 Innovative inward FDI by origin and investment mode, EU28, 2003-2016

	EU28	CA	CH	CN	IN	JP	KR	NO	RU	US	Other extra- EU28
Greenfield FDI	33.70	2.08	3.75	3.66	2.73	5.29	1.44	0.99	0.77	41.90	3.69
M&As	46.29	2.23	4.93	1.71	1.66	2.54	0.52	1.84	0.86	31.59	5.82

Source: Authors' calculation based on fDi Markets and Zephyr datasets

4 Econometric strategy

As laid out in Section 2, inward FDIs (either as greenfield or M&As) can 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 of foreign inventive outcomes as prior art knowledge for the development of local green and digital technologies, thus leading to citations of patents from inventors based in the home country of such MNEs.

To estimate the relationship between inward innovative FDIs and the knowledge sources of green and digital inventions, we adopt a gravity model, whose use has become popular in the economic literature over the past years. The gravity model, which is inspired by the basic gravity equation in Newton's physics, was initially adopted to study trade flows determinants.[4] It typically explains bilateral trade flows as a function of countries' size and the distance between countries pairs.

Overall, the focus of gravity models is on dyadic relationships, for which the coupling between specific receivers and senders of the flow at stake and their manifold distance, are crucial. This is particularly important in our case, as the knowledge base of regions receives different knowledge inputs by knowledge sources located in different areas. This study adopts a gravity model, wherein bilateral citations between an EU region and a foreign location (regions in the EU and countries outside the EU) depend on the number of bilateral FDI flows between the two locations and a number of additional potential explanatory factors. Our baseline equation is as follows:

$$backcit_{i,j,t}^{c} = \alpha + \sum_{s=1}^{4} \beta_s \, IFDI_{i,j,t-s} + \beta_{5_{i,j,t}} \log(PAT_{i,j,t}^{c}) + X'_{i,t}\beta_6 + C'_{j,t}\beta_7 + D'_{i,j}\beta_8 + \gamma_t + \delta_i + \mu_j + \varepsilon_{i,j,t} \qquad (1)$$

where $backcit_{i,j,t}^{c}$ stands for the number of citations that patents in technology *c* (either digital or green) filed in year *t* with inventors residing in EU region *i* make to patents with inventors residing in foreign location *j* (other EU regions and extra-EU countries). $PAT_{i,t}^{c}$ is the number of patents in technology *c* (either digital or green) filed by inventors residing in EU region *i* 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 (in log) and stock of patents (in log) filed under the Patent Co-operation Treaty (PCT). $D'_{i,j}$ is a vector of dyadic variables referring to the foreign location *j* and EU region *i* pairs and including contiguity, time-zone difference, common currency, common religion, common legal origin, and common language. γ_t, δ_i, and μ_j are year, citing and cited patents location fixed effects. $IFDI_{i,j,t}$ is our focal regressor. This is identified by a dummy variable, which is equal to one if the number of innovative inward (greenfield or brownfield) FDI projects in EU region *i* and originating from foreign country *j* is greater than 0, and 0 otherwise. To allow for the elapsing of time in the unfolding of the effect of FDI on backward citations, we adopt a distributed-lag model with respect to our focal regressor at four lags.

As a second step, we disentangle the effects of innovative greenfield FDIs ($IgFDI_{i,j,t-s}$) from that of innovative cross-border M&As ($IM\&A_{i,j,t-s}$) in the following model:

$$backcit_{i,j,t}^{c} = \alpha + \sum_{s=1}^{4} \rho_s \, IgFDI_{i,j,t-s} + \sum_{s=1}^{4} \rho_{4+s} \, IM\&A_{i,j,t-s} + \rho_{9_{i,j,t}} \log(PAT_{i,j,t}^{c}) + X'_{i,t}\rho_{10} + C'_{j,t}\rho_{11} + D'_{i,j}\rho_{12} + \gamma_t + \delta_i + \mu_j + \varepsilon_{i,j,t} \qquad (2)$$

We expect that the mode of entry can influence the relationship between innovative FDIs and foreign knowledge sourcing. Greenfield FDIs create new assets and bring in additional production capacity, while brownfield investment only involves a change of ownership of existing assets or production capacity. Accordingly, the former could have a more direct role in expanding the access to foreign-based knowledge, while the effects of the latter may take longer to materialise.

[4] See the seminal paper by Tinbergen (1962) and the theoretical foundations provided by Anderson and Van Wincoop (2003). Helpman et al. (2008) and Melitz and Ottaviano (2008) provide additional contributions to the theoretical micro-foundations, suggesting that heterogeneous firm models are compatible with the gravity approach. Theoretical background and micro-foundations of gravity equations are provided by Head and Mayer (2014).

Because both our dependent variables and our focal regressors can be correlated with omitted region- and country-level time varying characteristics, such as changes in innovation or industrial policies, we also run a variation of Eq. (1) and Eq. (2). In such a variation, citing and cited patents location dummies interacted by year are included in replacement of γ_t, δ_i, and μ_j.

Finally, we maintain that the effects of innovative inward FDIs on foreign knowledge sourcing can also depend on the origin of the investment. On one hand, we could expect FDIs originating from extra-EU countries to be more likely to increase the host regions' exposure to the inventing activities of the firms located in the home countries, than FDIs originating from another EU country. This hypothesis rests on two main considerations. Firstly, as shown in Section 3, EU inventors use more extra-EU than EU knowledge in their inventing activities. Secondly, because of economic and cultural linkages, knowledge transfer among EU countries is more likely to take place even without the occurrence of FDIs. The effect of the latter is therefore likely to be weaker. To tackle these issues, we distinguish between innovative FDIs originating from the EU and those from extra-EU countries. We then run a fully interacted variation of Eq. (1) and Eq. (2), where an interaction term between a dummy variable referring to the EU28 region and each of the model covariates is added to each equation.

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 2003-2017. Complete regression estimates are provided in Annex 1, while *Table 2* and *Table 3* report the cumulative coefficients of our focal regressors.

5 Main results

Table 2 reports our regression results for the estimates of Eq.(1) and Eq.(2). Model estimates show that inward innovative FDIs are significantly and positively associated with backward foreign citations in both digital and green EPO patents made by EU-based inventors (Columns 1,2, 4 and 5). This relationship appears stronger in the case of digital technologies: the coefficient of inward innovative FDI is nearly three times larger than that obtained in the green case. These results support our main research hypothesis about the mechanism through which inward-FDIs can benefit the hosting locations in innovative terms. Their contribution to the local knowledge-base of inventive activities is indeed significant and shows an interesting heterogeneity between green and digital technologies.

When distinguishing between mode of entry (Columns 3 and 6), we find that the positive association between inward FDIs and backward citations is largely driven by inward greenfield FDIs for both digital and green technologies. The estimates associated with cross-border M&A are, by contrast, not statistically significant in the digital case, while showing a weakly significant relationship in the case of green technologies. This result is also consistent with our expectations. The role of inward FDIs in adding to the local knowledge base of inventive activities, in both green and digital technologies, appears to require that FDIs create new assets in the hosting place and bring to it additional production and innovation capacity.

For what concerns control variables, model estimates support the expectation that the number of citations in both green and digital patents is negatively correlated with the distance and the time-zone difference between citing and cited locations. In addition, EU inventors of green technologies are more likely to cite patents of inventors residing in a location with a common language and a common legal origin. The parameters associated with contiguity and common religion between citing and cited locations are not statistically significant. Our estimates also indicate a positive relationship between the number of citations with the number of citing patents and the patent stock of the cited location in both green and digital technologies, a positive relationship with the GDP of the cited location for green technologies and a negative relationship with the patent stock of the origin region for digital ones. The latter may simply reveal that, citations are more likely in cases where digital technologies represent a larger share of overall patents.

Table 3 reports our regression results for the variations of Eq.(1) and Eq.(2) based on a fully interacted model using an EU28-related dummy. Our estimates confirm our hypothesis that greenfield inward FDIs act as pipelines allowing regions in the EU to access foreign knowledge. For digital technologies, it is the access to extra-EU knowledge that matters. For green technologies, by contrast, the coefficients associated with greenfield FDIs from both EU and extra-EU locations are both statistically significant. For green technologies, in addition, also the acquisition of innovative EU targets made by extra-EU MNEs seem to play a role, though the associated positive is of smaller magnitude. Considering the different extent to which EU countries master digital and green technologies with respect to extra-EU countries, with a relative advantage in the latter, this is another interesting result. Indeed, it suggests that the technological gap between the home FDI country and the local host of it, as revealed by the stage of development the extant technologies have across the two, could be an important conditioning factor of the role of FDIs for the construction of the regional knowledge base.

Table 2: Innovative FDIs and knowledge sources for green and digital inventions – regression estimation

	Dependent variable: Number of backward patent citations					
	Digital patents			Green patents		
	(1)	(2)	(3)	(4)	(5)	(6)
Inward FDI (Cumulative effect)	0.501*	0.611***		0.180**	0.202***	
	(0.269)	(0.180)		(0.072)	(0.054)	
Inward Greenfield FDI (Cumulative effect)			1.610***			0.516***
			(0.335)			(0.121)
Inward M&As (Cumulative effect)			0.062			0.108*
			(0.196)			(0.059)
Distance (in log)	-0.382***	-0.369***	-0.375***	-0.305***	-0.303***	-0.303***
	(0.107)	(0.098)	(0.097)	(0.031)	(0.027)	(0.027)
Contiguity	-0.495*	-0.461*	-0.423	0.048	0.047	0.064
	(0.263)	(0.261)	(0.259)	(0.078)	(0.065)	(0.065)
Time-zone difference	-0.436***	-0.441***	-0.378***	0.091***	0.090***	0.094***
	(0.082)	(0.071)	(0.067)	(0.027)	(0.022)	(0.022)
Common currency	-0.013	-0.012	0.038	0.227***	0.235***	0.244***
	(0.150)	(0.136)	(0.133)	(0.046)	(0.038)	(0.038)
Common religion	-0.171	-0.147	-0.103	-0.106	-0.123	-0.114
	(0.257)	(0.259)	(0.260)	(0.087)	(0.079)	(0.079)
Common legal origin	0.156*	0.086	0.072	0.244***	0.243***	0.240***
	(0.094)	(0.083)	(0.084)	(0.030)	(0.026)	(0.026)
Common language	-0.216	-0.145	-0.151	0.156***	0.156***	0.154***
	(0.146)	(0.129)	(0.131)	(0.054)	(0.045)	(0.044)
GDP origin (in log)	0.407			0.076		
	(0.346)			(0.103)		
GDP destination (in log)	0.690			0.440**		
	(1.181)			(0.198)		
Number of green/digital patents origin (in log)	0.957***			0.919***		
	(0.058)			(0.018)		
Patent stock origin (in log)	-0.579**			0.022		
	(0.257)			(0.084)		
Patent stock destination (in log)	1.221***			1.381***		
	(0.384)			(0.109)		
Fixed effects	Origin, destination and year	Origin-year and destination-year	Origin-year and destination-year	Origin, destination and year	Origin-year and destination-year	Origin-year and destination-year
Pseudo R2	0.619	0.595	0.596	0.716	0.710	0.710
N	39,375	19,211	19,211	331,327	192,761	192,761

*Note: PPML regression estimation. Standard errors clustered by region in parentheses. * p<0.1, ** p<0.05, *** p<0.01. Complete regression estimates are provided in Annex 1.*

Table 3: Innovative FDIs by origin and knowledge sources for green and digital inventions – regression estimation

	Dependent variable: Number of backward patent citations			
	Digital patents		Green patents	
	(1)	(2)	(3)	(4)
Inward FDI, extra-EU origin (Cumulative effect)	0.843***		0.298***	
	(0.200)		(0.065)	
Inward FDI, EU origin (Cumulative effect)	-0.557		0.057	
	(0.373)		(0.083)	
Inward Greenfield FDI, extra-EU origin (Cumulative effect)		1.563***		0.423***
		(0.374)		(0.130)
Inward Greenfield FDI, EU origin (Cumulative effect)		0.083		0.802***
		(1.080)		(0.239)
Inward M&As, extra-EU acquirer (Cumulative effect)		0.236		0.248***
		(0.229)		(0.075)
Inward M&As, EU acquirer (Cumulative effect)		-0.639		-0.101
		(0.408)		(0.089)
Fixed effects	Origin-year and destination-year	Origin-year and destination-year	Origin-year and destination-year	Origin-year and destination-year
Pseudo R2	0.597	0.597	0.710	0.710
N	19,211	19,211	192,999	192,999

*Note: PPML regression estimation based on a fully interacted model. Standard errors clustered by region in parentheses. * p<0.1, ** p<0.05, *** p<0.01. Complete regression estimates are provided in Annex 1.*

6 Conclusions

Several policy initiatives in Europe and beyond 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 of new environmental and digital technologies is at 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 with green and digital technologies.

In this study we 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 greenfield FDIs and cross-border M&As.

Our estimates indicate that inward innovative FDIs, and especially inward greenfield FDIs, are significantly and positively associated with the international knowledge sourcing in the development of both in digital and green technologies. This positive association is driven by innovative investments originating outside the EU in the case of digital technologies, suggesting that foreign MNEs carrying out innovative activities in the EU act as pipelines allowing the EU to access sources of knowledge abroad. In the case of green technologies, by contrast, FDIs from both the EU and outside the EU affect technological development. These findings are consistent with the relative strength of the EU in the development of green technologies, and conversely with its relative weakness in the development of the more advanced digital technologies that have picked up in the last decade. These findings support the view that innovative greenfield inward FDIs from outside the EU can facilitate access to foreign digital technologies that can help the catching-up of the EU with respect to more advanced foreign countries.

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. Indeed, our results show that the attraction of FDIs, and national and local policies that revolve around it, could have a non-negligible role in the toolbox of policy leverages so far assembled to assist the green and the digital transition. This should be retained with close scrutiny by EU policy makers given that, while being a leverage to source foreign knowledge for the development of digital and green technologies in the EU, inward innovative FDIs could pose issues of technological vulnerability due to foreign dependency, which could affect the strategic autonomy the EU is struggling to gain.

In concluding, it should be stressed that, while the primary focus of the study is on Europe, the results of the analysis can have a broader impact also outside of it. In particular, our study provides 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).

vitae dui lectus.

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List of abbreviations and definitions

CPC	Cooperative Patent Classification
EU	European Union
FDI	Foreign Direct Investment
M&A	Mergers and acquisitions
MNE	Multinational enterprise
NUTS	Nomenclature of Territorial Units for Statistics
IPC	International Patent Classification

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Annex 1. Additional tables

Table A.1 Descriptive statistics on main variables

Variable	Mean	Sd	Min	Max
Backward citations of digital patents	0.001	0.086	0.000	72.750
Backward citations of green patents	0.015	0.374	0.000	148.567
Inward FDI	0.004	0.065	0.000	1.000
Inward Greenfield FDI	0.001	0.025	0.000	1.000
Inward M&As	0.004	0.062	0.000	1.000
Contiguity	0.001	0.029	0.000	1.000
Time-zone difference	3.531	3.184	0.000	12.000
Common currency	0.056	0.229	0.000	1.000
Common religion	0.187	0.236	0.000	0.973
Common legal origin	0.225	0.417	0.000	1.000
Common language	0.068	0.251	0.000	1.000
Number of digital patents (origin, in log)	-0.224	0.969	-2.639	3.166
Number of green patents (origin, in log)	0.931	1.093	-2.890	4.581
GDP (origin, in log)	23.867	2.426	16.719	30.601
GDP (destination, in log)	8.702	1.160	5.093	13.688
Patent stock (origin, in log)	3.682	2.300	-6.072	9.663
Patent stock (destination, in log)	2.128	3.634	-8.256	12.114
Distance (in log)	8.460	0.860	0.612	9.904

Table A.2 Innovative FDIs and knowledge sources for digital inventions – complete regression results

	Dependent variable: Number of backward citations of digital patents		
	(1)	(2)	(3)
Inward FDI (t-1)	0.215**	0.161*	
	(0.098)	(0.094)	
Inward FDI (t-2)	0.124	0.149	
	(0.109)	(0.091)	
Inward FDI (t-3)	0.005	0.027	
	(0.111)	(0.098)	
Inward FDI (t-4)	0.157	0.273***	
	(0.107)	(0.090)	
Inward Greenfield FDI (t-1)			0.422*
			(0.218)
Inward Greenfield FDI (t-2)			0.484**
			(0.237)
Inward Greenfield FDI (t-3)			0.234
			(0.210)
Inward Greenfield FDI (t-4)			0.469**
			(0.203)
Inward M&As (t-1)			0.013
			(0.101)
Inward M&As (t-2)			-0.015
			(0.099)
Inward M&As (t-3)			-0.071
			(0.110)
Inward M&As (t-4)			0.135
			(0.099)
Distance (in log)	-0.382***	-0.369***	-0.375***
	(0.107)	(0.098)	(0.097)
Contiguity	-0.495*	-0.461*	-0.423
	(0.263)	(0.261)	(0.259)
Time-zone difference	-0.436***	-0.441***	-0.378***
	(0.082)	(0.071)	(0.067)
Common currency	-0.013	-0.012	0.038
	(0.150)	(0.136)	(0.133)
Common religion	-0.171	-0.147	-0.103
	(0.257)	(0.259)	(0.260)
Common legal origin	0.156*	0.086	0.072
	(0.094)	(0.083)	(0.084)
Common language	-0.216	-0.145	-0.151
	(0.146)	(0.129)	(0.131)
Number of digital patents origin (in log)	0.957***		
	(0.058)		
GDP origin (in log)	0.407		
	(0.346)		
GDP destination (in log)	0.690		

	Dependent variable: Number of backward citations of digital patents		
	(1)	(2)	(3)
	(1.181)		
Patent stock origin (in log)	-0.579**		
	(0.257)		
Patent stock destination (in log)	1.221***		
	(0.384)		
Constant	-23.919**	5.892***	5.555***
	(11.100)	(0.928)	(0.901)
Fixed effects	Origin, destination and year	Origin-year and destination-year	Origin-year and destination-year
Pseudo R2	0.619	0.595	0.596
N	39375	19211	19211

*Note: PPML regression estimation. Standard errors clustered by region in parentheses. * p<0.1, ** p<0.05, *** p<0.01.*

Table A.3 Innovative FDIs and knowledge sources for green inventions – complete regression results

	Dependent variable: Number of backward citations of green patents		
	(1)	(2)	(3)
Inward FDI (t-1)	0.004	0.059**	
	(0.032)	(0.028)	
Inward FDI (t-2)	0.107**	0.092**	
	(0.048)	(0.038)	
Inward FDI (t-3)	0.011	0.027	
	(0.034)	(0.029)	
Inward FDI (t-4)	0.059	0.024	
	(0.037)	(0.035)	
Inward Greenfield FDI (t-1)			0.158**
			(0.067)
Inward Greenfield FDI (t-2)			0.211***
			(0.067)
Inward Greenfield FDI (t-3)			0.176***
			(0.065)
Inward Greenfield FDI (t-4)			-0.029
			(0.088)
Inward M&As (t-1)			0.032
			(0.029)
Inward M&As (t-2)			0.065
			(0.042)
Inward M&As (t-3)			-0.019
			(0.030)
Inward M&As (t-4)			0.029
			(0.036)
Distance (in log)	-0.305***	-0.303***	-0.303***
	(0.031)	(0.027)	(0.027)
Contiguity	0.048	0.047	0.064
	(0.078)	(0.065)	(0.065)
Time-zone difference	0.091***	0.090***	0.094***
	(0.027)	(0.022)	(0.022)
Common currency	0.227***	0.235***	0.244***
	(0.046)	(0.038)	(0.038)
Common religion	-0.106	-0.123	-0.114
	(0.087)	(0.079)	(0.079)
Common legal origin	0.244***	0.243***	0.240***
	(0.030)	(0.026)	(0.026)
Common language	0.156***	0.156***	0.154***
	(0.054)	(0.045)	(0.044)
Number of green patents origin (in log)	0.919***		
	(0.018)		
GDP origin (in log)	0.076		
	(0.103)		
GDP destination (in log)	0.440**		

	Dependent variable: Number of backward citations of green patents		
	(1)	(2)	(3)
	(0.198)		
Patent stock origin (in log)	0.022		
	(0.084)		
Patent stock destination (in log)	1.381***		
	(0.109)		
Constant	-21.055***	2.823***	2.796***
	(3.099)	(0.243)	(0.243)
Fixed effects	Origin, destination and year	Origin-year and destination-year	Origin-year and destination-year
Pseudo R2	0.716	0.710	0.710
N	331327	192761	192761

*Note: PPML regression estimation. Standard errors clustered by region in parentheses. * p<0.1, ** p<0.05, *** p<0.01.*

Table A.4 Innovative FDIs by origin and knowledge sources for digital inventions – complete regression results

	Dependent variable: Number of backward citations of digital patents	
	(1)	(2)
Inward FDI (t-1)	0.225**	
	(0.108)	
Inward FDI (t-2)	0.342***	
	(0.111)	
Inward FDI (t-3)	-0.038	
	(0.115)	
Inward FDI (t-4)	0.313***	
	(0.107)	
Inward FDI (t-1) * EU28	-0.340*	
	(0.194)	
Inward FDI (t-2) * EU28	-0.833***	
	(0.253)	
Inward FDI (t-3) * EU28	0.043	
	(0.235)	
Inward FDI (t-4) * EU28	-0.270	
	(0.211)	
Inward Greenfield FDI (t-1)		0.382
		(0.241)
Inward Greenfield FDI (t-2)		0.464
		(0.285)
Inward Greenfield FDI (t-3)		0.259
		(0.232)
Inward Greenfield FDI (t-4)		0.458
		(0.289)
Inward Greenfield FDI (t-1) * EU28		-0.840
		(0.848)
Inward Greenfield FDI (t-2) * EU28		-0.206
		(0.525)

	Dependent variable: Number of backward citations of digital patents	
	(1)	(2)
Inward Greenfield FDI (t-3) * EU28		-0.165
		(0.671)
Inward Greenfield FDI (t-4) * EU28		-0.269
		(0.445)
Inward M&As (t-1)		0.064
		(0.121)
Inward M&As (t-2)		0.183
		(0.122)
Inward M&As (t-3)		-0.210
		(0.130)
Inward M&As (t-4)		0.199*
		(0.115)
Inward M&As (t-1) * EU28		-0.187
		(0.208)
Inward M&As (t-2) * EU28		-0.730***
		(0.272)
Inward M&As (t-3) * EU28		0.302
		(0.238)
Inward M&As (t-4) * EU28		-0.260
		(0.244)
Distance (in log)	-0.318	-0.366*
	(0.215)	(0.216)
Contiguity	0.574	0.560
	(0.503)	(0.501)
Time-zone difference	-0.375***	-0.328***
	(0.084)	(0.081)
Common currency	0.006	0.067
	(0.137)	(0.136)
Common religion	0.646	0.555

	Dependent variable: Number of backward citations of digital patents	
	(1)	(2)
	(0.572)	(0.556)
Common legal origin	0.125	0.143
	(0.106)	(0.107)
Common language	0.055	-0.063
	(0.197)	(0.194)
Distance (in log) * EU28	-0.086	-0.011
	(0.243)	(0.243)
Contiguity * EU28	-1.165**	-1.129*
	(0.583)	(0.582)
Time-zone difference * EU28	-0.184	-0.182
	(0.197)	(0.187)
Common religion* EU28	-0.886	-0.706
	(0.647)	(0.632)
Common legal origin * EU28	-0.090	-0.165
	(0.191)	(0.195)
Common language * EU28	-0.283	-0.114
	(0.268)	(0.272)
Constant	5.092***	5.100***
	(1.443)	(1.460)
Fixed effects	Origin-year and destination-year	Origin-year and destination-year
Pseudo R2	0.597	0.597
N	19211	19211

*Note: PPML regression estimation based on a fully interacted model. Standard errors clustered by region in parentheses. * p<0.1, ** p<0.05, *** p<0.01*

Table A.5 Innovative FDIs by origin and knowledge sources for green inventions – complete regression results

	Dependent variable: Number of backward citations of green patents	
	(1)	(2)
Inward FDI (t-1)	0.063*	
	(0.035)	
Inward FDI (t-2)	0.140***	
	(0.053)	
Inward FDI (t-3)	0.054	
	(0.037)	
Inward FDI (t-4)	0.041	
	(0.049)	
Inward FDI (t-1) * EU28	-0.013	
	(0.057)	
Inward FDI (t-2) * EU28	-0.117	
	(0.071)	
Inward FDI (t-3) * EU28	-0.065	
	(0.059)	
Inward FDI (t-4) * EU28	-0.046	
	(0.066)	
Inward Greenfield FDI (t-1)		0.130
		(0.080)
Inward Greenfield FDI (t-2)		0.216***
		(0.079)
Inward Greenfield FDI (t-3)		0.144*
		(0.075)
Inward Greenfield FDI (t-4)		-0.067
		(0.109)
Inward Greenfield FDI (t-1) * EU28		0.089
		(0.140)
Inward Greenfield FDI (t-2) * EU28		0.015
		(0.148)
Inward Greenfield FDI (t-3) * EU28		0.122
		(0.145)
Inward Greenfield FDI (t-4) * EU28		0.153
		(0.168)
Inward M&As (t-1)		0.052
		(0.038)
Inward M&As (t-2)		0.116*
		(0.061)
Inward M&As (t-3)		0.007
		(0.040)
Inward M&As (t-4)		0.073
		(0.051)
Inward M&As (t-1) * EU28		-0.053
		(0.061)

	Dependent variable: Number of backward citations of green patents	
	(1)	(2)
Inward M&As (t-2) * EU28		-0.124
		(0.079)
Inward M&As (t-3) * EU28		-0.067
		(0.061)
Inward M&As (t-4) * EU28		-0.104
		(0.069)
Distance (in log)	-0.245***	-0.246***
	(0.067)	(0.067)
Contiguity	0.485**	0.486**
	(0.212)	(0.213)
Time-zone difference	0.096***	0.096***
	(0.027)	(0.027)
Common currency	0.209***	0.213***
	(0.039)	(0.039)
Common religion	-0.195	-0.198
	(0.190)	(0.189)
Common legal origin	0.212***	0.215***
	(0.033)	(0.033)
Common language	0.189***	0.177***
	(0.062)	(0.062)
Distance (in log) * EU28	-0.054	-0.058
	(0.075)	(0.075)
Contiguity * EU28	-0.481**	-0.445**
	(0.222)	(0.223)
Time-zone difference * EU28	-0.062	-0.059
	(0.047)	(0.046)
Common religion* EU28	0.031	0.046
	(0.197)	(0.197)
Common legal origin * EU28	0.101	0.089
	(0.063)	(0.062)
Common language * EU28	-0.076	-0.065
	(0.091)	(0.090)
Constant	2.473***	2.486***
	(0.402)	(0.402)
Fixed effects	Origin-year and destination-year	Origin-year and destination-year
Pseudo R2	0.710	0.710
N	192999	192999

*Note: PPML regression estimation based on a fully interacted model. Standard errors clustered by region in parentheses. * p<0.1, ** p<0.05, *** p<0.01*

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