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# Determinants of cross-border co-patents: empirical evidence from 45 European regions

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**Abstract** Innovation processes are often interactive because the actors involved require complementary knowledge assets. Given the potentially lower institutional proximity (in terms of language, culture and formal regulations) when compared to domestic counterparts, cross-border interactive innovation processes between actors are less likely to occur. However, these processes are important for firms and (cross-border) regions to ensure economic growth and competitiveness in the long term. In addition, cross-border interactive innovation processes provide opportunities to enhance creative potentials through the combination of knowledge generated in different (national) innovation systems.

By simultaneously exploring the effects of institutional proximity, technological proximity, spatial distance and European integration, this paper further enriches the literature. Negative binomial gravity models give insight into the reasons for differences in the number of generated co-patents in 45 European cross-border regions. As expected, spatial and technological distance have negative impacts on co-patent activities in all models. Sharing a common official language (i.e., institutional proximity) significantly increases the number of cross-border co-patents *ceteris paribus* by a factor of 1.83 to 2.49. Further (qualitative) research is, however, necessary to concretely determine the underlying language effects and to isolate these from cultural factors.

Surprisingly, the results also reveal that, *ceteris paribus*, length of EU membership exerts a significant negative effect on co-patenting, whereas belonging to ‘Central and Eastern European Countries’ has a significant positive effect on co-patenting. Consequently, cross-border regions of the founding EU member states are relatively

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and *ceteris paribus* less involved in cross-border co-patenting activities than their Eastern European counterparts.

**Keywords** Co-patents · Interactive innovation processes · European cross-border regions · Institutional proximity · European integration · Negative binomial gravity models

**JEL codes** C20 · O31 · R15

## **Determinanten grenzüberschreitender Ko-Patentaktivitäten: Empirische Befunde aus 45 europäischen Regionen**

**Zusammenfassung** Innovationsprozesse sind häufig interaktiv, weil die beteiligten Akteure komplementäres Wissen benötigen. Aufgrund der im Vergleich zu intranationalen Partnern/-innen geringeren institutionellen Nähe (im Hinblick auf Sprache, Kultur und formelle Regularien) sind grenzüberschreitende interaktive Innovationsprozesse zwischen Akteuren unwahrscheinlicher. Diese Prozesse sind jedoch im Allgemeinen für Unternehmen und (Grenz-)Regionen wichtig, um langfristig ökonomisches Wachstum und Wettbewerbsfähigkeit zu gewährleisten. Außerdem bergen grenzüberschreitende Innovationsprozesse aufgrund der Verknüpfung von Wissen, das im Kontext verschiedener (nationaler) Innovationssysteme entstanden ist, kreative Potenziale.

Indem gleichzeitig Effekte institutioneller Nähe, technologischer Nähe, räumlicher Distanz und der Europäischen Integration untersucht werden, bereichert dieser Artikel den Forschungsstand. Negative Binomial-Gravitationsmodelle geben Aufschluss über die Gründe unterschiedlich stark ausgeprägter Ko-Patentaktivitäten in den 45 untersuchten europäischen Grenzregionen. Erwartungsgemäß wirken sich räumliche und technologische Distanz in allen Modellen signifikant negativ auf die Anzahl von Ko-Patenten aus. Das Sprechen einer gemeinsamen Amtssprache (d. h. institutionelle Nähe) erhöht die Anzahl grenzüberschreitender Ko-Patente *ceteris paribus* um den Faktor 1,83 bis 2,49. Weitere (qualitative) Forschung ist jedoch vonnöten, um die zugrundeliegenden Spracheffekte konkreter zu beleuchten und diese isoliert von kulturellen Einflüssen zu betrachten.

Entgegen der Erwartungen zeigen die Resultate jedoch auch, dass sich die Länge der EU-Mitgliedschaft signifikant negativ und die Einbettung „mittel- und osteuropäischer Länder“ signifikant positiv auf Ko-Patentaktivitäten auswirken. Folglich sind Grenzregionen der EU-Gründungsstaaten relativ betrachtet und *ceteris paribus* weniger intensiv in grenzüberschreitende Ko-Patentaktivitäten involviert als osteuropäische Grenzregionen.

## **1 Introduction**

Co-patents are of critical importance for actors with complementary knowledge assets that seek to protect their corporately developed intellectual property, specifically innovations (Belderbos et al. 2014; Agostini and Caviggioli 2015; Cassiman

and Veugelers 2006). Based on the empirical results of Hoekman et al. (2009), Morescalchi et al. (2015), Maggioni and Uberti (2007), Lata et al. (2015) and Lata et al. (2018), one can assume that co-patenting is highly distance sensitive and that (co-)patents are an expression of interactive innovation processes. The likelihood of interactive innovation processes and, in particular, co-patent activities occurring potentially decreases with increasing spatial distance between the involved parties (which can include firms, universities and individuals).

Actors in cross-border regions are consequently more dependent on foreign actors than their domestic counterparts with regard to accessing complementary knowledge assets (Agostini and Caviggioli 2015; Arndt and Sternberg 2000). It is widely acknowledged that interactive (cross-border) innovation processes, for example those manifested in co-patents, are essential for firms and (cross-border) regions to achieve economic growth and competitiveness in the long term (Trippel 2010; Asheim and Isaksen 1997; Cooke et al. 1997). In addition, cross-border collaborations hold creative potentials as knowledge embedded in different (national) innovation systems is combined in such ventures (Fromhold-Eisebith 2007). However, cross-border regions are characterised by heterogeneous institutional settings (e.g., in terms of language, culture and formal regulations). Thus, interactive innovation processes are less likely to occur in cross-border regions when compared to relations within regions that are not separated by linguistic and/or country borders (Lundquist and Trippel 2013; Koschatzky 2000; Javidan et al. 2005).

As one form of interactive innovation processes, co-patents in cross-border regions (i.e., patents developed in cooperation between actors from different countries and/or language areas) are of particular importance to the European Commission for two reasons: First, patent-related measures were an integral part of the Innovation Union, which was the core of the Europe 2020 strategy (European Commission 2011). These measures especially refer to the establishment of the interdependent ‘European Unitary patent’ and the ‘Unified Patent Court’. The inauguration of the former will enable patent applicants to obtain patent protection in all EU member states (with the exceptions of Croatia and Spain) by submitting a single patent (European Patent Office n.d.). Due to the elimination of national validation procedures, the costs (especially legal and translation fees) for patent protection in all 25 participating EU member states will be reduced by approximately 78% (European Commission 2015a). Furthermore, the ‘Unified Patent Court’ will, with the exceptions of Spain and Poland, eliminate cost- and time-intensive court procedures in all ‘Contracting Member States’ (Unified Patent Court n.d.).

Second, the fact that the vast majority of the European Territorial Cooperation goal’s budget (around 78.4% of €9.6 billion) has been allocated to the explicit promotion of relatively small (Interreg A) cross-border regions highlights the relevance of these regions to the EU (European Commission 2015b; Interreg 2019). By exploring the determinants of cross-border co-patents as a proxy for interactive innovation processes and confining the analysis to relatively small cross-border regions, more specific implications for the EU’s Territorial Cooperation policy can be deduced. Cross-border co-patent activities in this paper are limited to ‘Nomenclature des unités territoriales statistiques’ (NUTS) 3 regions belonging to different sub-regions within one cross-border region (Sect. 3).

More specifically, this paper aims to answer the following research question: Which determinants explain the magnitude of co-patents in European cross-border regions?

The negative effect of spatial distance, technological (cognitive) distance and linguistic borders on co-patenting as well as research and development (R&D) collaboration between European NUTS 2 and 3 regions while controlling for country borders has been verified in multiple econometric studies (Lata et al. 2018, 2015; Scherngell and Barber 2009). By simultaneously investigating European integration effects (i.e., length of EU border, involvement of ‘Central and Eastern European Countries’ that joined the EU in 2004 or later), this paper further enriches the literature. Furthermore, the impact of sharing the same official language (on the NUTS 3 level) is accurately quantified in this paper by the computation of so-called incidence rate ratios.

The remainder of this article is as follows: The literature review (including hypotheses) and the operationalisations of the variables of interest are presented in Sects. 2 and 3. Based on the results of the applied negative binomial regression models presented in Sect. 4, policy implications, the research outlook and the limitations of this paper are finally discussed in Sect. 5.

## 2 Literature review: determinants of cross-border co-patents

Because (co-)patent activities are a widely applied proxy for innovation processes, potential determinants of cross-border co-patents are mainly derived from literature on innovation and knowledge. Despite understandable criticism—for example, that patent citations rather than patent counts provide more insight into innovation performances (Trajtenberg 1990; Griliches 1998)—this paper utilises (cross-border) co-patent counts (co-inventorship) as the proxy for successful (cross-border) interactive innovation processes. This approach is justifiable given that empirical analyses have revealed that both patent citations and patent counts are acceptable proxies (Hagedoorn and Cloudt 2003; Acs et al. 2002). In addition, it can be assumed that potential distortions in any respect will be neutralised by the considerable number of observations. However, not all inventions applied at patent offices are innovations and not all innovations are patented (Beneito 2006; Faber and Heslen 2004; Arundel and Kabla 1998; De Rassenfosse and van Pottelsberghe de la Potterie 2009).

### 2.1 Technological (cognitive) proximity

As mentioned in the introduction, actors engage in co-patenting to exploit complementary knowledge assets. Cognitive proximity has been identified as the absolute prerequisite for such interactive innovation processes as it principally enables actors (for example firms) to understand and exploit new knowledge (Boschma 2005; Nooteboom 1999; Cohen and Levinthal 1990). Concretely speaking, cognitive proximity refers to the knowledge background (i.e., of a scientific field, technology area or industrial sector) and the absorptive capacity and learning ability of actors.

Actors (as well as regions) are cognitively close to one another if their knowledge background is similar (Davids and Frenken 2018; Nootboom et al. 2007; Hardeman et al. 2015). If the cognitive proximity between actors is too low, they will not be able to understand and exploit new (complementary) knowledge (Boschma 2005; Cohen and Levinthal 1990). However, the literature also strongly emphasises that cognitive proximity must not be excessive to ensure novelty. Hence, the relationship between cognitive proximity and innovative output follows an inverted U-shaped pattern (Nootboom 2001; Boschma et al. 2002).

The term technological proximity is widely utilised to denote the cognitive proximity between regions and to indicate the similarity of their economy- or technology-related structures and is thus used hereafter. Based on the 121 third-digit classes of the International Patent Classification (IPC), several econometric studies have revealed a significant negative impact of technological distance on co-patent activities and R&D collaborations in Europe and OECD (partner) countries (Lata et al. 2015, 2018; Morescalchi et al. 2015; Scherngell and Barber 2009).

**Hypothesis 1:** The higher the technological proximity between two NUTS 3 regions belonging to different sub-regions within one cross-border region, the higher the number of generated co-patents.

## 2.2 Institutional proximity

Furthermore, it has been revealed that actors struggle to develop interactive innovation processes when they do not share the same language and/or similar values, norms and routines (culture), all of which are components of institutional proximity (Maskell and Malmberg 1999; Boschma 2005; Gertler 2003). Corroborating these findings, Gertler (2003) and Koschatzky (2000) have stated that absorptive capacity is enhanced by institutional factors (e.g., language, shared values, norms and routines) at the micro level. Transferring the subject of institutional factors (consisting of language, culture and formal regulations) to cross-border constellations, it is evident that interactive innovation processes are less likely to occur in such contexts due to increasing institutional distance (Lundquist and Trippel 2013; Koschatzky 2000; Javidan et al. 2005).

While controlling for country border effects, several econometric studies have shown that not sharing a common official language (i.e., institutional proximity is not given) decreases the number of co-patent activities and R&D collaborations between European NUTS 2 and 3 regions significantly (Lata et al. 2015, 2018; Scherngell and Barber 2009). Put differently, if two regions differ in terms of the language which is spoken by the majority of the population, significantly fewer co-patents will be generated by actors from those two regions. In this context, Lata et al. (2018) have demonstrated that language barrier effects on co-patent activities between 1260 European NUTS 3 regions (1999–2009) increased over time.

**Hypothesis 2:** If the same official language is spoken by the majorities of the inhabitants in two NUTS 3 regions, actors from those regions are engaged in more cross-border co-patent activities.

### 2.3 Spatial proximity

Spatial proximity is important, as innovation-based relations often feature the exchange of tacit knowledge, and because the exchange of tacit knowledge itself strongly depends on face-to-face interactions (Boschma 2004; Williams 2006; Howells 2002; Lam 2002). The results of the European Regional Innovation Survey suggest a clear correlation between the knowledge intensity of manufacturing firms' activities and the relevance of spatial proximity to other innovating actors (Koschatzky and Sternberg 2000; Arndt and Sternberg 2000).

In the context of inter- and intranational co-patent activities and R&D collaborations in Europe and the United States, the negative impact of spatial distance has been econometrically proven multiple times (Maggioni and Uberti 2007; Hoekman et al. 2009; Lata et al. 2015, 2018; Scherngell and Barber 2009). Furthermore, Morescalchi et al. (2015) computed the elasticity of co-patents and found that spatial proximity became increasingly relevant for co-patents among all NUTS 3 regions in 50 OECD (partner) countries over time (1988–2009).

**Hypothesis 3:** The less expenditure of time required to interact, the higher the number of generated co-patents in European cross-border regions.

However, based on data gathered from the European Regional Innovation Survey, Koschatzky and Sternberg (2000) assigned spatial proximity a subordinated role to that of institutional proximity with regard to impact on cross-border innovation linkages.

### 2.4 Length of shared EU borders

The Treaty of Rome (1957) came into effect on 1 January, 1958, and resulted in the foundation of the European Economic Community and European Atomic Energy Community which consisted of Belgium, France, Germany, Italy, Luxembourg and the Netherlands. The EU subsequently expanded to include 28 member states through seven enlargements, which occurred in 1973, 1981, 1986, 1995, 2004, 2007 and 2013, respectively (European Parliament n.d.; European Commission 2020).

Thus, the time period in which cross-border relations have been institutionalised in the context of European integration differs for many cross-border regions. Economic, political, legal and social integration within the EU underlies regionally different dynamics and has deepened (vertical integration) and widened (horizontal integration) at different points in time (Leuffen et al. 2013; Beerkens 2008; Stone Sweet and Sandholtz 1998).

Border research has further indicated that the cultural, administrative and legal dimensions of borders within the EU still pose obstacles to cross-border interactions. However, there is a consensus that the EU's internal borders have overall become more permeable in terms of citizen and labour mobility as well as transnational economic exchange over time (O'Dowd 2001; Checkel and Katzenstein 2009; Fries-Tersch et al. 2018; Berger and Nitsch 2008).

**Hypothesis 4:** The longer the existence of a shared EU border, the higher the number of cross-border co-patents between two NUTS 3 regions.

## 2.5 Belonging to a ‘Central and Eastern European Country’

Border research has suggested that the economic and political integration of ‘Central and Eastern European Countries’ (CEECs) into the EU has been particularly challenging due to their late economic and political opening in the beginning of the 1990s (Boerzel and Schimmelfennig 2017; Albuлесcu 2011; De Benedictis and Tajoli 2007). In fact, Eastern European NUTS 2 regions were only marginally integrated into the European R&D network between 1998 and 2002 (Scherngell and Barber 2009). All countries which joined the EU in 2004, 2007 or 2013, with the exception of Cyprus and Malta, are CEECs (OECD 2001).

**Hypothesis 5:** If one or even both NUTS 3 regions belong to a CEEC, the number of generated cross-border co-patents is lower when compared to constellations where this is not the case.

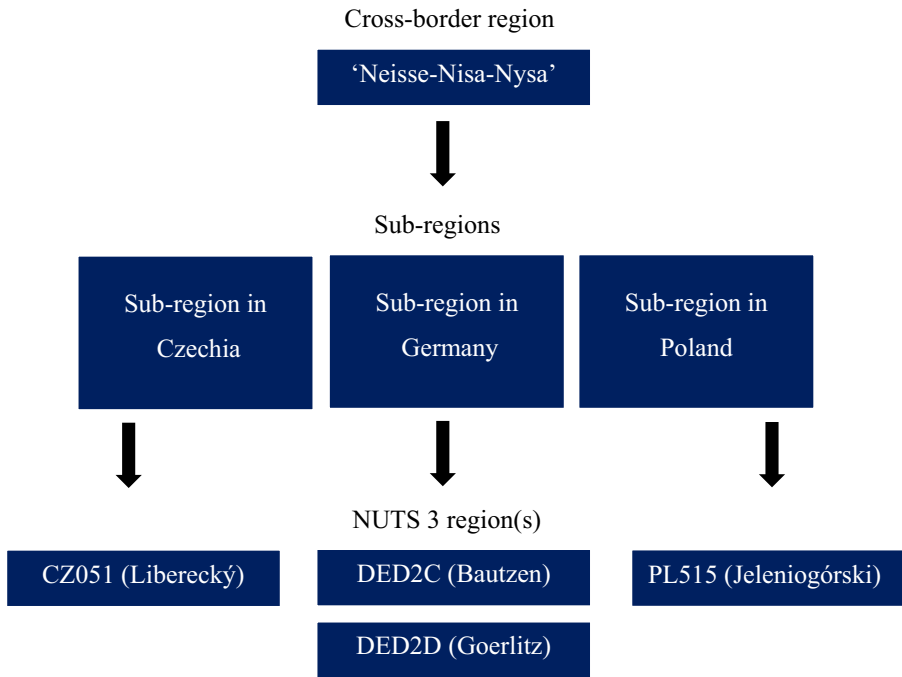
## 3 Operationalisation and data

As noted in Sect. 2, co-patents generated by individuals (inventors) from two NUTS 3 regions  $i$  and  $j$  belonging to different sub-regions within one cross-border region constitute the dependent variable in this paper ( $Y_{ij}$ ). The full counting procedure is applied to identify the number of co-patents (i.e., the interaction frequency) between two NUTS 3 regions  $i$  and  $j$  (in accordance with Scherngell and Barber 2009; Lata et al. 2015; Hoekman et al. 2009). If inventors contributing to one patent stem from NUTS 3 regions  $i, j$  and  $k$  (each belonging to different sub-regions within one cross-border region), three co-patent activities are counted: from  $i$  to  $j$ ,  $i$  to  $k$  and  $j$  to  $k$ . The number of patents per region (Patents <sub>$i$</sub>  and Patents <sub>$j$</sub> ) are used as origin and destination variables, and their inclusion ensures that the results are not distorted by the NUTS 3 regions’ diverging magnitudes (patent counts).

The patent data (1991–2015) originate from the European Patent Office’s PAT-STAT Online (2020 Autumn) database, whose broad coverage ensures an appropriate basis for an analysis at the supranational European level. As a consequence of the time lag between the filing and publication dates, the former are used. The observation period begins in 1991, as this year marks the collapse of the Soviet Union and the end of the Warsaw Pact (Hoegselius 2010; Mastny and Byrne 2005). For reasons of representativity and actuality, the observation period lasts until 2015.

Sub-regions within one cross-border region are separated from one another by distinct official languages and/or the fact that they belong to different nations. One cross-border region consists of at least two sub-regions and one sub-region consists of at least one NUTS 3 region. This hierarchical order is illustrated on the example of the Association of European Border Regions (AEBR) region ‘Neisse-Nisa-Nysa’ (Czech—German—Polish borderland) presented in Fig. 1. One Polish, one Czech and two German NUTS 3 region(s) lead to five observations in total.



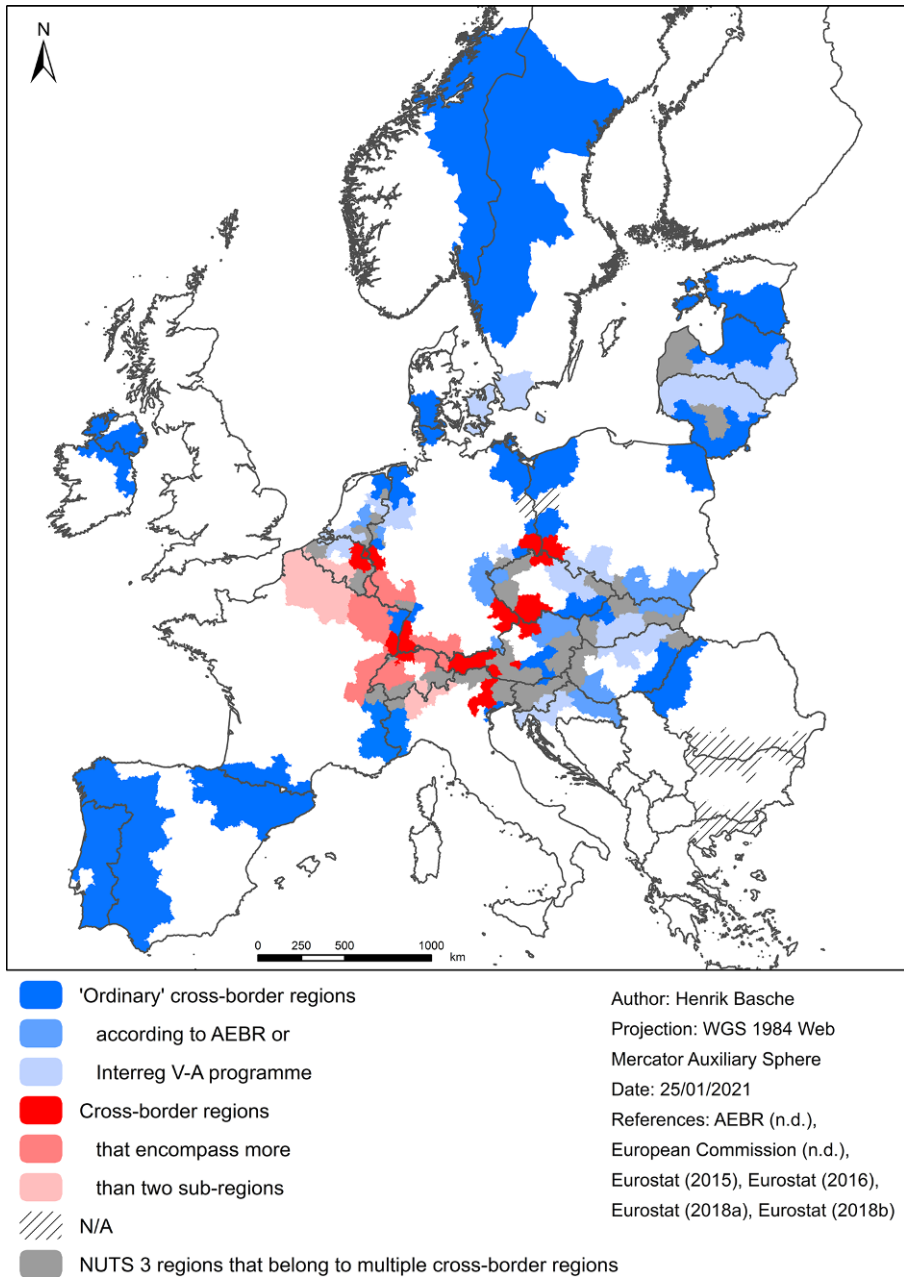


**Fig. 1** The hierarchical order of one cross-border region, at least two sub-regions per cross-border region and at least one NUTS 3 region per sub-region on the example of the AEBR region ‘Neisse-Nisa-Nysa’

### 3.1 European cross-border regions

In this paper, cross-border regions encompass NUTS 3 regions from at least two EU-28/European Free Trade Association countries that belong either to the AEBR or the Interreg V-A programme (AEBR *n.d.*; European Commission *n.d.*). The Interreg V-A regions span all land borders within and between the EU-28 and European Free Trade Association, but did not constitute the population exclusively. In case of overlaps between AEBR and Interreg V-A regions, the former were given priority if they covered major parts of borderlands. In fact, the AEBR regions, which co-exist with the relatively large Interreg V-A regions, are interpreted as further institutionalisation of functional cross-border relations on a small geographical scale. An example of the consequences of this approach is that four smaller AEBR regions instead of one large Interreg V-A region span for instance the Dutch—German borderland in the present paper. Fig. 2 shows the 45 investigated official (non-maritime) European cross-border regions which serve as the basis for the following analysis.

To comply with the principle of independent observations, two AEBR regions were merged in the case of the Irish—Northern Irish borderland (‘Irish Central Border Area Network’ and ‘East Border Region’). Thus, no observation (i.e., pair of NUTS 3 regions) occurred twice. Therefore, the Interreg V-A regions ‘Austria-Czech Republic’ and ‘Austria-Germany/Bavaria’ were not taken into consideration. To ensure that observations were not counted twice, some rather remotely



**Fig. 2** The investigated 45 European cross-border regions

located NUTS 3 regions were not allocated to the Interreg V-A regions ‘France-Belgium-Germany-Luxembourg’, ‘Belgium—The Netherlands’, ‘Germany-Austria-Switzerland-Liechtenstein’, ‘Czech Republic—Poland’ and the AEBR region ‘Euregio’ (Dutch—German borderland).

Fig. 2 distinguishes between three types of cross-border regions: Cross-border regions marked in the three different shades of blue are ‘ordinary’ cross-border regions according to the AEBR or the Interreg V-A programme, whereas those in the three shades of red consist of more than two sub-regions. The three cross-border regions emphasised with black stripes solely contain pairs of NUTS 3 regions which consist of at least one region to which less than 20 patent applications (1991–2015) were assigned. These have therefore been treated as not applicable (N/A). NUTS 3 regions that belong to multiple cross-border regions are depicted in grey (75 in total). In the case of the Interreg V-A regions ‘Austria-Hungary’ and ‘Slovenia-Hungary’, all NUTS 3 regions belong to at least one other cross-border region; as such, these cross-border regions are fully shown in grey.

This paper’s scope is deliberately limited to co-patents generated in two different NUTS 3 regions within one cross-border region which are separated by country and/or linguistic borders. Thus, the total number of observations does not equal a matrix of all NUTS 3 regions in the 45 cross-border regions under investigation ( $n*n-1/2$ ). In fact, there are in total 2145 pairs of NUTS 3 regions (with at least 20 patent counts each) belonging to different sub-regions (108 in total) within one cross-border region (45 in total).

### 3.2 Technological proximity

The magnitude (i.e., the number of patents generated between 1991 and 2015) of the European NUTS 3 regions under investigation is distinctively diverse. The range is 21–51,152, the arithmetic means per region  $i$  and  $j$  equal 1321 and 1912, respectively, and the standard deviation amounts to 2089 and 4912, respectively (see Table 1). Thus, technological proximity (TechPROX) between NUTS 3 regions  $i$  and  $j$  was computed on the basis of the more aggregated ‘Nomenclature statistique des activités économiques dans la Communauté européenne’ (NACE) instead of the more fine-grained three-/four-digit classes of the IPC.

Following the concordance scheme developed by Van Looy et al. (2015), 623 potential IPC four-digit classes of the generated patents between 1991 and 2015 were assigned to 26 eligible two-digit NACE industry categories to depict the ‘techno-

**Table 1** Descriptive statistics of cross-border co-patents in European regions

Variable	$n$	Mean	Standard deviation	Min	Max
Co-patents	2145	13.59	82.18	0	1746
Patents <sub><math>i</math></sub>	2145	1320.70	2088.75	21	21,043
Patents <sub><math>j</math></sub>	2145	1912.00	4912.02	21	51,152
(1 + TechPROX)	2145	1.58	0.29	0.05	1.99
SpatialDIST	2145	146.75	83.90	15	754
EU	1674	38.35	20.53	2	57

logical structure’ of the NUTS 3 regions. To ensure that patents were only counted once, they were weighted by the total number of IPC four-digit classes assigned to them. To reflect TechPROX between two NUTS 3 regions, the vectors  $\mathbf{t}(\mathbf{i})$  and  $\mathbf{t}(\mathbf{j})$ —the share of each of the 26 NACE industry categories of the total number of patents—were built first. TechPROX between region  $i$  and  $j$  was then calculated on the basis of Pearson’s correlation coefficient  $r_{ij}$  (following Scherngell and Barber 2009; Morescalchi et al. 2015; Lata et al. 2015):

$$r_{ij} = \text{corr}[\mathbf{t}(\mathbf{i}), \mathbf{t}(\mathbf{j})]$$

In accordance with the ‘min-complement distance measure’ proposed by Bar and Leiponen (2012), it is assumed that TechPROX depends solely on the shares of NACE industry categories which are represented in both NUTS 3 regions  $i$  and  $j$ . Thus, in the case of relatively low patent counts or highly specialised sub-regions, the calculation of  $r_{ij}$  is not distorted by zero values within the vectors  $\mathbf{t}(\mathbf{i})$  and/or  $\mathbf{t}(\mathbf{j})$ . All NACE industry categories whose share on the total number of patents of NUTS 3 region  $i$  and/or  $j$  equals zero were consequently irrelevant with regard to the computation of  $r_{ij}$ .

Given the difficulty to reflect the fine line between being technologically (cognitively) close and technologically (cognitively) too close at the regional level, the inverted U-shaped relation between proximity and innovation discussed in Sect. 2.1 is transformed into a linear or exponential relation. The following correlation hence applies: The higher  $r_{ij}$ , the higher TechPROX and the greater the positive impact on the number of cross-border co-patents. As opposed to state-of-the-art research (Scherngell and Barber 2009; Morescalchi et al. 2015; Lata et al. 2015),  $r_{ij}$  is not squared but added to 1 in order to distinguish between positive and negative TechPROX values. In fact, 99 of 2145 observations show a negative TechPROX sign. Otherwise, positive and negative correlations between two NUTS 3 regions’ ‘technological structure’ would be treated equally.

### 3.3 Institutional proximity

As elaborated on in Sect. 2.2, institutional proximity can be divided into language (in the narrow sense), formal regulations and culture (e.g., values, norms and routines). This classification is also in line with the ‘Sources of Differences Between Countries and Groups’ postulated by Hofstede et al. (2010). These sources consist of (1) visible identity (language, religion), (2) invisible values (‘software of the minds’) and (3) visible institutions (rules, laws, organisations).

Several research projects have focused on and succeeded in disentangling the cultural dimension of institutional proximity (see, e.g., Hofstede et al. 2010; European Values Study Foundation 2017; World Values Survey Association 2020; GLOBE Foundation 2004). As a result, it is possible to compare nations in quantitative terms. However, their explanatory value for the present paper is potentially limited as these operationalisations of culture are too coarse for analyses on the NUTS 3 level. Due to the difficulties associated with operationalising the degree of differences in formal regulations, this paper does not include this factor either.

Therefore, Language, as the only proxy for institutional proximity, is straightforwardly treated as a dummy variable indicating whether the majorities of the populations in NUTS 3 regions belonging to different sub-regions within one cross-border region speak the same official language. In this context, literature on the interrelation between language and culture suggests that culture is at least partly indicated by the dummy variable Language (Kramsch 1998; Riley 2007; Gui et al. 2018).

The ‘Encyclopedia of the Languages of Europe’, edited by Glanville Price (1998), served as the main source regarding officially spoken languages in European countries and sub-regions. Nations Online (n.d.) was used as an additional overview. In cases where the officially spoken language varies regionally (as in Belgium, Italy or Switzerland), research was conducted to determine which languages are officially spoken (by the majority of the population) in the NUTS 3 regions under investigation.

### 3.4 Spatial distance

As pure distance may not necessarily be correlated with the expenditure of time, spatial distance (SpatialDIST) is interpreted as indicating the latter (following Moodysson and Jonsson 2007; Coenen et al. 2004). In contrast to most comparable econometric studies, its operationalisation here is therefore based on Google Maps data. The data were gathered 4–26 January 2021 between 10 a.m. and 4 p.m. on weekdays. To assure comparability between the regional pairs, the time-based distance (minutes by car) was considered under the precondition of no restrictions on the route (indicated in green in Google Maps). Those positions within the NUTS 3 regions which had been automatically selected in Google Maps were chosen. In the event that the NUTS 3 regions could not be found or the automatically selected positions were implausible, the automatically selected locations of the most populous cities of these NUTS 3 regions in Google Maps were used.

### 3.5 Length of shared EU border

The variable EU is metrically scaled and indicates the length of a shared EU border until 2015. The span ranges from two years (Croatia’s borders with Hungary and Slovenia) to 57 years (the borders between the founding EU member states Belgium, France, Germany, Italy, Luxembourg and the Netherlands). Sub-regions within one cross-border region frequently belong to countries which joined the EU at different times. In these cases, the length of the EU membership of the country which joined the EU later was allocated to the corresponding observations (e.g., 20 years with regard to the Interreg V-A region ‘Italy-Austria’).

Despite the existence of bilateral agreements on legal and economic affairs, such as the Schengen Agreement’s implementation in 2001 in Norway, in 2008 in Switzerland and in 2011 in Liechtenstein, these countries have never been EU member states (Vahl and Grolimund 2006; Wichmann 2009; Maresceau 2011; Hillion 2011; Østhagen and Raspotnik 2017; Council Decisions [2008/903/EC], [2000/777/EC] and [2011/842/EU]). Therefore, observations which include Swiss or Norwegian

NUTS 3 regions or Liechtenstein are inapplicable. Furthermore, the explanatory variable EU is not applicable to observations which relate to linguistic borders in Belgium and Italy.

Table 1 presents key descriptive statistics (mean, standard deviation, minimum, maximum) concerning all metrical variables of interest.

### 3.6 Belonging to a ‘Central and Eastern European Country’ (CEEC)

CEEC is an ordinal variable with three categories: none/one/both of the two NUTS 3 regions under investigation belong(s) to a CEEC. As noted in Sect. 2.5, this variable comprises all countries which joined the EU in 2004 (with the exception of Cyprus and Malta). As intranational observations in Belgium, Italy and Switzerland (203 in total) are subject to linguistic but no country borders, these observations are inapplicable with regard to the independent variable CEEC.

## 4 Modelling approach and empirical results

Considering that the total number of co-patents is a count variable, Poisson or negative binomial regressions are principally eligible (Zeileis et al. 2008; Morescalchi et al. 2015; Hoekman et al. 2009). The choice of the regression model depends on whether the distribution of the co-patents corresponds more to the Poisson or to the negative binomial distribution. As expected, the application of the Kolmogorov–Smirnov test to the underlying data record demonstrates that the distribution of the dependent variable (number of co-patents) is significantly different from the Poisson distribution (0.1% level). The Poisson distribution assumes that the dependent’s variable arithmetic mean equals its variance. In this case, the variance of the dependent variable (6753.55) is much larger than its arithmetic mean (13.59). Furthermore, a computed regression-based test according to Cameron and Trivedi (1990) strongly indicates that the distribution is significantly overdispersed.

Co-patents (1991–2015) were generated in 37.62% of the analysed cross-border constellations (807 out of 2145 observations). Corresponding Vuong tests yield the values 3.309–7.653 (see Table 1) and indicate that the standard negative binomial model is significantly superior (0.1% level) over its zero-inflated counterparts (Vuong 1989; Long and Freese 2014). Therefore, standard negative binomial models are computed instead of zero-inflated negative binomial models (in accordance with Allison 2012; Hilbe 2014).

Following the principle of gravity models—namely that the magnitude of two objects positively influences (spatial) interactions, and that the (technological, institutional and spatial) distance between them has a negative influence (Sen and Smith 1995; Haynes and Fotheringham 1984; De Benedictis and Taglioni 2011)—the basic model explaining cross-border co-patents in European regions takes the following form (in accordance with Krisztin and Fischer 2015):

$$Y_{ij} = \beta_0 X_i^{\beta_1} X_j^{\beta_2} D_{ij}^{\beta_3} \quad i, j = 1, \dots, n$$

The dependent variable  $Y_{ij}$  corresponds to the observed co-patent applications of the regions  $i$  and  $j$ .  $Y_{ij}$  is proportional to the product of the two NUTS 3 regions' mass (number of generated patents), indicated by  $X_i$  and  $X_j$ , and various types of distances between  $i$  and  $j$  (according to Sects. 3.2–3.6), denoted by  $D_{ij}$ .  $\beta_0$ ,  $\beta_1$ ,  $\beta_2$  and  $\beta_3$  are unknown parameters. The specified negative binomial gravity model (negative binomial pseudo maximum likelihood estimator, following Krisztin and Fischer 2015; Woelwer et al. 2018) in its multiplicative form with a log-link is given by

$$\begin{aligned} \mu_{ij} &= E[Y_{ij} | (1 + \text{TechPROX}_{ij}), \text{Language}_{ij}, \text{SpatialDIST}_{ij}, \text{EU}_{ij}, \text{CEEC}, \\ &\quad \text{Patents}_i, \text{Patents}_j] \\ &= \exp[\ln\beta_0 + \beta_1 \ln(1 + \text{TechPROX}_{ij}) + \beta_2 (\text{Language}_{ij}) \\ &\quad + \beta_3 \ln(\text{SpatialDIST}_{ij}) + \beta_4 \ln(\text{EU}_{ij}) + \beta_5 (\text{CEEC}) \\ &\quad + \beta_6 \ln(\text{Patents}_i) + \beta_7 \ln(\text{Patents}_j)] \end{aligned}$$

$\mu_{ij}$  denotes the conditional expectation of cross-border co-patents  $Y_{ij}$  (expected mean interaction frequency) between NUTS 3 regions  $i$  and  $j$  given  $\text{TechPROX}_{ij}$ ,  $\text{Language}_{ij}$ ,  $\text{SpatialDIST}_{ij}$ ,  $\text{EU}_{ij}$ ,  $\text{CEEC}$ ,  $\text{Patents}_i$  and  $\text{Patents}_j$ .

Table 2 lists the results of the four computed negative binomial gravity models with regard to the theoretically and empirically derived determinants' effects on the number of co-patents generated in European cross-border regions between 1991 and 2015.

Due to the existence of linguistic borders in Belgium, Italy and Switzerland, it was additionally decided to control for in Model I whether NUTS 3 regions lie in the same country. The implementation of EU and CEEC in Models II to IV, however, excluded pairs of NUTS 3 regions which are subject to linguistic borders by definition (Sects. 3.5 and 3.6). If NUTS 3 regions in Europe lie in the same country, the higher *ceteris paribus* the likelihood of significantly (5% level) more co-patent activities (in accordance with Lata et al. 2018, 2015; Scherngell and Barber 2009).

Significantly more co-patents were generated by pairs of NUTS 3 regions whose technological structures are highly correlated with each other.  $\text{TechPROX}$  exerts highly significant (positive) effects (0.1% level) in any calculated model. Hence, Hypothesis 1 can be fully confirmed. However, the effect of  $\text{TechPROX}$  is likely to be supported by a certain circular reasoning effect, as both the computation of  $\text{TechPROX}$  and the obtainment of the number of co-patents are based on the same database.

In all models,  $\text{Language}$ , serving as indicator for institutional proximity, exerts a significant positive impact on generated co-patents in European cross-border regions. It is hence more likely that cross-border innovation processes will occur between pairs of NUTS 3 regions belonging to different sub-regions within one cross-border region that have an official language in common. Computed incidence rate ratios show that the number of co-patents increases by a factor of 1.83 to 2.49 in Models I–IV (significant at the 0.1% level) if NUTS 3 regions share a common official language. Thus, Hypothesis 2 can clearly be confirmed.

**Table 2** The application of negative binomial gravity models to generated cross-border co-patents in European regions between 1991 and 2015

Parameter	Model I	Model II	Model III	Model IV
Constant	-0.037 (0.579)	4.667*** (0.698)	-0.554 (0.677)	3.234*** (0.971)
ln (1 + TechPROX)	2.053*** (0.300)	1.421*** (0.351)	2.000*** (0.324)	1.477*** (0.352)
Language	0.604*** (0.096)	0.870*** (0.116)	0.804*** (0.101)	0.913*** (0.119)
ln SpatialDIST	-2.013*** (0.090)	-2.551*** (0.115)	-2.090*** (0.099)	-2.503*** (0.117)
ln EU	–	-0.507*** (0.080)	–	-0.281* (0.138)
CEEC	–	–	0.703*** (0.114)	0.405 (0.210)
ln Patents <sub>i</sub>	0.630*** (0.036)	0.539*** (0.043)	0.660*** (0.040)	0.565*** (0.045)
ln Patents <sub>j</sub>	0.696*** (0.036)	0.737*** (0.047)	0.761*** (0.040)	0.750*** (0.047)
Vuong test statistic	5.995***	3.548***	7.653***	3.309***
Log likelihood	-7101	-4521	-6369	-4517
AIC	7117	4537	6385	4535
Theta	0.419	0.414	0.423	0.414
<i>n</i>	2145	1674	1942	1674
Non-zero observations	807	541	723	541

Note: Robust standard errors in parentheses;

\* $p < 0.05$ , \*\*\* $p < 0.001$

SpatialDIST leads *ceteris paribus* to a significant decrease (0.1% level) to the number of cross-border co-patents in all models and therefore soundly corroborates Hypothesis 3. Cross-border co-patenting is highly space-sensitive. Related econometric analyses have repeatedly proven that spatial distance (measured in kilometres) has a negative influence (at the 1% level or below) on co-patenting between actors from different European NUTS 2 and 3 regions (see, e.g., Maggioni and Uberti 2007; Hoekman et al. 2009; Lata et al. 2015, 2018). The present study further confirms spatial distance's negative role by applying a different indicator (time- instead of kilometre-based distance) on a much smaller geographical scale, as the investigation into co-patent activities in this paper is restricted to cross-border regions.

Model III and IV yield surprising results in terms of belonging to a CEEC and the length of a shared EU border: The longer the existence of a shared EU border between two NUTS 3 regions, the lower *ceteris paribus* the number of generated cross-border co-patents. This result strongly suggests that cross-border co-patent activities are relatively more intense in constellations where NUTS 3 regions do not belong to one of the founding EU member states. The negative effect of EU may also be attributed to the relatively strong integration of Western European countries which joined the EU rather late (especially Austria and Sweden, which joined in 1995). As an example, the six observations regarding the Danish–Swedish borderland ('Øre-



sund' region) show an average cross-border co-patent intensity of 3.37% (number of cross-border co-patents divided by the patent count of the smaller NUTS 3 region), whereas the Dutch–German borderland's (120 observations) average intensity equals 0.35%. Moreover, the length of EU membership until 2015 does not necessarily equal European integration intensity, as the British and Danish opt-outs from the Economic and Monetary Union and border, asylum, migration and justice policies have shown (Adler-Nissen 2014; Kolliker 2006).

However, the negative effect of EU, which is significant at the 0.1% level, even holds true when substituting the metric variable for an ordinal (eight categories) or dummy variable (whether observations relate to intra EU-15 borders). Similarly, Morescalchi et al. (2015) have demonstrated that EU-15 membership (while controlling for country borders) only significantly positively influenced cross-border co-patent activities between NUTS 3 regions in 50 OECD (partner) countries (1988–2009) in two out of six cases. In one part of the three computed zero-inflated negative binomial models, the effect of intra EU-15 collaboration was *ceteris paribus* even negative (1% level). Furthermore, Chessa et al. (2013) have shown that the effect of EU-15 integration on co-patents (in comparison with non-EU OECD countries) was insignificant between 2003 and 2010 (the end of the observation period).

The significant negative effect of length of EU membership revealed in the present paper might be attributed to fewer eligible actors possessing complementary knowledge assets within countries that joined the EU after 1995. Within EU-15 member states, however, the need to exploit complementary knowledge sources beyond country and linguistic borders might be less distinctive, as actors might be more likely to identify and find suitable national counterparts to innovate with.

Similarly, CEEC exhibits a strikingly significant positive effect at the 0.1% level (Model III). Thus, both Hypotheses 4 and 5 have to be rejected. In fact, the opposite of the expected holds true: If one or both NUTS 3 regions belong to a CEEC, the number of generated co-patents is higher when compared to constellations where this is not the case (Model III). The Interreg V-A regions 'Austria-Hungary' and 'Slovakia-Austria' are for instance characterised by a cross-border co-patent intensity of 1.65% and 0.94%, respectively.

As opposed to these relatively high cross-border co-patent intensities, the Interreg V-A regions 'France-Italy (ALCOTRA)' and 'Belgium—The Netherlands' exemplify relatively low levels of interactive cross-border innovation processes in Western European regions, despite the fact that the latter forms one language area (Van Keymeulen 2015; De Vogelaer and van der Auwera 2010; Willemyns 2002; Treffers-Daller 1994). The share of cross-border co-patents on the smaller NUTS 3 regions' patent counts equals on average 0.21% and 0.87%, respectively. The Interreg V-A region 'Slovakia-Czech Republic', which is characterised by two CEECs, reaches an average cross-border co-patent intensity per pair of NUTS 3 regions of 2.44%.

However, the fact that Czechia and Slovakia share a long history and similar cultures further points to potential culture-related effects on cross-border collaboration (Dumetz and Gáboriková 2016; Ogrodnik 2017). When implementing CEEC and EU simultaneously (Model IV), CEEC exerts a weakly significant ( $p$ -value: 0.053) effect, implying that EU's negative impact is superior. By definition, both variables

are highly associated with each other. The (weakly) significant positive effects of CEEC might, as the negative influence of EU, be attributed to fewer eligible actors within CEECs with complementary knowledge assets. The necessity to collaborate across borders may therefore on average be more distinctive. To conclude, these result may—at least to a certain extent—dispel the myth that the (relative) level of interactive innovation processes in Eastern European cross-border regions is inferior to that of cross-border regions which have shared an EU border for several decades.

## 5 Conclusion

The negative effect of spatial distance, technological (cognitive) distance and linguistic borders on co-patenting and R&D collaboration in Europe while controlling for country borders has been detected in multiple econometric studies (Lata et al. 2018, 2015; Scherngell and Barber 2009). This paper further contributes to the literature by additionally analysing European integration effects (i.e., length of EU border, embeddedness of CEECs). To derive more accurate implications for the European Territorial Cooperation policy, the analysis in this paper was confined to European cross-border regions in the narrow sense. Thus, links in this paper were intentionally restricted to NUTS 3 regions belonging to different sub-regions within one cross-border region.

The empirical results strongly suggest that the magnitude of interactive cross-border innovation processes in European regions, as indicated by co-patents, significantly depends on whether NUTS 3 regions share the same official language. Corresponding incidence rate ratios show that if the majorities of the populations in two NUTS 3 regions belonging to different sub-regions within one cross-border region speak the same official language, the number of co-patents increases *ceteris paribus* by a factor of 1.83 to 2.49. In this context, one should acknowledge that a high patent count does not necessarily equal a high level of innovation. However, one could hardly argue that the importance of sharing the same language would significantly decrease in the context of interactive innovation processes other than co-patent activities.

One could interpret the significant positive coefficients of sharing a common official language in all four models as suggesting that the level of foreign language skills also determines the level of cross-border interactions. A simple and conceivable measure—both at national and European levels—would be the greater political promotion of knowledge of foreign languages (especially neighbouring languages) at schools, universities and other public institutions. Enhancing skills in terms of command of neighbouring languages may both promote institutional proximity (including familiarity with neighbouring countries' cultures) and sensitise (young) inhabitants in border regions to cross-border relations (as indicated by Olsen 2014, and to a lesser extent, by Fuss et al. 2004). Since the concrete effects of foreign language skills on interactive innovation processes across borders remain unclear, future research endeavours should address this research gap.

Given the assumed interrelations of culture and language mentioned above, further qualitative research to isolate the possibly very subtle effects of sharing a common

official language from cultural aspects (e.g., shared values, norms and routines) is inevitable. Furthermore, some sub-regions within one cross-border region may be culturally proximate despite not sharing an official language (as in the case of the Czech–Slovakian borderland). Multiple reasons for the importance of sharing a common official language are conceivable: Apart from the evident explanation that it facilitates communication between innovating actors, it is also imaginable that an above-average share of inventors lives beyond the border in constellations where sub-regions within one cross-border region share the same official language.

On the one hand, the proven and repeatedly confirmed negative role of spatial distance could imply that financial means should be pooled to a greater extent. Informal collaboration at a small geographical scale, as it has already been established by the AEBR regions, could be fostered EU-wide. Overall, the Interreg V-A regions seem to be too spacious, considering that, for example, the ‘Spain-Portugal (POCTEP)’ region spans 21 out of 23 NUTS 3 regions on the Portuguese mainland. On the other hand, larger regions potentially encompass more actors to be involved in interactive innovation processes across borders, implying a need to balance these trade-offs within the context of the European Territorial Cooperation policy. The specific values in terms of spatial distance may have been distorted by the retrospective data collection in 2021; it is uncertain to what extent those values differed between 1991 and 2015.

Finally, in future, it would be interesting to observe the extent to which the reduction of patent costs and the harmonisation of the legal systems as a result of the ‘European Unitary patent’ and ‘Unified Patent Court’ will lead to more cross-border co-patent activities. It seems not unlikely that more (potential) innovations that would not otherwise have been uncovered will be identified.

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