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EU Framework Programmes and green co-invention across European regions

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Abstract

We examine how participation in EU Framework Programmes (FPs) relates to green patenting and interregional green co-invention. Combining OECD REGPAT applications classified using ENV-TECH with CORDIS records for FP7 (2007-2013) and Horizon 2020 (2014-2020), we construct regional and dyadic panels for EU-28 NUTS 2 regions. Regional fixed-effects Poisson pseudo-maximum likelihood (PPML) models show no statistically significant association between green FP project participation and green patent counts. Green project-network connectedness, however, is positively and significantly associated with these counts. At the dyadic level, green FP collaboration is positively associated with green co-patenting between the same region pairs after controlling for dyad and region-time fixed effects. This association is consistent across the reported specifications for patent counts and the green-to-non-green patent ratio but less consistent for the green share of total patenting. Descriptive evidence shows concentrated green co-patenting alongside more geographically dispersed FP collaboration and uneven increases in cross-border orientation. The findings distinguish regional programme participation from the breadth of project networks and the intensity of bilateral links. They identify conditional associations, supporting a network-based interpretation of FP collaboration without establishing its causal effect on green invention.

Keywords: EU Framework Programmes, green patenting, NUTS 2 regions, regional innovation, interregional co-invention, knowledge networks

JEL classification: O38, O31, Q55, R11, R58

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1. Introduction

Climate-mitigation technologies are central to the EU's decarbonisation agenda, which requires the invention, diffusion and deployment of low-carbon solutions across sectors (IPCC, 2022; Lenaerts et al., 2021). Two market failures weaken private incentives to develop these technologies: the benefits of avoided climate damage are not fully reflected in market prices, while knowledge spillovers limit innovators' ability to capture the social returns to their research. These problems provide a rationale for public research support alongside environmental regulation, pricing and standards (Dechezleprêtre et al., 2013; OECD, 2023). Understanding how such support relates to inventive activity is therefore important for assessing the contribution of research policy to the green transition.

The regional distribution of innovation adds a spatial dimension to this policy challenge. European regions differ in their industrial structures, research capabilities and capacity to absorb external knowledge. Existing capabilities shape both the volume of invention and the technological fields into which regions can diversify (Martin & Sunley, 2006; Corradini, 2019). Green technologies frequently combine knowledge from several fields, making access to complementary expertise particularly relevant (Barbieri et al., 2020). Interregional collaboration can widen this access, but geographical, institutional and technological differences may impede the formation of productive partnerships (Boschma, 2005). Public research policy consequently operates within a geographically uneven system in which local capabilities and external connections jointly influence opportunities for invention.

EU Framework Programmes (FPs) address funding and coordination problems by supporting research through transnational consortia. Their relevance can therefore be examined through both participation in funded projects and the collaboration networks associated with that participation. These dimensions need not have the same relationship with patented invention; a region may participate in numerous projects while working repeatedly with a relatively narrow group of partners, whereas another may access a broader network through fewer projects. Similarly, changes in collaboration between particular region pairs may be obscured in aggregate regional patent counts. Distinguishing participation volume, network breadth and bilateral ties can therefore provide a more informative picture of the relationship between FPs and green invention.

Previous research establishes the importance of these network dimensions. Hoekman et al. (2013) find that FP funding generates additional scientific collaboration, particularly between region pairs with limited previous collaboration. Lata et al. (2015) show that geographical frictions are weaker in FP project networks than in co-patenting and co-publication networks. However, comparisons of these networks also reveal differences in regional positions, determinants and patterns of evolution (Wanzenböck et al., 2014; Akçomak et al., 2023; D'Adda et al., 2025). Project co-participation and co-patenting thus represent distinct forms of knowledge interaction. For environmental innovation specifically, Fabrizi et al. (2025) document an association with green FP research networks across European regions. This evidence motivates a closer examination of whether green project links are also reflected in patent-based collaboration between the same regions.

This paper contributes to that literature by combining regional and dyadic perspectives on green invention. At the regional level, we distinguish the number of green FP projects from the breadth of a region's project partnerships. At the dyadic level, we examine whether shared green projects are associated with green co-patenting between the same region pairs. We also distinguish the scale of green patenting from its importance within regional and bilateral patent portfolios. This approach extends existing evidence on regional green FP networks by incorporating bilateral patent-based co-invention and its geographical structure. Descriptive network analysis places these relationships within the broader geography of European green collaboration.

The analysis addresses four research questions: (RQ1) how regional FP participation and project-network connectedness are associated with green patenting and its technological orientation; (RQ2) how concentrated green co-patenting is and how its geography compares with FP collaboration; (RQ3) whether the cross-border orientation of green co-invention increases between FP7 (2007-2013) and Horizon 2020 (2014-2020); and (RQ4) whether bilateral FP links are associated with green co-patenting between the same region pairs. The descriptive questions provide context for interpreting the regional and dyadic estimates.

We combine patent applications in the OECD's REGPAT database with CORDIS project participation records for FP7 and Horizon 2020, covering EU-28 NUTS 2 regions over the 2007-2020 period. Patents are assigned to regions using inventor addresses and dated by priority year. Green patents are identified through OECD ENV-TECH classifications, while green projects are selected using the programmes' environmental and climate-related thematic categories. The resulting data describe regional project participation, project-network connectedness and green patenting, together with annual counts of shared projects and co-patents for region pairs. This structure allows us to compare the geography of funded collaboration with that of patented co-invention.

The empirical approach combines descriptive network analysis with Poisson pseudo-maximum likelihood (PPML) estimation. Regional models include region and year fixed effects and examine green patent counts, the green-to-non-green patent ratio and the green share of total patenting. Dyadic models use analogous outcomes and include dyad and region-time fixed effects, together with controls for technological proximity and differences in regional innovation performance and R&D expenditure. PPML estimation accommodates non-negative outcomes, including zeros, without log-transforming the dependent variable (Santos Silva & Tenreyro, 2006). The fixed effects account for persistent regional or bilateral differences as well as relevant common or region-specific changes. The estimates describe conditional associations rather than causal programme effects.

The results reveal a consistent positive association between green project-network connectedness and regional green patent counts. By comparison, the number of green FP projects is not statistically significantly associated with these counts. Evidence of regional portfolio reorientation is more sensitive to the specification: the positive association between green project participation and the green-to-non-green patent ratio becomes insignificant when connectedness is included in the model. At the dyadic level, shared green FP projects are positively and significantly associated with green co-patent counts and the green-to-non-green co-patent ratio, including in the common-sample specifications. The association with the green share of co-patenting is less consistent across samples. Technological proximity is positively associated with green co-invention throughout the reported dyadic specifications.

The descriptive findings complement these estimates. Green co-patenting is concentrated around established innovation centres, whereas the strongest green FP project ties appear more geographically dispersed. Among the 278 regions with a defined External–Internal (E–I) index in both programme periods, 59.0% exhibit an increase in cross-border orientation between 2007-2013 and 2014-2020. This shift is uneven and concerns the balance between domestic and cross-border collaboration rather than necessarily indicating growth in the volume of co-invention.

Together, these findings support examining collaborative research programmes through both regional inventive outcomes and the structure of interregional partnerships. Project counts alone provide an incomplete description of programme participation when the breadth of research connections and the intensity of bilateral links have distinct associations with green patenting. For policy assessment, this suggests considering the structure of interregional collaboration alongside regional patenting when examining the contribution of publicly funded research.

The remainder of the paper is organised as follows. Section 2 reviews the relevant literature, and Section 3 presents the data and methodology. Section 4 describes the geographical and network patterns of green invention and collaboration. Section 5 reports the estimation results, and Section 6 concludes.

2. Literature review: Regional green innovation and collaboration networks

This section briefly reviews the relevant literature. The first subsection focuses on regional green patenting and innovation capabilities. The second examines interregional co-invention and the role of proximity, while the third reviews studies on FP collaboration and green patenting.

2.1. REGIONAL GREEN PATENTING AND INNOVATION CAPABILITIES

Green technologies often combine knowledge from different fields and require complementary infrastructure and sector-specific capabilities (Barbieri et al., 2020). Clean invention can also generate substantial knowledge spillovers relative to more polluting technologies (Dechezleprêtre et al., 2013). These characteristics reinforce the case for public support but also suggest that funding alone may be insufficient: regions need the capacity to absorb, combine and apply the knowledge generated through research (OECD, 2023).

Green inventive activity is spatially uneven and depends on regional capabilities (Corradini, 2019; Kim et al., 2023). Evolutionary approaches emphasise path dependence: existing knowledge influences both the volume of invention and the technological fields into which regions can diversify (Martin & Sunley, 2006; Rigby & Essletzbichler, 1997). Regional institutions, industrial structures, R&D resources and human capital shape these trajectories, together with access to external knowledge (Maskell & Malmberg, 2007; Filippopoulos & Fotopoulos, 2022). Research on less developed regions also highlights the role of non-local firm networks and multinational enterprises in technological diversification (Vlčková et al., 2026). Publicly supported research may therefore relate differently to the scale of green invention and to its importance within a region's patent portfolio.

Definitions of green innovation vary across the literature (Schiederig et al., 2012). We focus on patented green invention, using OECD ENV-TECH classifications to identify the relevant technologies (Haščič & Migotto, 2015). Patent records provide standardised information on technological content, inventors and locations, making it possible to map inventive activity and co-invention across regions (Hall et al., 2001). Although they do not capture all environmental innovation and patent counts do not measure the commercial value or environmental impact of inventions, they provide a consistent basis for comparing the geography of codified inventive activity.

2.2. INTERREGIONAL CO-INVENTION AND PROXIMITY

Knowledge creation and diffusion remain geographically concentrated (Sonn & Storper, 2008). Tacit and context-dependent knowledge often requires repeated interaction, shared institutions and access to specialised labour markets, so knowledge spillovers tend to decline with distance (Audretsch & Feldman, 1996; Jaffe et al., 1993). Part of this localisation operates through social and organisational channels,

including inventor mobility and co-invention networks (Almeida & Kogut, 1999; Breschi & Lissoni, 2004). Geographical distance thus captures several barriers to collaboration rather than a single mechanism.

Cognitive, organisational, social and institutional proximity can also reduce the costs of exchanging and interpreting knowledge (Boschma, 2005). Interregional ties allow firms, universities and inventors to access expertise beyond their local knowledge base, complementing the advantages of local interaction with external knowledge pipelines (Bathelt et al., 2004; Wanzenböck et al., 2014). Networks can support knowledge recombination, while bridging ties connect otherwise separated groups (Burt, 1992; Powell et al., 1996). Co-patenting provides an observable indicator of inventive collaboration when a patent includes inventors located in different regions.

Cross-border collaboration connects actors embedded in different national innovation systems and may therefore provide access to complementary expertise (Fromhold-Eisebith, 2007). It also faces coordination costs arising from distance, language and institutional differences (Lundquist & Trippl, 2013). A gravity perspective offers a useful framework for these spatial frictions (Anderson & van Wincoop, 2003), while evidence on European research collaboration shows the continuing relevance of geographical and institutional proximity (Hoekman et al., 2009; Ponds et al., 2007). Green co-patenting networks have expanded internationally but remain concentrated around a small core of countries (Gonçalves et al., 2023). Their development therefore needs to be assessed in terms of both the distribution of collaboration ties and changes in cross-border orientation.

2.3. FRAMEWORK PROGRAMME COLLABORATION AND GREEN PATENTING

EU Framework Programmes combine R&D funding with the organisation of transnational collaboration. Consortia and common participation rules connect organisations across regions and national innovation systems (Hoekman et al., 2013; Lata et al., 2015). Participation can consequently provide access to both funding and research networks (Wanzenböck et al., 2014). Regional evidence links FP network positions to innovation and growth (Meliciani et al., 2022), and green FP research networks are also associated with environmental innovation in European regions (Fabrizi et al., 2025).

An important finding in this literature is collaboration additionality, meaning collaboration that would not otherwise have occurred. Hoekman et al. (2013) find that FP funding increases subsequent co-publication, particularly between region pairs with limited previous collaboration. Lata et al. (2015) show that geographical frictions are weaker in FP project networks than in co-patenting and co-publication networks. These findings suggest that FPs can broaden research collaboration, although the creation of a project tie does not necessarily imply a joint patent. Evidence from subsidised R&D also suggests that patenting outcomes depend on project design and partner composition: Fornahl et al. (2011) find stronger patent intensity when subsidies support joint projects.

Comparisons of FP collaboration, co-patenting and co-publication show that regions occupy different positions in these networks and that the determinants of those positions vary (Wanzenböck et al., 2014). Akçomak et al. (2023) similarly document different evolutionary patterns in EU project and patent networks. At the NUTS 2 level, D'Adda et al. (2025) find partly different determinants of FP7 project links and European Patent Office (EPO) co-patenting. This evidence motivates examining the association between project ties and co-invention directly rather than using one network as a proxy for the other.

For green invention, access to external knowledge may operate through several channels, including foreign investment and research collaboration (Ghodsi & Jovanović, 2022). Fabrizi et al. (2025) provide closely related evidence on regional environmental innovation and green FP networks. We extend this regional perspective by combining measures of green patenting and technological orientation with a dyadic analysis of green co-patenting. Our contribution is to examine how regional FP participation and project-network connectedness relate to green patenting and whether bilateral FP collaboration is associated with green co-patenting between the same region pairs.

3. Data and methodology

We combine patent applications from the OECD's REGPAT database with EU Framework Programme project records from CORDIS. The sample covers the EU-28 (i.e. the EU-27 plus the United Kingdom), over the 2007-2020 period, covering FP7 (2007-2013) and Horizon 2020 (2014-2020). Patent applications are assigned to NUTS 2 regions using inventor addresses, locating inventive activity rather than patent ownership (Hall et al., 2001). Historical NUTS 2 codes are harmonised to later territorial units to account for classification revisions. Patents are dated by priority year, which approximates the timing of invention more closely than publication or grant dates (OECD, 2009). Ending the sample in 2020 also limits exposure to incomplete coverage of recent patent cohorts.

Green patents are identified using OECD ENV-TECH classifications based on the International Patent Classification (IPC) and Cooperative Patent Classification (CPC) systems (Haščič & Migotto, 2015). When an upper-level CPC category is classified as green, its subordinate classes are included. A green classification at a lower level does not, however, extend automatically to its parent category. This approach limits the inclusion of unrelated technologies within broad classes. The remaining patents are classified as non-green. We use these categories to construct regional patent indicators and bilateral co-patenting measures.

Regional patent variables record green (P_{rt}^{G}) and non-green (P_{rt}^{nG}) applications in region *r* and year *t*. Dyadic patent variables (P_{rnt}) are constructed from inventor locations on the same patent. We identify the distinct regions represented on each patent and form all unique unordered region pairs. Each pair is counted once per patent, regardless of the number of inventors in either region. A patent involving more than two regions can therefore contribute to several dyads. Separate annual counts are constructed for green and non-green co-patenting. The resulting undirected region-pair panel includes zero counts for pair-years with no observed co-patent.

CORDIS provides project participation records for the FP7 and Horizon 2020 periods. Participating organisations are assigned to NUTS 2 regions by location. Green projects are identified through the thematic categories FP7-ENVIRONMENT and H2020-EU.3.5 'Fighting and adapting to climate change'. This narrow definition excludes projects with environmental components classified elsewhere, including some projects in other thematic areas. We refer to the remaining projects as non-green for the purposes of this classification. The project and patent classifications therefore identify related but not identical technological activities.

At the regional level, F_{rt}^{G} and F_{rt}^{nG} record the numbers of green and non-green FP projects involving organisations in a region. We also measure project-network connectedness ($Connectedness_{rt}$), defined as the share of potential regional partners with which a region shares at least one FP project in a given year. Separate indicators are constructed for green ($Connectedness_{rt}^{G}$) and non-green ($Connectedness_{rt}^{nG}$) projects. This normalisation accounts for changes in the number of active regions over time. Connectedness measures the breadth of a region's project partnerships, whereas project counts measure its volume of participation.

Dyadic project variables use the same pairing procedure as co-patents. For each project, participating regions are converted into unique unordered pairs. Projects enter each year of their implementation period, so an ongoing collaboration contributes to the annual measure throughout its duration. We then aggregate shared green and non-green projects by region pair and year and assign zero counts to pair-years with no observed shared project. These measures capture co-participation in a consortium; they do not require every pair of participants to interact directly.

Regional controls describe economic development and innovation capacity. A technological complexity index ($Complexity_{rt}$) is constructed from regional patent portfolios across four-digit CPC classes, drawing on the economic complexity literature (Hidalgo & Hausmann, 2009). Annual region-by-technology matrices are converted into binary indicators of revealed comparative advantage and used to calculate the index. Higher values indicate greater technological complexity in the patent portfolio. Eurostat controls include GDP per capita ($GDPperCap_{rt}$), industrial gross value added ($IndustryGVA_{rt}$), employment ($Empl_{rt}$), investment ($Invest_{rt}$), gross domestic expenditure on R&D ($GERD_{rt}$), labour productivity ($Productivity_{rt}$) and tertiary education ($TerEduc_{rt}$). The network regressors come from FP projects, keeping project-network connectedness distinct from the co-patenting outcomes.

The dyadic models include three time-varying controls. Technological proximity (Tp_{rnt}) is measured by the cosine similarity of regional patent portfolios across four-digit CPC classes (Jaffe, 1986). These portfolios use fractional patent counts, and similarity is calculated annually for each region pair. Differences in regional innovation performance (ΔRIS_{rnt}) – measured as the absolute difference in the Regional Innovation Index from the Regional Innovation Scoreboard 2023 (Hollanders & Es-Sadki, 2023) – and in regional R&D expenditure ($\Delta GERD_{rnt}$) describe further dimensions of the regions' innovation profiles. For the RIS-based measure, we use the Regional Innovation Index series labelled 'Innovation index – same year' for the 2016-2020 period. Missing dyad-year observations are filled using the nearest available year within the same dyad; consequently, the 2016 absolute difference is used for the 2007-2015 period. Where RIS scores are reported at a regional level above NUTS 2, the corresponding score is assigned to each constituent NUTS 2 region. These controls relate to the proximity conditions discussed by Boschma (2005), Hoekman et al. (2009) and Ponds et al. (2007). Dyad fixed effects absorb time-invariant factors, such as geographical distance and same-country status.

We estimate regional models using Poisson pseudo-maximum likelihood (PPML) with region and year fixed effects. PPML estimation accommodates non-negative outcomes, including zeros, without log-transforming the dependent variable. Its use does not require a Poisson-distributed outcome; consistency instead depends on a correctly specified conditional mean (Santos Silva & Tenreyro, 2006; Yotov et al., 2016). We apply the exponential mean specification to patent counts and to two measures of patent composition. The baseline model and the model adding connectedness are:

$$\begin{aligned} Y_{rt}^{G} = exp[&\alpha_0 + \alpha_1 F_{rt}^{G} + \alpha_2 F_{rt}^{nG} + \alpha_3 P_{rt}^{nG} + \alpha_4 GERD_{rt} + \alpha_5 TerEduc_{rt} + \alpha_6 GDPperCap_{rt} \\ &+ \alpha_7 Complexity_{rt} + \alpha_8 Productivity_{rt} + \alpha_9 IndustryGVA_{rt} + \alpha_{10} Invest_{rt} \\ &+ \alpha_{11} Empl_{rt} + \alpha_r + \alpha_t] \times \nu_{rt} \end{aligned} \quad (1)$$

$$Y_{rt}^{G} = exp[\alpha_0 + \alpha_1 F_{rt}^{G} + \alpha_2 F_{rt}^{nG} + \alpha_3 P_{rt}^{nG} + \alpha_4 Connectedness_{rt}^{G} + \alpha_5 Connectedness_{rt}^{nG} + \alpha_6 GERD_{rt} + \alpha_7 TerEduc_{rt} + \alpha_8 GDPperCap_{rt} + \alpha_9 Complexity_{rt} + \alpha_{10} Productivity_{rt} + \alpha_{11} IndustryGVA_{rt} + \alpha_{12} Invest_{rt} + \alpha_{13} Empl_{rt} + \alpha_r + \alpha_t] \times \nu_{rt} \quad (2)$$

Here, Y_{rt}^{G} denotes one of three regional outcomes: the green patent count (P_{rt}^{G}), the green-to-non-green patent ratio ($\frac{P_{rt}^{G}}{P_{rt}^{nG}}$) or the green share of total patenting ($\frac{P_{rt}^{G}}{P_{rt}^{nG}+P_{rt}^{G}}$). The first measures scale, while the latter two describe technological orientation. An increase in either composition measure can reflect more green patents, fewer non-green patents or both. Region fixed effects (α_r) absorb persistent regional differences, and year fixed effects (α_t) capture common shocks and trends. Standard errors are clustered by region. Regressors are transformed using the inverse hyperbolic sine to retain zero observations (Bellemare & Wichman, 2020). The transformation approximates a logarithm for large positive values, but its coefficients should not be read uniformly as elasticities, particularly near zero.

The baseline specifications relate FP project counts to each outcome, with and without regional controls. The second set adds green and non-green project-network connectedness. The non-green patent count is included as a control in the extended green-count models, but not in the composition models, where it already enters the dependent variable. Comparing the two sets of models shows whether project participation and the breadth of partnerships have distinct conditional associations with green patenting.

The dyadic analysis uses analogous outcomes for green co-patenting between regions *r* and *n* in year *t*: the green co-patent count, its ratio to non-green co-patents and its share of total co-patenting. We denote the relevant outcome by Y_{rnt}^{G} and estimate the following PPML specification:

$$Y_{rnt}^{G} = exp[\alpha_0 + \alpha_1 F_{rnt}^{G} + \alpha_2 F_{rnt}^{nG} + \alpha_3 Tp_{rnt} + \alpha_4 \Delta RIS_{rnt} + \alpha_5 \Delta GERD_{rnt} + \alpha_{rt} + \alpha_{nt} + \alpha_{rn}] \times \nu_{rnt} \quad (3)$$

Here, F_{rnt}^{G} and F_{rnt}^{nG} are the numbers of shared green and non-green FP projects, respectively. The remaining regressors are technological proximity (Tp_{rnt}), the difference in innovation performance (ΔRIS_{rnt}) and the difference in R&D expenditure ($\Delta GERD_{rnt}$). Dyad fixed effects (α_{rn}) absorb persistent pair-specific collaboration propensities, including geographical and institutional factors. Region-time fixed effects (α_{rt} and α_{nt}) absorb time-varying characteristics of each region. Standard errors are clustered by dyad to account for serial correlation within pairs. The estimates therefore describe within-dyad associations conditional on these fixed effects and the included controls. They do not establish that FP participation causes co-patenting, as time-varying bilateral factors, partner selection and joint responses to technological opportunities may still influence both.

The descriptive network analysis complements these regressions. Adjacency matrices constructed from green co-patent counts show the geographical concentration of inventive collaboration and its relationship to FP project ties. We compare the FP7 and Horizon 2020 periods using the External–Internal (E–I) index, which measures the balance between cross-border and within-country collaboration. This distinguishes changes in the geographical orientation of ties from changes in their overall volume.

4. Descriptive patterns in green innovation and collaboration

Green projects represent a small share of projects but a larger share of European Commission (EC) funding in both programmes. FP7 included approximately 25,800 projects, of which about 500 fell under FP7-ENVIRONMENT: around 2% of projects and 4% of the EC contribution. Horizon 2020 included approximately 35,400 projects, of which about 730 fell under the selected H2020-EU.3.5 category: around 2% of projects and 4.7% of the EC contribution. Projects in these categories thus received larger average contributions than projects overall, with their share of funding increasing between the two programmes.

Table 1 / Top 10 NUTS 2 regions by EC contribution to green FP projects and by green patent counts

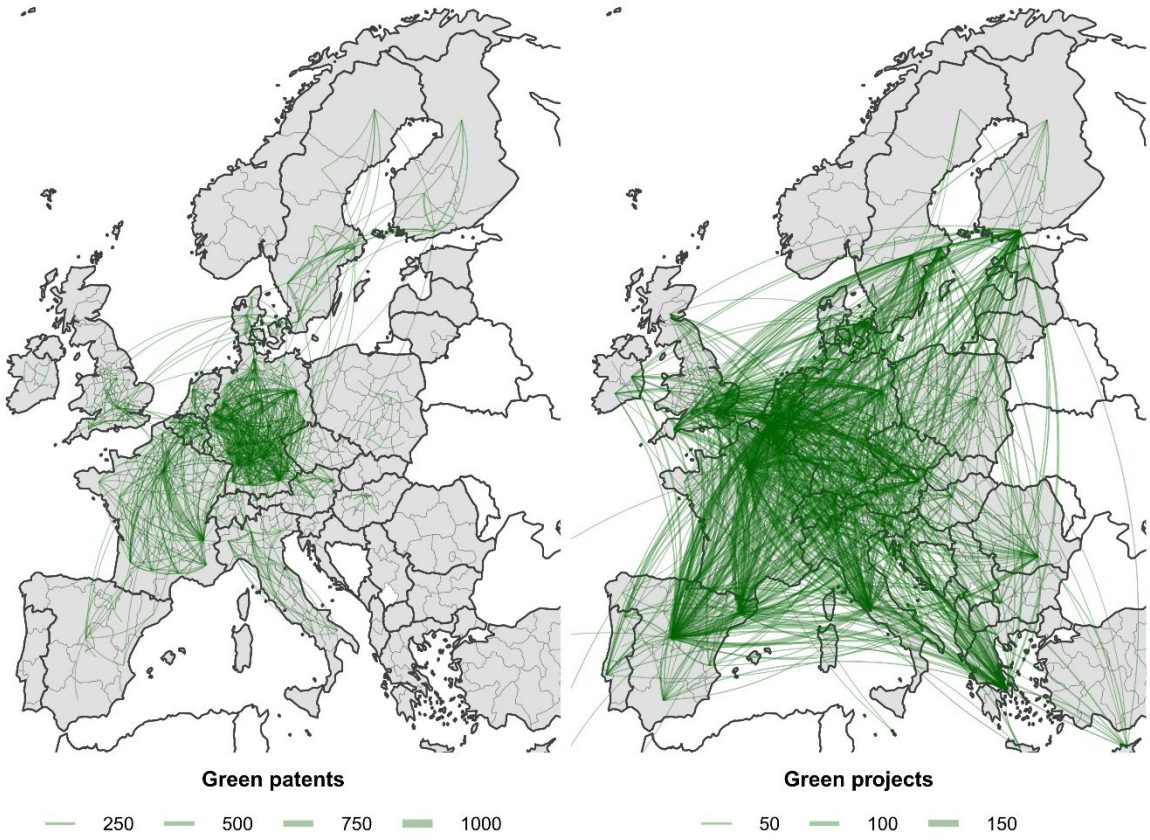
FP7 Green projects EC contribution (th. EUR)		Horizon 2020 Green projects EC contribution (th. EUR)		Green patents 2007-2013		Green patents 2014-2020	
Île-de-France	83,675	Île-de-France	122,872	Île-de-France	21,835	Île-de-France	23,273
Zuid-Holland	53,829	Cataluña	112,351	Oberbayern	17,615	Oberbayern	20,129
Cataluña	49,791	Région de Bruxelles	83,059	Stuttgart	16,851	Noord-Brabant	14,445
Lazio	48,511	Comunidad de Madrid	79,967	Rhône-Alpes	12,005	Stuttgart	14,437
Gelderland	47,257	Zuid-Holland	79,822	Noord-Brabant	10,907	Rhône-Alpes	12,573
Oberbayern	43,936	Noord-Holland	72,429	Düsseldorf	10,170	Lombardia	9,940
East Anglia	37,413	Attiki	70,550	Darmstadt	9,612	Darmstadt	9,046
Inner London – West	37,096	Helsinki-Uusimaa	64,883	Karlsruhe	9,307	Karlsruhe	8,986
Comunidad de Madrid	35,745	Lazio	61,969	Lombardia	9,135	Düsseldorf	8,953
Région de Bruxelles	35,360	Lombardia	54,523	Köln	8,419	Stockholm	8,244

Table 1 shows substantial concentration in both green project funding and green patenting. Île-de-France leads all four rankings. Zuid-Holland, Cataluña and Lazio are among the leading recipients in FP7, while Cataluña, the Brussels Capital Region and Comunidad de Madrid rank prominently in Horizon 2020. The patent rankings are dominated by Île-de-France and major German innovation regions, including Oberbayern and Stuttgart, alongside Noord-Brabant and Rhône-Alpes. Some regions appear in both the funding and patent rankings, but the rankings do not coincide. This overlap is compatible with cumulative advantages in established innovation centres; the differences indicate that funding participation and patented invention have distinct regional distributions. The rankings alone do not show whether projects generate additional patents or co-patenting ties.

Figure 1 compares green co-patenting and green FP co-participation across NUTS 2 regions over the 2007-2020 period. To make the maps readable, each network is restricted to its 900 strongest dyadic links. The displayed co-patenting network has a concentrated core in Western and Central Europe, whereas the project network appears more geographically dispersed. These maps address RQ2 by illustrating the different geographies of the strongest project and patent ties. Because only selected links

are displayed, they do not provide a complete comparison of network density or the participation of peripheral regions.

Figure 1 / Green co-patenting and FP co-participation across EU NUTS 2 regions, 2007-2020



For RQ3, the E–I index measures each region's balance of cross-border (external) and within-country (internal) green co-patenting. It is defined as the difference between external and internal collaboration divided by their sum, ranging from −1 for entirely domestic collaboration to +1 for entirely cross-border collaboration. We compare the index for the 2007-2013 and 2014-2020 periods. Its change (Δ E–I) ranges from −2 to +2 and measures a change in orientation, not collaboration volume. Figure 2 maps the 100 regions with the largest positive changes. These include regions outside the established innovation core, showing that a stronger cross-border orientation is geographically widespread.

The E–I index is undefined when a region has no green co-patenting ties in a given period, so that the sum of external and internal collaboration is zero. No value is imputed in these cases. The comparison only includes regions for which the index is defined in both the 2007-2013 and 2014-2020 periods. This excludes 13 regions, leaving 278 regions in Table 2. Of these, 164 regions (59.0%) show an increase in cross-border orientation, 106 (38.1%) show a decrease and eight (2.9%) show no change. The shift towards cross-border collaboration is therefore widespread but uneven. An increase in the index can result from more cross-border ties, fewer domestic ties or both. The number of available domestic partners also differs across countries. These results describe changes in the geographical orientation of

existing green co-patenting networks rather than the emergence or overall growth of co-invention, and they should not be interpreted as evidence of a causal effect of FP participation.

Figure 2 / The 100 regions with the largest increases in cross-border green co-patenting orientation between 2007-2013 and 2014-2020

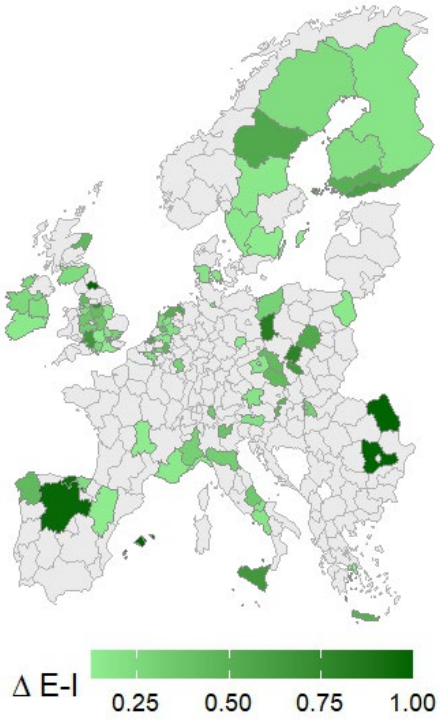


Table 2 / Changes in cross-border green co-patenting orientation between 2007-2013 and 2014-2020

Change in cross-border orientation	Number of regions	Share (%)	Minimum Δ E–I	Mean Δ E–I	Maximum Δ E–I
Strong decrease	21	7.6	−2.000	−1.320	−0.500
Moderate decrease	23	8.3	−0.424	−0.334	−0.257
Slight decrease	62	22.3	−0.239	−0.095	−0.002
No change	8	2.9	0.000	0.000	0.000
Slight increase	107	38.5	0.000	0.103	0.237
Moderate increase	31	11.2	0.253	0.355	0.473
Strong increase	26	9.4	0.500	0.740	1.000

Notes: Δ E–I denotes the change in the External–Internal index between 2007-2013 and 2014-2020. The E–I index ranges from −1 to +1, while Δ E–I can range from −2 to +2. Positive values indicate a shift towards more cross-border green patent collaboration. Values are rounded to three decimal places. Percentages may not sum to 100% due to rounding.

5. Estimation results

Tables 3 and 4 address RQ1 using regional PPML models with region and year fixed effects. Table 3 relates project participation to green patenting, while Table 4 adds connectedness in green and non-green FP project networks. Each outcome is reported with and without the extended regional controls. This comparison distinguishes participation volume from the breadth of project partnerships, reflecting the funding and network dimensions of FP participation discussed in the literature (Hoekman et al., 2013; Meliciani et al., 2022; Wanzenböck et al., 2014).

Table 3 / Regional green patenting and technological orientation without project-network connectedness

Dependent variables:	P^G_{rt}	P^G_{rt}	$\frac{P^G_{rt}}{P^{nG}_{rt}}$	$\frac{P^G_{rt}}{P^{nG}_{rt}}$	$\frac{P^G_{rt}}{P^{nG}_{rt}+P^G_{rt}}$	$\frac{P^G_{rt}}{P^{nG}_{rt}+P^G_{rt}}$
	(1)	(2)	(3)	(4)	(5)	(6)
F^G_{rt}	−0.019	−0.021	0.070**	0.056*	0.020	0.014
	(0.017)	(0.015)	(0.031)	(0.031)	(0.026)	(0.025)
F^{nG}_{rt}	0.048	0.040	−0.054	−0.061	−0.031	−0.033
	(0.032)	(0.027)	(0.074)	(0.077)	(0.040)	(0.040)
P^{nG}_{rt}		0.50***				
		(0.054)				
$GERD_{rt}$		−0.095		0.13		0.093
		(0.073)		(0.16)		(0.11)
$TerEduc_{rt}$		0.35***		−0.50**		−0.25
		(0.10)		(0.25)		(0.18)
$GDPperCap_{rt}$		−0.38		−1.66*		−0.81
		(0.37)		(0.85)		(0.62)
$Complexity_{rt}$		−0.0056		0.0075		0.019
		(0.0064)		(0.022)		(0.021)
$Productivity_{rt}$		0.69		1.62*		0.23
		(0.44)		(0.88)		(0.67)
$IndustryGVA_{rt}$		−0.090		0.024		−0.100
		(0.12)		(0.29)		(0.18)
$Empl_{rt}$		−0.043		2.52***		0.91
		(0.34)		(0.83)		(0.66)
$Invest_{rt}$		0.17*		−0.39		−0.010
		(0.099)		(0.25)		(0.20)
Constant	4.49***	0.38	−1.40***	−2.70	−1.69***	1.70
	(0.18)	(3.04)	(0.32)	(6.75)	(0.17)	(4.55)
Observations	3,243	3,243	3,179	3,179	3,197	3,197
Pseudo R-squared	0.924	0.927	0.050	0.051	0.027	0.028
AIC	21,834.9	21,035.9	2,735.5	2,748.2	2,369.8	2,384.9
BIC	21,847.1	21,102.8	2,747.7	2,808.9	2,381.9	2,445.6

Notes: Region-clustered standard errors in parentheses. * p < 0.10; ** p < 0.05; *** p < 0.01. All models include region (α_r) and year (α_t) fixed effects.

In Table 3, the green-project coefficient is negative and statistically insignificant in both green patent-count specifications. These estimates provide no evidence of a positive association between green project participation and green patent volumes, but they do not establish that project participation has negative effects on green patent volumes. For the green-to-non-green patent ratio, the coefficient is positive and significant at the 5% level without the extended controls and at the 10% level with them. The green-share coefficients are positive but statistically insignificant. Non-green projects have no statistically significant association with any of the three outcomes. Evidence of a greener patent portfolio is consequently limited to the ratio measure and is weaker in the specification with additional controls. Since the ratio also depends on non-green patenting, this finding need not imply a rise in green patent counts.

Table 4 / Regional green patenting and technological orientation with project-network connectedness

Dependent variables:	P^{G}_{rt}	P^{G}_{rt}	$\frac{P^{G}_{rt}}{P^{nG}_{rt}}$	$\frac{P^{G}_{rt}}{P^{nG}_{rt}}$	$\frac{P^{G}_{rt}}{P^{nG}_{rt}+P^{G}_{rt}}$	$\frac{P^{G}_{rt}}{P^{nG}_{rt}+P^{G}_{rt}}$
	(1)	(2)	(3)	(4)	(5)	(6)
$Connectedness^{G}_{rt}$	0.24**	0.21**	0.29	0.26	0.26	0.24
	(0.094)	(0.095)	(0.31)	(0.30)	(0.22)	(0.21)
$Connectedness^{nG}_{rt}$	−0.68	−0.63	−1.13**	−0.87	−0.74**	−0.51
	(0.56)	(0.68)	(0.57)	(0.67)	(0.36)	(0.40)
F^{G}_{rt}	−0.023	−0.025	0.051	0.039	0.0041	−0.00037
	(0.017)	(0.015)	(0.036)	(0.035)	(0.028)	(0.027)
F^{nG}_{rt}	0.055	0.046	−0.030	−0.042	−0.018	−0.024
	(0.036)	(0.030)	(0.083)	(0.086)	(0.047)	(0.047)
P^{nG}_{rt}		0.49***				
		(0.054)				
$GERD_{rt}$		−0.097		0.13		0.094
		(0.072)		(0.16)		(0.11)
$TerEduc_{rt}$		0.35***		−0.48*		−0.24
		(0.10)		(0.25)		(0.18)
$GDPperCap_{rt}$		−0.36		−1.48*		−0.73
		(0.37)		(0.88)		(0.63)
$Complexity_{rt}$		−0.0058		0.0063		0.018
		(0.0064)		(0.022)		(0.021)
$Productivity_{rt}$		0.70		1.56*		0.19
		(0.44)		(0.89)		(0.67)
$IndustryGVA_{rt}$		−0.095		0.00036		−0.12
		(0.12)		(0.29)		(0.18)
$Empl_{rt}$		−0.041		2.46***		0.88
		(0.34)		(0.84)		(0.67)
$Invest_{rt}$		0.16*		−0.41*		−0.017
		(0.099)		(0.24)		(0.19)
Constant	4.54***	0.25	−1.32***	−3.55	−1.63***	1.36
	(0.15)	(3.04)	(0.30)	(6.94)	(0.15)	(4.68)
Observations	3,243	3,243	3,179	3,179	3,197	3,197
Pseudo R-squared	0.924	0.927	0.050	0.051	0.027	0.028
AIC	21,822.2	21,026.2	2,738.8	2,751.8	2,373.5	2,388.7
BIC	21,846.5	21,105.3	2,763.1	2,824.6	2,397.8	2,461.5

Notes: Region-clustered standard errors in parentheses. * p < 0.10; ** p < 0.05; *** p < 0.01. All models include region (α_r) and year (α_t) fixed effects.

Adding connectedness in Table 4 reveals a positive association between the breadth of green project partnerships and green patent counts. The coefficients are 0.24 and 0.21, respectively, and are statistically significant at the 5% level in both specifications. Green project counts remain insignificant in the count models, and their association with the green-to-non-green patent ratio is no longer significant. Green connectedness is positive but insignificant for both orientation measures. Non-green connectedness is negatively associated with these measures in the parsimonious specifications, but neither association remains significant after the regional controls are added. These results distinguish network breadth from participation volume, but they do not establish that connectedness mediates the effect of project participation. The regional evidence is most consistent for the association between green project-network connectedness and the scale of green patenting.

Table 5 addresses RQ4 by relating bilateral FP collaboration to green co-patenting. To facilitate comparison across outcomes, columns (4)-(6) use a common estimation sample. The green-to-non-green ratio specifications in columns (2) and (5) are identical because the sample used in column (2) is also the common sample. Dyad fixed effects control for persistent differences in collaboration propensities, while region-time fixed effects account for changing characteristics of both regions. The estimates therefore ask whether changes in shared projects within a region pair are associated with changes in its co-patenting, conditional on these controls. This is a more direct comparison of project and patent ties than the regional models, although the two analyses measure different relationships.

Table 5 / Bilateral green co-patenting and technological orientation with dyad and region-time fixed effects

	Different samples			Common samples		
Dependent variables:	P^{G}_{rnt}	$\frac{P^{G}_{rnt}}{P^{nG}_{rnt}}$	$\frac{P^{G}_{rnt}}{P^{nG}_{rnt}+P^{G}_{rnt}}$	P^{G}_{rnt}	$\frac{P^{G}_{rnt}}{P^{nG}_{rnt}}$	$\frac{P^{G}_{rnt}}{P^{nG}_{rnt}+P^{G}_{rnt}}$
	(1)	(2)	(3)	(4)	(5)	(6)
F^{G}_{rnt}	0.041***	0.067**	0.051**	0.047***	0.067**	0.030
	(0.015)	(0.029)	(0.022)	(0.017)	(0.029)	(0.023)
F^{nG}_{rnt}	0.028	−0.0075	−0.035	0.040**	−0.0075	−0.019
	(0.017)	(0.029)	(0.021)	(0.020)	(0.029)	(0.023)
Tp_{rnt}	2.02***	1.08***	0.37**	1.98***	1.08***	0.87***
	(0.13)	(0.24)	(0.17)	(0.16)	(0.24)	(0.19)
ΔRIS_{rnt}	−0.0076	−0.084*	−0.059*	−0.011	−0.084*	−0.065*
	(0.023)	(0.049)	(0.034)	(0.025)	(0.049)	(0.036)
$\Delta GERD_{rnt}$	−3.47	55.9***	−4.36	11.9	55.9***	26.1
	(11.0)	(20.6)	(14.4)	(13.9)	(20.6)	(16.4)
Constant	0.15	−1.17***	−1.04***	0.45***	−1.17***	−1.90***
	(0.12)	(0.22)	(0.15)	(0.14)	(0.22)	(0.17)
Observations	77,071	28,952	39,308	28,952	28,952	28,952
Pseudo R-squared	0.643	0.247	0.167	0.645	0.247	0.122
AIC	106,824.2	27,574.9	33,649.3	65,970.4	27,574.9	18,932.2
BIC	106,879.7	27,624.5	33,700.8	66,020.0	27,624.5	18,981.9

Notes: Dyad-clustered standard errors in parentheses. * p < 0.10; ** p < 0.05; *** p < 0.01. All models include region-time (α_{rt} and α_{nt}) and dyad (α_{rn}) fixed effects.

The coefficient on shared green FP projects is positive and significant at the 1% level in both green co-patent count specifications (0.041 and 0.047, respectively). It is also positive and significant at the 5% level in green-to-non-green ratio specifications (0.067). For the green share of co-patenting, the reported

coefficients are positive, but only one is statistically significant at the 5% level in column (3), where the sample size is larger. Non-green FP links are positively associated with green co-patent counts in one specification, but there is no significant association in the other reported models. Thus, the association between green project ties and green co-invention is consistent across the reported count and ratio specifications, while the orientation result depends on the measure used. Differences in estimation samples also limit comparisons across outcomes.

Technological proximity is positively and statistically significantly associated with green co-patenting in every reported specification. This is consistent with the argument that related technological capabilities facilitate knowledge exchange and recombination (Boschma, 2005), and it also accords with evidence on the importance of proximity in European research collaboration (Ponds et al., 2007; Hoekman et al., 2009).

Taken together, the regional and dyadic results distinguish the volume of programme participation from the breadth and intensity of collaboration. Regional green project counts are not significantly associated with green patent counts, whereas green connectedness and bilateral green project links show more consistent positive associations with their respective count outcomes. This pattern is compatible with FPs supporting opportunities for interregional knowledge exchange. The regional and dyadic models capture different dimensions of that relationship, so their results should be read as complementary evidence.

6. Conclusion

This paper examined the relationship between EU Framework Programme (FP) collaboration and green patenting across EU-28 regions during FP7 and Horizon 2020, which together cover the 2007-2020 period. The main finding is that different dimensions of programme participation relate differently to patented invention. Regional green project counts are not significantly associated with green patent counts. The breadth of green FP partnerships, however, is positively associated with regional green patenting, and shared green FP projects are positively associated with green co-patenting between the same region pairs. Evidence of a shift towards greener patent portfolios is less consistent and depends on the outcome measure and specification.

The descriptive evidence provides the geographical context for these findings. Green co-patenting is concentrated in established innovation centres, while the strongest FP project ties appear more geographically dispersed. Cross-border co-patenting orientation increases for a majority of regions between 2007-2013 and 2014-2020, although sizeable differences remain across regions. These changes concern the balance between domestic and international partners, but they do not necessarily indicate growth in the volume of green co-invention.

This paper's contribution is to connect regional inventive performance with two distinct collaboration networks. It extends previous evidence on green FP networks and regional environmental innovation (Fabrizi et al., 2025) by examining whether project links are also reflected in bilateral green co-patenting. The results are compatible with accounts that emphasise accumulated regional capabilities and access to external knowledge (Martin & Sunley, 2006; Maskell & Malmberg, 2007). They also reinforce the empirical distinction between project collaboration and patent-based co-invention, as documented by Wanzenböck et al. (2014), Akçomak et al. (2023) and D'Adda et al. (2025). The analysis does not identify the mechanisms through which knowledge moves between the two networks.

For research policy, the findings suggest evaluating collaborative programmes through both regional outputs and the partnerships they support. Project counts alone provide an incomplete description of programme participation, as the breadth of collaboration networks is also associated with green patenting. Brokerage, partner search and support for the absorptive capacity of less-connected regions are plausible complements to project funding, consistent with evidence that the design of subsidised collaboration matters for patenting (Fornahl et al., 2011). Our estimates do not evaluate these measures directly, so they provide a rationale for considering and assessing them rather than evidence of their effectiveness.

Several limitations qualify this interpretation. The narrow project categories exclude some environmentally relevant research and do not match the patent classification exactly. Patents capture codified invention, leaving out non-patented innovation, deployment and organisational change, and counts do not distinguish inventions by their value. In addition, region-level project ties do not show whether the organisations in a consortium are those listed on a joint patent. Finally, the fixed-effects models identify conditional associations rather than causal programme effects. Selection into projects, time-varying bilateral factors and the timing of research and patenting may influence the results. Future work could examine the timing and technological content of these links or exploit quasi-experimental funding variation.

References

Akçomak, İ. S., Çetinkaya, U. Y., Erdil, E. & Gossart, M. Ö. (2023). What drives network evolution? Comparing R&D project and patent networks in the EU. *Industrial and Corporate Change*, 32(5), 1109–1134. https://doi.org/10.1093/icc/dtad044

Almeida, P. & Kogut, B. (1999). Localization of knowledge and the mobility of engineers in regional networks. *Management Science*, 45(7), 905–917. https://doi.org/10.1287/mnsc.45.7.905

Anderson, J. E. & Van Wincoop, E. (2003). Gravity with gravitas: A solution to the border puzzle. *American Economic Review*, 93(1), 170–192. https://doi.org/10.1257/000282803321455214

Audretsch, D. B. & Feldman, M. P. (1996). R&D spillovers and the geography of innovation and production. *The American Economic Review*, 86(3), 630–640. https://doi.org/10.2307/2118216

Barbieri, N., Marzucchi, A. & Rizzo, U. (2020). Knowledge sources and impacts on subsequent inventions: Do green technologies differ from non-green ones? *Research Policy*, 49(2), 103901. https://doi.org/10.1016/j.respol.2019.103901

Bathelt, H., Malmberg, A. & Maskell, P. (2004). Clusters and knowledge: Local buzz, global pipelines and the process of knowledge creation. *Progress in Human Geography*, 28(1), 31–56. https://doi.org/10.1191/0309132504ph469oa

Bellemare, M. F. & Wichman, C. J. (2020). Elasticities and the inverse hyperbolic sine transformation. *Oxford Bulletin of Economics and Statistics*, 82(1), 50–61. https://doi.org/10.1111/obes.12325

Boschma, R. A. (2005). Proximity and innovation: A critical assessment. *Regional Studies*, 39(1), 61–74. https://doi.org/10.1080/0034340052000320887

Breschi, S. & Lissoni, F. (2004). Knowledge networks from patent data: Methodological issues and research targets (Working Paper No. 150 / WP150). KITeS/CESPRI, Università Bocconi.

Burt, R. S. (1992). Structural holes: The social structure of competition. Harvard University Press.

Corradini, C. (2019). Location determinants of green technological entry: Evidence from European regions. *Small Business Economics*, 52(4), 845–858. https://doi.org/10.1007/s11187-017-9938-7

D'Adda, D., Iacobucci, D. & Perugini, F. (2025). Regional technological profiles and collaborations: An empirical analysis of joint patents and EU-funded projects. *Papers in Regional Science*, 104(1), 100073. https://doi.org/10.1016/j.pirs.2024.100073

Dechezleprêtre, A., Martin, R. & Mohnen, M. (2013). Knowledge spillovers from clean and dirty technologies: A patent citation analysis (Grantham Research Institute Working Paper No. 135; CCCEP Working Paper No. 151). London School of Economics and Political Science. https://www.lse.ac.uk/granthaminstitute/wp-content/uploads/2013/10/WP135-Knowledge-spillovers-from-clean-and-dirty-technologies.pdf

Fabrizi, A., Fiorelli, C. & Meliciani, V. (2025). The role of green networks for environmental innovation in European regions. *Journal of Industrial and Business Economics*, 52(4), 935–966. https://doi.org/10.1007/s40812-024-00339-8

Filippopoulos, N. & Fotopoulos, G. (2022). Innovation in economically developed and lagging European regions: A configurational analysis. *Research Policy*, 51(2), 104424. https://doi.org/10.1016/j.respol.2021.104424

Fornahl, D., Broekel, T. & Boschma, R. (2011). What drives patent performance of German biotech firms? The impact of R&D subsidies, knowledge networks and their location. *Papers in Regional Science*, 90(2), 395–418. https://doi.org/10.1111/j.1435-5957.2011.00361.x

Fromhold-Eisebith, M. (2007). Bridging scales in innovation policies: How to link regional, national and international innovation systems. *European Planning Studies*, 15(2), 217–233. https://doi.org/10.1080/09654310601078754

Ghodsi, M. & Jovanović, B. (2022). Determinants and effects of foreign direct investment in Austria: Spillovers to novel innovative environmental technologies (FIW Research Reports 01-2022). FIW. https://www.fiw.ac.at/wp-content/uploads/2023/02/FIW_RR_01_2022_Determinants_and_Effects_of_FDI_in_Austria.pdf

Gonçalves, E., Costa, H. S., Montenegro, R. L., Chiarini, T. & Taveira, J. G. (2023). Green technology co-patenting networks: International dynamics. *Quality & Quantity*, 57(2), 1603–1627. https://doi.org/10.1007/s11135-022-01427-4

Hall, B. H., Jaffe, A. B. & Trajtenberg, M. (2001). The NBER patent citation data file: Lessons, insights and methodological tools. https://doi.org/10.3386/w8498

Haščič, I. & Migotto, M. (2015). Measuring environmental innovation using patent data. OECD Publishing.

Hidalgo, C. A. & Hausmann, R. (2009). The building blocks of economic complexity. *Proceedings of the National Academy of Sciences*, 106(26), 10570–10575. https://doi.org/10.1073/pnas.0900943106

Hoekman, J., Frenken, K. & van Oort, F. (2009). The geography of collaborative knowledge production in Europe. *The Annals of Regional Science*, 43(3), 721–738. https://doi.org/10.1007/s00168-008-0252-9

Hoekman, J., Scherngell, T., Frenken, K. & Tijssen, R. (2013). Acquisition of European research funds and its effect on international scientific collaboration. *Journal of Economic Geography*, 13(1), 23–52. https://doi.org/10.1093/jeg/lbs011

Hollanders, H. & Es-Sadki, N. (2023). Regional Innovation Scoreboard 2023. European Commission, Publications Office of the European Union. https://doi.org/10.2777/70412

IPCC (2022). Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (incl. Summary for Policymakers). Cambridge University Press.

Jaffe, A. B. (1986). Technological opportunity and spillovers of R&D: Evidence from firms' patents, profits, and market value. *American Economic Review*, 76(5), 984–1001. https://doi.org/10.3386/w1815

Jaffe, A. B., Trajtenberg, M. & Henderson, R. (1993). Geographic localization of knowledge spillovers as evidenced by patent citations. *Quarterly Journal of Economics*, 108(3), 577–598. https://doi.org/10.2307/2118401

Kim, K., Nonnis, A., Özaygen, A. & Kogler, D. F. (2023). Green-tech firm creation in Germany: The role of regional knowledge. *International Entrepreneurship and Management Journal*, 19(1), 97–120. https://doi.org/10.1007/s11365-022-00808-3

Lata, R., Scherngell, T. & Brenner, T. (2015). Integration processes in European research and development: A comparative spatial interaction approach using project-based R&D networks, co-patent networks and co-publication networks. *Geographical Analysis*, 47(4), 349–375. https://doi.org/10.1111/gean.12079

Lenaerts, K., Tagliapietra, S. & Wolff, G. B. (2021). Can climate change be tackled without ditching economic growth? Bruegel Working Paper. https://hdl.handle.net/10419/264196

Lundquist, K.-J. & Trippl, M. (2013). Distance, proximity and types of cross-border innovation systems: A conceptual analysis. *Regional Studies*, 47(3), 450–460. https://doi.org/10.1080/00343404.2011.560933

Martin, R. & Sunley, P. (2006). Path dependence and regional economic evolution. *Journal of Economic Geography*, 6(4), 395–437. https://doi.org/10.1093/jeg/lbl012

Maskell, P. & Malmberg, A. (2007). Myopia, knowledge development and cluster evolution. *Journal of Economic Geography*, 7(5), 603–618. https://doi.org/10.1093/jeg/lbm020

Meliciani, V., Di Cagno, D., Fabrizi, A. & Marini, M. (2022). Knowledge networks in joint research projects, innovation and economic growth across European regions. *The Annals of Regional Science*, 68(3), 549–586. https://doi.org/10.1007/s00168-021-01092-9

OECD (2009). OECD Patent Statistics Manual. OECD Publishing.

OECD (2023). OECD Science, Technology and Innovation Outlook 2023. OECD Publishing.

Ponds, R., van Oort, F. & Frenken, K. (2007). The geographical and institutional proximity of research collaboration. *Papers in Regional Science*, 86(3), 423–443. https://doi.org/10.1111/j.1435-5957.2007.00126.x

Powell, W. W., Koput, K. W. & Smith-Doerr, L. (1996). Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology. *Administrative Science Quarterly*, 41(1), 116–145. https://doi.org/10.2307/2393988

Rigby, D. L. & Essletzbichler, J. (1997). Evolution, process variety, and regional trajectories of technological change in U.S. manufacturing. *Economic Geography*, 73(3), 269–284. https://doi.org/10.1111/j.1944-8287.1997.tb00089.x

Santos Silva, J. M. C. & Tenreyro, S. (2006). The log of gravity. *The Review of Economics and Statistics*, 88(4), 641–658. https://doi.org/10.1162/rest.88.4.641

Schiederig, T., Tietze, F. & Herstatt, C. (2012). Green innovation in technology and innovation management: An exploratory literature review. *R&D Management*, 42(2), 180–192. https://doi.org/10.1111/j.1467-9310.2011.00672.x

Sonn, J. W. & Storper, M. (2008). The increasing importance of geographical proximity in knowledge production: An analysis of U.S. patent citations, 1975-1997. *Environment and Planning A*, 40(5), 1020–1039. https://doi.org/10.1068/a3930

Vlčková, J., Sankot, O. & Květoň, V. (2026). The role of multinational enterprises in technological diversification in less developed regions: An analysis from Czechia. *Eurasian Geography and Economics*, 1–23. https://doi.org/10.1080/15387216.2026.2705846

Wanzenböck, I., Scherngell, T. & Brenner, T. (2014). Embeddedness of regions in European knowledge networks: A comparative analysis of inter-regional R&D collaborations, co-patents and co-publications. *The Annals of Regional Science*, 53(2), 337–368. https://doi.org/10.1007/s00168-013-0588-7

Yotov, Y. V., Piermartini, R., Monteiro, J.-A. & Larch, M. (2016). An Advanced Guide to Trade Policy Analysis: The Structural Gravity Model. World Trade Organization. https://doi.org/10.30875/abc0167e-en

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Offenlegung nach § 25 Mediengesetz: Medieninhaber (Verleger): Verein "Wiener Institut für Internationale Wirtschaftsvergleiche", A 1060 Wien, Rahlgasse 3. Vereinszweck: Analyse der wirtschaftlichen Entwicklung der zentral- und osteuropäischen Länder sowie anderer Transformationswirtschaften sowohl mittels empirischer als auch theoretischer Studien und ihre Veröffentlichung; Erbringung von Beratungsleistungen für Regierungs- und Verwaltungsstellen, Firmen und Institutionen.

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