

Bürger, Matthias

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by

Matthias Buerger

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www.uni-jena.de

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Kahlaische Str. 10
D-07745 Jena
www.econ.mpg.de

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DYNAMICS OF COLLABORATIVE INVENTION

Tracking Growth of Cooperative and Total Patents in the Region

Matthias Buerger*

*Department of Economics and Business Administration, Friedrich-Schiller-University Jena
& Graduate College "The Economics of Innovative Change" (DFG-GK-1411)
Carl-Zeiss-Strasse 3, 07743 Jena, Germany; Tel.: +49 3641 943 280 – Fax: +49 3641 943 202
Email: matthias.buerger@uni-jena.de*

Abstract. The paper targets the relationship between growth of cooperation and later growth of innovation at the regional level. Patent data for German regions and eleven subsequent years is used to identify collaborative activity as well as the innovative output in each region. The results confirm to some extent previous expectations based on the assumption of an inverted U-relationship. Depending on the regional level of cooperation there are positive and negative effects of a change in regional cooperation behaviour in the industries *Radio, Television and Communication Equipment* and *Machinery and Equipment*. No significant results are obtained for the industries *Chemicals and Chemical Products* as well as *Medical, Precision and Optical Instruments*.

JEL codes: O18, R11,

Keywords: Regional Innovativeness, Cooperation, Regional Growth

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I Introduction

It is widely acknowledged in the field of innovation research that the innovating firm cannot be treated as an isolated entity. It was Allen (1983) who first described the concept of collective invention in the light of the development of furnaces. Later on, the literature on the systemic nature of innovation processes stressed the importance of both formal cooperation as well as the informal exchange of knowledge (Camagni, 1991; Lundvall, 1995; Malerba, 2002; Nelson 1992). Ever since this has been underlined empirically by a number of studies showing that cooperation potentially boosts firms' innovation performance (see, e.g., Boschma and ter Wal, 2007; Powell et al., 1996; Uzzi, 1996).

Though, most empirical studies are based on firm-level data it has been argued that the analysis of the collective behaviour of regional actors also requires a distinct regional perspective (Broekel and Meder, 2008). The observation that innovation processes can show a distinct regional focus has attracted the attention of both economists and economic geographers and influenced the emergence of such influential concepts as the regional innovation systems approach (Cooke, 1992; Cooke et al., 1997). In this respect it has been shown that differences in regional innovation performance are caused in parts by varying levels of regional cooperation intensity (Aydalot and Keeble, 1985; Camagni, 1991; Florida, 1995).

Despite a great many studies approaching this relationship in a qualitative way (e.g., Asheim and Isaksen, 2002; Isaksen, 2005; Saxenian, 1994), empirical evidence is rare. Moreover the few empirical results obtained so far are rather heterogeneous. Some authors do not find any relationship between regional levels of cooperation and innovation (e.g., Fritsch, 2004; Fritsch and Franke, 2004). Others, instead, find both positive and negative effects (Broekel and Meder, 2008; Broekel et al., 2010). Instead, scarcely anything is known about how these two variables co-evolve over time.

Regardless of the lacking empirical underpinnings government initiatives were set up in order to maximise the number of cooperative projects (e.g., Lo et al., 2006). However, no one knows how a change in regional cooperation behaviour actually affects the innovativeness of a region. Most likely this effect also varies between regions with different cooperation behaviour. To know about these processes is a prerequisite for a better understanding of regional economic development.

The present paper thus contributes by focussing on the dynamics between regional cooperation behaviour and regional innovativeness. For this purpose the distinction is

made between regions in which firms intensely cooperate and those in which firms cooperate less. The main aim of the paper is to answer the question as to how the co-evolution of regional cooperation behaviour and regional innovativeness differs between these regions. A dataset is introduced that tracks the industries of the manufacturing sector in 97 German regions over a period of eleven subsequent years. Patent data is used to quantify regional innovative activity as well as to construct a measure of regional cooperation behaviour.

The remainder of the paper is structured as follows. In the next section some theoretical considerations as to the impact of cooperation on innovation performance are presented and the most important findings from the empirical literature are summarised. Based thereon hypotheses are extracted regarding the dynamics between both variables. The third section introduces the dataset as well as the industries considered in the subsequent analysis. The empirical approach is explained in the fourth section. In the fifth section the regression results are presented and discussed. The sixth section concludes and offers some critical discussion.

II Cooperation and Innovation

Regional Levels of Cooperation and Innovation

From a firm's point of view cooperation broadly serves as a means to more than one end. Besides sharing costs and risks of the innovation process as described in the approach of the transaction cost theory (Williamson, 1985) the firms involved in cooperation projects also seek access to external know-how. Evidently the latter aspect of cooperation is very much related to the resource based view of the firm (Penrose, 1959). Within this approach each firm is regarded as consisting of a bundle of different resources which distinguish it from others and thus make the firm unique. With respect to innovation the most important amongst these resources are knowledge, routines but also human capital, patents and the like. While such resources potentially constitute a firm's competitive advantage they may also turn out to be constraints since a firm itself can only build on its own internal resources (Cantner and Meder, 2008a).

Accordingly it has been argued that creating something new requires access to both internal as well as external sources of knowledge (e.g., Beise and Stahl, 1999; Zellner and Fornahl, 2002). In contrast to internal knowledge which is part of a firm's own resources or which is at least within trivial reach, external knowledge refers to knowledge the

individual actor or firm does not possess (Broekel and Binder, 2007). To acquire external knowledge a firm basically faces three different options, viz. (i) to buy it on appropriate markets, (ii) to integrate those actors who possess the respective knowledge, or (iii) to cooperate with partners who contribute this knowledge (Cantner and Meder, 2008a). The present paper concentrates on the latter option where two or more actors contribute to a common R&D project in order to exchange knowledge, i.e. they participate in a process of interactive learning.

Though, scholars in general share the opinion that firms may improve their innovation performance via collaborative R&D projects (e.g., Faems et al., 2005) there is also the consensus in the literature that the benefits of cooperation are not unconditional (Broekel and Meder, 2008). Efforts need to be made in order to establish and maintain collaborative agreements. The outcome of such cooperation, however, is uncertain a priori (Bleeke and Ernst, 1993). While imperfect appropriability of knowledge can increase total benefits of cooperation it may also give incentives to free ride (Kesteloot and Veugelers, 1995). Not surprisingly, a great deal of collaborative projects fail (Kogut, 1988; Dacin et al., 1997).

The pros and cons of cooperation have also been discussed amongst economic geographers. It has been observed that some regions with a distinct cooperation culture show outstanding innovation performances (Saxenian, 1998; Asheim and Isaksen, 2002). The assumption that there is a causal relationship between both phenomena is at the heart of the literature on industrial districts (e.g., Becattini, 2004) innovative milieus and innovation networks (e.g., Aydalot and Keeble, 1985; Camagni, 1991; Grabher, 1993), learning regions (Florida, 1995) or regional innovation systems (Cooke, 1992).

However, an intense cooperative atmosphere within a region might also indicate a less competitive attitude amongst regional actors. As Porter (1990) specifically emphasises the importance of competition for firms' innovativeness one may conclude that a high level of cooperation in a region can be potentially detrimental to the region's innovative performance.

Moreover, there are concerns that strong intra- or inter-regional ties might result in a situation of regional over- or under-embeddedness, respectively (Broekel and Meder, 2008). Regional over-embeddedness is characterised by long-term relationships amongst regional actors that involve too much trust, and thus become thick and eventually redundant (Granovetter, 1985; Uzzi, 1996). Therefore regional over-embeddedness can

“stifle effective economic action if the social aspects of exchange supersede the economic imperatives” (Uzzi, 1997 p.59).

Regional under-embeddedness, instead, refers to a situation where a considerable number of actors are regionally isolated, although, they might perhaps be intensively linked to partners outside the region (Broekel and Meder, 2008). It is widely acknowledged that geographic proximity is conducive to inter-organisational learning processes (e.g., Boschma, 2005) as it keeps travel and transportation costs to a minimum, facilitates the exchange of non-codifiable knowledge and enhances the development of trust (e.g., Feldman and Florida, 1994; Bathelt et al., 2004). Thus under-embedded regional actors simply miss the benefits of a functioning regional innovation system.

Summarizing this subsection, from the theoretical literature one may presume an inverted U- relationship between regional levels of cooperation and innovation. On the one hand a certain degree of cooperation is needed in order to share the costs and risks of innovative projects as well as to gain access to external knowledge. Very high levels of cooperation on the other hand can be detrimental to innovation for several reasons. First, regional overinvestment in cooperation activities might result in severe free riding problems (Cassiman and Veugelers, 2002) or learning races (Faems et al., 2005). Second, an intense regional cooperation behaviour might indicate a lack of rivalry between regional actors, which, however, is a key motivation for firms to innovate at all (Porter, 1990). Third, high levels of cooperation bear the risk of regionally over- or under-embedded actors.

Empirical Studies

Throughout the rich empirical literature on the effects of cooperation and networking at the firm level a frequent finding is that cooperation increases firms' innovation performance (Powell et al., 1996; Uzzi, 1996; Faems et al., 2005; Tsai, 2009). Uzzi (1996) also finds evidence for what has been introduced as over-embeddedness, i.e. many strong and few weak ties (Broekel and Meder, 2008). However, some authors find that the positive effect of cooperation on innovation might not be overwhelming. Negassi (2004, p.382), for example, mentions that, “compared to size, human capital, market share and R&D intensity, R&D collaboration seems to play only a minor role for achieving a large innovation output.” In a similar way Frenz and Ietto-Gillies (2009, p.1132) point out that “cooperation is less likely to be effective in increasing innovation

performance” compared to “in-house R&D expenditure, bought-in R&D, and intra-company knowledge transfers”.

In economic geography – though, rather focussed on the spatial (or geographic) dimension of knowledge networks (e.g. Boschma and ter Wal, 2007) – most work on cooperation is conducted at the firm level as well. Amongst these studies some find intra-regional cooperation to be especially important for small and medium sized firms (e.g., Arndt and Sternberg, 2000; Sternberg, 1999).

Broekel and Meder (2008), however, argue that investigating a regional phenomenon such as regional innovation systems required a distinct regional approach taking into account the collective behaviour of actors. In doing so some scholars provided evidence – though, mostly of qualitative nature – for a positive relationship between cooperation and innovation (e.g., Grabher, 1993; Saxenian, 1998; Asheim and Isaksen, 2002). Others instead furnished proof of regional lock-in situations (Hassink, 2007; Cho and Hassink, 2009).

So far, however, very little quantitative empirical evidence has been provided on the relationships between regional cooperation behaviour and regional innovation performance. Some of the authors, as for example Fritsch (2004) or Fritsch and Franke (2004), do not find any evidence on a positive relationship whatsoever. Broekel and Meder (2008) on the contrary report an inverted U-relationship between levels of intra- as well as inter-regional cooperativeness on the one hand and regional innovation efficiency on the other hand. While these studies are mostly restricted to a few regions or a single industry Broekel et al. (2010) use data on a wide range of industries covering all German labour market regions to quantify the impact of cooperation on regional innovation performance. Their findings indicate a negative impact of high levels of overall regional cooperativeness but also a trade-off between for intra- and inter-regional cooperation.

Cooperation Dynamics

As was pointed out above the theoretical literature suggests that the relationship between regional cooperation behaviour and regional innovativeness probably follows an inverted U-shape. The few quantitative studies that approach this topic empirically confirm this view to some extent. However, most of these studies take a rather static perspective, i.e. they investigate levels of regional cooperative behaviour and regional innovativeness but do not consider how both variables co-evolve over time. But significant correlations between the levels of two variables yet do not imply that a change in one automatically

results in a change in the other variable. For a better understanding of regional economic development it is thus important to know how a change in regional cooperative behaviour relates to subsequent growth of regional innovativeness.

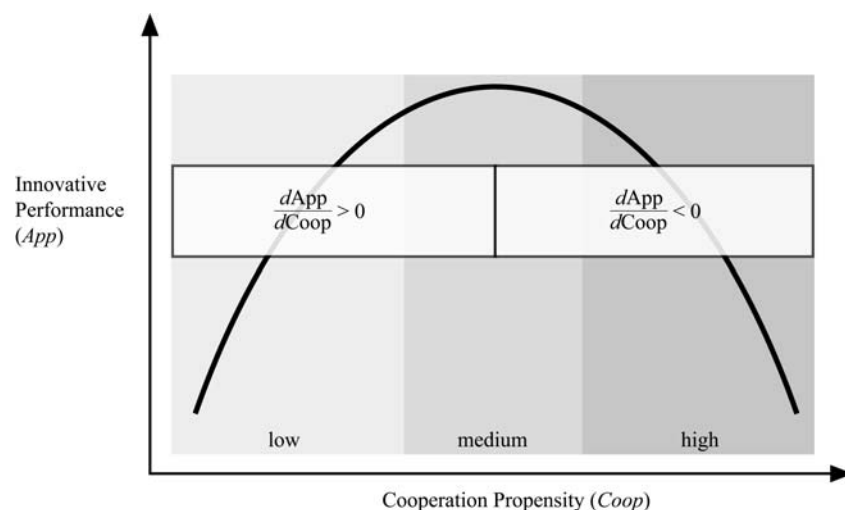


Figure 1: Inverted U-relationship between regional levels of cooperation and innovation.

Taking the basic assumption of an inverted U-relationship between regional levels of cooperation and innovation as a starting point one may draw some conclusions regarding the dynamics between both variables. Obviously the effect of a change in regional cooperative behaviour must vary between regions with low and high levels of cooperative activity (cf. figure 1). As the literature clearly exhibits a lack of empirical evidence the present paper aims at making a first step in filling this gap by empirically testing the following two hypotheses.

Hypothesis 1: Growth of cooperation is associated with subsequent growth of innovation in regions with low levels of cooperative activity.

Hypothesis 2: In regions with high levels of cooperative activity a negative relationship exists between growth of cooperation and later growth of innovation.

For regions with a level of cooperation close to the optimum, instead, this relationship is not as clear. Depending on which side of the peak the individual region is located the impact will be either positive or negative. Hence it is quite likely that there will be no clear empirically detectable effect from a change of cooperation behaviour for this group of regions.

In order to test the hypotheses a regional framework is applied which has been argued to be the “proper choice” when “investigating regional phenomena” (Broekel and Meder, 2008 p. 5). The data on which the empirical analysis builds as well as the exact approach are presented in the following section.

III Data on Industries and Regions

The paper draws on a new panel dataset that contains information on German inventions for the eleven subsequent years from 1995 to 2005. As in most other studies on regional innovativeness patent data is used as an indicator for the innovative output of the firms in a particular region. It is obtained from the German Patent and Trademark Office (DPMA). The dataset covers all German patent applications for which the location of the inventors is stated. Since patents refer to new ideas – which not necessarily enter the market – it shall be acknowledged that the paper focuses on collaborative invention rather than innovation.

As Brenner (2007, p.123) points out “It seems obvious that industries differ in the relevance of knowledge sources and in the importance of different ways of knowledge transfer.” Accordingly one might assume that the importance of cooperation differs between the industries as well. This is even more so as patent data is used as innovation indicator. Evidently industries pretty much differ in their reliance on patents as a means to protect intellectual property (Arundel and Kabla, 1998, Cohen et al., 2000). Moreover one cannot rule out the possibility that the time lag between a change in regional cooperation behaviour and the resulting impact on regional innovativeness differs between industries as well. In order to cope with such differences the relationship between regional cooperation behaviour and regional innovativeness will be investigated separately for different industries.

Conducting industry specific analysis based on patents requires information on the technological dimension in the data. Such information is necessary to assign the patent applications to the respective industries. The technological dimension of patents is reflected in the international patent classification (IPC) codes, which allow for a technological categorisation of each invention. A concordance developed by Schmoch et al. (2003) is used to relate the IPC classes to NACE¹ industry codes at a 3-digit level. As patent applications frequently feature more than one IPC class a significant number of

¹ Nomenclature statistique des activités économiques dans la Communauté européenne (NACE).

patent applications is simultaneously attributed to different industries. In such a case the same weights are attributed to each IPC class.

Within a regional framework particular relevance is granted to the geographic dimension in the data. For the purpose of this paper each patent needs to be assigned to the region it originates from. This first of all requires a clarification as to how a region is defined. In regional science one typically distinguishes functional areas and administrative units. The latter represent historically grown spatial units (e.g., NUTS-regions) which are rather stable over time regarding their spatial extensions. Functional areas, instead, reflect economic activity in space. As a consequence they represent much more dynamic regions, i.e. their spatial boundaries change more rapidly than those of administrative units. Altogether functional areas are argued to better match the requirements of economic analysis compared to administrative units (Eckey et al., 2007).

For Germany one can basically build on two types of functional areas, i.e. planning regions and labour market regions. Formed out of NUTS-3-regions (districts) both are designed to match commuting distances. While the larger planning regions usually encompass an economic centre plus its hinterland, labour market regions are restricted to shorter commuting times. In this regard Germany is composed of 270 labour market regions but only comprises 97 planning regions. Both types of regions are frequently used in empirical studies on the regional innovative activity in Germany. Amongst others Brenner (2005), Brenner and Greif (2006), Broekel and Brenner (2010), Cantner and Meder (2008a, b), and Fritsch and Slavtchev (2010) make use of planning regions. Instead, Broekel and Brenner (2007), Broekel and Meder (2008), and Buerger et al. (2009) draw on labour market regions. Whether the one or the other type of region is better suited for economic analysis is subject to ongoing debate.

While a general comparison of the results from both types of regions would of course be desirable the present study only focuses on planning regions due data constraints. In applying the inventor principle each patent is assigned to the planning region where its inventor is located. Whenever an invention was developed by a group of inventors who are located in different regions the patent is assigned to each region according to the number of inventors from that region. The main advantage of applying the inventor principle is that patents are not automatically assigned to the region of a company's headquarter which would result in overrating of large cities such as Munich (BMW and Siemens) or Stuttgart (Daimler and Porsche).

Another crucial aspect in this study is to identify collaborative activities. A collaborative invention will be referred to as any invention that is the outcome of joint research efforts of more than one actor. Following Cantner and Meder (2007) any co-application, i.e. a patent for which at least two actors jointly apply, is considered the outcome of a collaborative R&D project.

Based on these definitions the following two main variables are extracted. The variable $APP_{i,r,t}$ captures the total of industry i 's patent applications, i.e. its innovative output in region r at time t . Additionally $Coop_{i,r,t}$ depicts a region's industry-specific level of cooperative activity at a given point in time. It is defined as the ratio between collaborative and total patent applications and will be referred to as a region's cooperation propensity in the following.

Three region specific control variables are obtained from the German Federal Statistical Office (Statistisches Bundesamt). First, a region's gross domestic product ($GDP_{r,t}$) captures the economic strength of region r at time t . Second, population density ($Pop_dens_{r,t}$) is used to account for the size of a region. It is defined as the number of inhabitants per square kilometre. Third, the number of students at universities and universities of applied sciences ($Students_{r,t}$) is included as a general proxy for the availability of scientific knowledge in the region.

	CHEM	MACH	COMM	INST
Mean	0.0847	0.0620	0.0601	0.0870
Std. Dev.	0.0770	0.0596	0.0669	0.0723
10%	0.0095	0.0093	0.0000	0.0156
25%	0.0281	0.0256	0.0163	0.0360
Median	0.0650	0.0449	0.0395	0.0693
75%	0.1159	0.0774	0.0848	0.1176
90%	0.1913	0.1364	0.1429	0.1786
Min	0.0000	0.0000	0.0000	0.0000
Max	0.5422	0.5806	0.5735	0.4796
Obs	819	1033	769	935

Table 1: Summary statistics for the industries' cooperation propensities.

Following Broekel et al. (2010) for each industry only those regions will be considered to which more than five patents of that very industry are assigned. This is done in order to keep the number of regions with biased cooperation propensities to a minimum and hence to reduce the outliers in the sample. Motivated by the need for a sufficient amount of patents in as many regions as possible the data for the 3-digit industries is aggregated to the 2-digit level. Out of the industries for which patents can be regarded a decent

indicator of their innovative activity (cf., e.g., Arundel and Kabla, 1998, Cohen et al., 2000) only a few exhibit an appropriate number of patents per region and year. For a sound empirical analysis only four industries come into consideration. These industries are *Chemicals and Chemical Products* (CHEM, NACE 24), *Machinery and Equipment* (MACH, NACE 29), *Radio, Television and Communication Equipment* (COMM, NACE 32), and *Medical, Precision and Optical Instruments* (INST, NACE 33).

Table 1 provides the summary statistics for the four industries' regional cooperation propensities ($Coop_{i,r,t}$). While the mean values of these variables lie in between six and almost nine per cent the maximum values are notably larger (fifty per cent and more). However, ninety per cent of all regions show quite reasonable cooperation propensities, i.e. less than twenty per cent. There is a rather simple explanation for the high outlier values. Almost without exception those values pertain to rural regions with only a very small number of patents, i.e. the absolute number of cooperative patents is very low as well. The regions with the highest cooperation propensities of the four industries are Western Pomerania (CHEM), North Thuringia (MACH), Allgäu (COMM), and Oberlausitz-Niederschlesien (INST). For each of these regions less than ten patents are reported for the respective industry and the relevant period.

IV Methodological Approach

The main aim of this paper is to test how a change in regional cooperation propensity relates to a later change in regional innovative output. In keeping with previous studies the measure of growth rates used in this paper is calculated by taking the differences of the logarithms of patent applications and cooperation propensities respectively:

$$\Delta X_{i,r,t} = \log(X_{i,r,t}) - \log(X_{i,r,t-1}) \quad (1)$$

where X is measured in terms of industry i 's patent applications or cooperation propensity for region r and year t . Based thereon the regression equation can be written as follows:

$$\Delta App_{i,r,t} = \alpha_0 + \alpha_1 \Delta App_{i,r,t-1} + \alpha_2 \Delta App_{i,r,t-2} + \alpha_3 \Delta Coop_{i,r,t-1} + \alpha_4 \Delta Coop_{i,r,t-2} + \alpha_5 CTRL_{r,t} + y_t + \varepsilon_{i,r,t} \quad (2)$$

Since the dependent variable captures growth of patents, expressed in differences, rather than the number of patents, expressed in levels time-invariant region-specific fixed effects in the dependent variable are effectively removed. Previous studies revealed a significant negative autocorrelation for regional growth of patents (e.g., Buerger et al., 2009). In order to account for this phenomenon the lagged values of the dependent

variable enter the regression equation on the right hand side. The main explanatory variable is growth of cooperation propensity for which as well the lagged values are included. $CTRL_{r,t}$ refers to the above mentioned variables $GDP_{r,t}$, $Pop_dens_{r,t}$, and $Students_{r,t}$ which enter as region specific controls without a time lag. Moreover a set of year dummies (y_t) is included in order to capture common macro-economic events.

	$\Delta Coop$ CHEM	$\Delta Coop$ MACH	$\Delta Coop$ COMM	$\Delta Coop$ INST	GDP	Pop_dens	$Students$
$\Delta Coop$ CHEM	1.0000						
p-value							
$\Delta Coop$ MACH	0.1343	1.0000					
p-value	0.0004						
$\Delta Coop$ COMM	0.1628	0.1211	1.0000				
p-value	0.0002	0.0041					
$\Delta Coop$ INST	0.2390	0.1202	0.1824	1.0000			
p-value	0.0000	0.0010	0.0000				
GDP	-0.0312	-0.0481	0.0453	-0.0180	1.0000		
p-value	0.4011	0.1609	0.2778	0.6118			
Pop_dens	-0.0100	-0.0027	0.0302	0.0053	0.3745	1.0000	
p-value	0.7874	0.9383	0.4685	0.8806	0.0000		
$Students$	-0.0119	-0.0123	0.0103	0.0037	0.3652	0.3850	1.0000
p-value	0.7486	0.7198	0.8052	0.9161	0.0000	0.0000	

Table 2: Correlation Matrix

The number of lags that can be included in the model is restricted by the size of the dataset to a maximum of two since any additional lag comes at the cost of a decrease in the number of observations. Hence, the empirical framework allows for detecting the impact of a change of regional cooperative behaviour up to two years later but not beyond this period. The true lead-lag relationship, however, is unknown a priori and might as well vary between industries. Moreover in some industries short-term changes in regional cooperative activity might not result immediately in short-term changes of innovative output. Instead long-term changes of regional cooperative behaviour may show a clearer impact. For these and other reasons the results may differ significantly between the industries.

Table 2 shows the correlations between the growth rates of the industries' regional cooperation propensities and the region specific controls. One can see that the control variables are not correlated with the respective explanatory variables (the growth rates of the industries' regional cooperation propensities). The coefficients are small and insignificant. But significant correlations show up *amongst* the control variables with

coefficients between 0.3 and 0.4. However, these correlations turn out to be irrelevant for the subsequent analysis. The results are robust to different model specifications, e.g. excluding the control variables or taking them separately into the regressions.

More interesting in this respect are the correlations between the growth rates of cooperation propensities of the four industries. As the variables do not enter the same model these correlation neither affect the results. Nonetheless they show that short-term changes in regional cooperation propensities (i.e., yearly growth rates) do not simply depict random fluctuations but that they are rather part of a regional phenomenon. Put differently, up to a certain degree there seems to exist some kind of common cooperation behaviour of the firms in the same region.

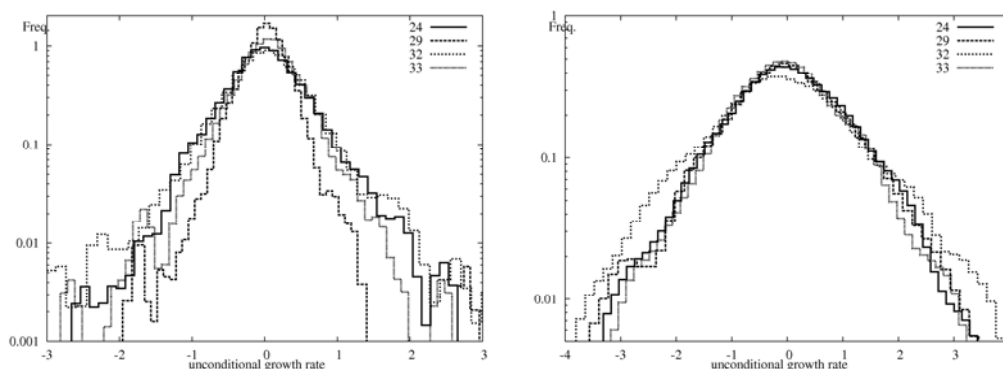


Figure 2: Annual growth rate distributions of patent applications (left) and cooperation propensities (right). Kernel densities are computed using an Epanechnikov kernel. The numbers 24, 29, 32, and 33 refer to the 2-digit NACE codes for the industries CHEM, MACH, COMM, and INST, respectively.

As Figure 2 shows the dependent variable – growth of patent applications – displays a heavy-tailed ‘tent-shape’², i.e. while most of the regions have little variation in yearly growth rates of patenting activity some regions experience accelerated growth of patents. In keeping with the literature LAD (least absolute deviation) is preferred over OLS because of the heavy-tailed nature of the dependent variable (cf., e.g., Bottazzi et al., 2008). Least-squares based estimators perform best in the case of Gaussian residuals. LAD on the contrary is argued to be more robust than OLS to outliers and extreme observations on the dependent variable (Coad and Rao, 2010).³ LAD, also known as median regression, estimates the median of the dependent variable, conditional on the values of the independent variable. The LAD estimator has been successfully applied in

² Similar growth rate distributions are reported for the growth of firms (Coad, 2009 Chapter 3).

³ OLS results are rather similar compared to the LAD estimation and can be obtained from the author upon request.

similar studies at the firm level (Coad and Rao, 2010) as well as at the level of the region (Buerger et al., 2009).

As pointed out above the literature suggests an inverted U-relationship between regional levels of cooperation and innovation. A number of methodologies have been applied in the empirical literature in order to deal with nonlinear effects. Quantile regressions, for example, are frequently used to test for an explanatory variable's effect that varies with the size of the dependent variable (e.g., Coad, 2010). Moreover, the explanatory variable's squared term is often added to the regression equation in order to find out whether larger values show a different effect than smaller ones (e.g., Cantner and Meder, 2008a).

Obviously neither of both solutions is applicable in the present case. Since there is no reason to assume that the effect of cooperation depends on the regional growth rate of innovation the application of quantile regressions turns out to be rather meaningless. Moreover the inverted U-relationship is postulated for levels of cooperation and innovation but not for their growth rates. Hence there is little justification for including the squared term of the growth rate of cooperation. Including both the level and the growth rate of cooperation alongside their interaction term at first glance seems to be more promising in this respect. Given an inverted U-relationship one could expect a positive impact of levels and growth rates but a negative effect of their interaction term. However, a major drawback of this procedure is that in doing so one assumes the same lag-structure for positive and negative effects of cooperation. As the results reveal this is not necessarily the case, though.⁴

In order to test the hypotheses specified above the whole sample of regions is, thus, split into subsamples with different cooperation propensities. Equation 2 is then estimated for each subsample separately. Though, the whole sample covers a total of 97 regions over a period of eleven years disaggregating into industries, computing growth rates and including time lags reduce it to only a few hundred observations per industry. Hence, there is a trade off between the number of possible subsamples and the feasibility of the econometric approach.

Therefore, in a first step the sample of regions for each industry is just split in half. The resulting subsamples *A* and *B* might be regarded as regions with low and high cooperation propensities, respectively. To allow for two subsamples of about the same size the median value of the regions' cooperation propensities is used as a dividing rule. More

⁴ Nonetheless this has been tested leading, however, to rather inconclusive results.

probably than not, the median value does not coincide with the peak of the inverted U-relationship. Consequently only one subsample is exclusively composed of regions with cooperation propensities either below or above the peak. The other one, instead, encompasses regions from both sides of the peak. Accordingly, a clear-cut correlation between the growth rates of cooperation and innovation can be expected only in the former subsample while in the latter one the coefficients are likely to be insignificant (see Figure 3).

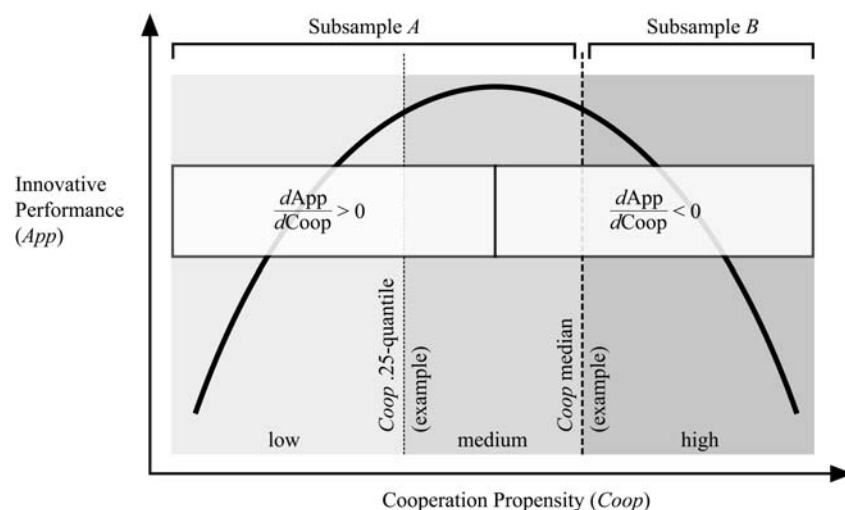


Figure 3: An example for the regional distribution of cooperation propensities and the resulting subsamples.

If the median value of regional cooperation propensities is below (above) the true peak of the inverted U-relationship the coefficients for growth of cooperation will be positive (negative) only in the subsample of regions with low (high) cooperation propensities. The example in figure 2 illustrates the case in which the median value is located above the peak of the inverted U, i.e. subsample A consists of regions with low *and* medium cooperation propensities. In any case the subsample in which the coefficients remain insignificant must encompass the peak of the inverted U-relationship. In order to verify this the respective subsample is divided once more if the sample size is large enough. This time the .25-quantile or the .75-quantile serves as a dividing rule. In doing so one obtains three different subsamples of regions with low, medium, and high cooperation propensities, respectively (Figure 3).

As expressed in hypothesis 1 growth of cooperation is presumably followed by an increase of innovation in the subsample made up by regions with low cooperation propensities. In contrast an increase in cooperation is probably associated with a subsequent decrease in innovation in the subsample of regions with high cooperation

propensities (hypothesis 2). Insignificant coefficients, instead, are to be expected for regions with medium cooperation propensities.

As in most regional studies the question arises as to the presence of spatial autocorrelation which potentially violates the assumption about the independence of observations. For this reason Moran's I is estimated for the residuals from the LAD estimation of equation 2. From Table 3 in the appendix one can see that all coefficients are rather small and apart from a few sporadic instances remain insignificant. One can therefore conclude that the results are not seriously affected by spatial autocorrelation.

V Regression Results

In line with previous studies the results reveal a strong and persistent negative autocorrelation for the regional growth rates of patent applications. While the coefficients for the first lags are highly significant and rather similar for all industries they become smaller for the second lag and in some cases lose significance. This result is consistent with previous work on the topic (e.g., Buerger et al., 2009) and underlines the erratic nature of yearly growth rates of patents at the regional level. Bearing this in mind it does not come as a surprise that the levels of the region specific control variables mostly remain insignificant. Variables as regional GDP or population density that change rather in the long run can hardly explain short term growth rates of patenting activity. Table 3 shows the results for the four industries and the two subsamples of regions with low and high cooperation propensities, respectively.

Interestingly, there seems to be no association of growth of cooperation with later growth of innovation for the two industries with the highest average cooperation propensities (cf. Table 1), i.e. *Chemicals and Chemical Products* (CHEM) as well as *Medical, Precision and Optical Instruments* (INST). The same result is obtained when the entire sample of regions is considered (cf. Table A1 in the appendix). A further division of the subsamples along the .25 and .75-quantiles neither changed anything in this regard.⁵

A rather naïve interpretation might be that the industries are simply unsusceptible to a change in cooperation. Given the high average cooperation propensities, though, two other explanations seem to be more plausible in this respect. First, this result might well reflect the fact that a change in cooperation becomes effective only after a time-lag longer than the two years considered here. Especially in industries that face relatively long

⁵ Those results are not reported but can be obtained from the author.

Industry <i>i</i> NACE code Coop level	CHEM 24		MACH 29		COMM 32		INST 33	
	low	High	low	high	low	high	low	high
	$\Delta App_{i,r,t-1}$	-0.3405*** (-3.70)	-0.5355*** (-6.44)	-0.5360*** (-6.13)	-0.4719 *** (-10.53)	-0.3676*** (-5.88)	-0.5781*** (-5.10)	-0.5117*** (-5.78)
$\Delta App_{i,r,t-2}$	-0.0213 (-0.23)	-0.2723*** (-3.26)	-0.2042* (-2.09)	-0.1911*** (-4.49)	-0.1578** (-2.59)	-0.2726** (-2.33)	-0.2552*** (-3.01)	-0.1675** (-2.33)
$\Delta Coop_{i,r,t-1}$	0.0169 (0.51)	-0.0111 (-0.34)	-0.0304 (-1.36)	-0.0309*** (-2.61)	0.0466** (2.45)	0.0166 (0.45)	0.0005 (0.02)	0.0085 (-0.27)
$\Delta Coop_{i,r,t-2}$	0.0443 (1.37)	-0.0291 (-0.88)	-0.0044 (0.20)	-0.0234* (-1.93)	0.0172 (0.86)	-0.0202 (-0.54)	-0.0196 (-0.73)	0.0256 (0.83)
$GDP_{r,t}$	0.0001 (0.02)	-0.0026 (-0.54)	-0.0000 (-0.01)	0.0026 (1.36)	0.0025 (0.72)	-0.0058 (-0.85)	-0.0024 (-0.59)	-0.0021 (-0.56)
$Pop_dens_{r,t}$	0.0000 (0.12)	-0.0000 (-0.40)	-0.0000 (-0.30)	-0.0000 (-0.33)	-0.0001* (-1.78)	-0.0000 (-0.75)	-0.0000 (-0.64)	-0.0000 (-1.03)
$Students_{r,t}$	-0.0004 (-0.20)	-0.0028 (-1.31)	-0.0002 (-0.13)	-0.0014* (-1.92)	0.0003 (0.22)	0.0017 (0.59)	0.0009 (0.57)	0.0013 (0.78)
<i>Year dummies</i>	yes	yes	yes	yes	yes	yes	yes	Yes
Obs	236	262	321	332	224	168	295	280
Pseudo R ²	0.2990	0.2805	0.3206	0.2798	0.2717	0.2556	0.3267	0.2398

Table 3: LAD estimation of equation 2 for the four industries CHEM, MACH, COMM and INST regarding regions with high and low cooperation propensities; *t*-statistics are given in parentheses; *, **, *** indicates significance at the 10%, 5%, and 1% level, respectively

development times a potential effect of a change in cooperation should become effective only after a longer period of time. Second and also mentioned earlier in this paper it is possible that changes in the long-term cooperation behaviour are more relevant in these industries so that yearly growth rates of cooperation cannot explain much of the variance in growth of patent applications. Either way the results do not allow making any conclusions regarding hypotheses 1 and 2 for the industries CHEM and INST.

The more meaningful results pertain to the industries *Machinery and Equipment* (MACH) as well as *Radio, Television and Communication Equipment* (COMM). In both industries the results meet the expectations based on the presumed existence of an inverted U-relationship. In the industry COMM growth of cooperation is associated with subsequent growth of innovation in regions with comparatively low cooperation behaviour, i.e. cooperation propensities below the median value. The coefficient for the first lag of growth of cooperation is positive and significant indicating that growth of cooperation is followed by growth of innovation one year later. Hence, hypothesis 1 appears to be valid for this industry.

Regarding regions with high cooperation propensities, instead, the coefficients for the first and second lag of growth of cooperation remain insignificant which may indicate that the peak of the inverted U-relationship is located above the median cooperation value. In this case the majority of regions would show cooperation propensities below the optimum. However, the same reservations apply as in the case of the industries CHEM and INST. Whether or not there actually exists an inverted U-relationship between cooperation and innovation and, thus, also a negative effect of cooperation must remain speculative since there are clearly not enough observations for a further splitting of the subsamples.

For the machinery industry, instead, the results confirm hypothesis 2, i.e. there is a negative association between growth of cooperation and later growth of innovation for regions with high levels of cooperative activity. The coefficient for the first lag is negative and highly significant while the coefficient for the second lag is negative as well but significant only at the 10% level. Hence growth of cooperation is associated with a decrease in total patents mainly one year later.

On the contrary the coefficients for both lags of growth of cooperation remain insignificant in the subsample of regions with low cooperation propensities. Again this is in line with what one must expect based on the assumption of an inverted U-relationship. In contrast to the case of the COMM industry the supposed peak must be located below

the median value of regional cooperation propensities. Put differently, in most of the regions the firms' cooperation behaviour seems to exceed the optimum level.

The number of observations for MACH is relatively large compared to COMM allowing for a further splitting of that subsample in which the coefficients are insignificant, i.e. the group of regions with the lower cooperation propensities. The .25-quantile is used to divide this subsample into regions with low and medium cooperation propensities. Table 4 shows the results for the machinery industry and all three subsamples. The high cooperation subsample on the very right is identical with the one in Table 3 and so are the results. But Table 4 additionally illustrates that the coefficient for the first lag in this subsample is negative and significant whether or not the second lag is included.

The results for the regions with medium cooperation propensities are to be found in the middle of Table 4. As expected the coefficients for growth of cooperation are insignificant. Only when both lags are included without the region specific control variables the coefficient for the first lag of growth of cooperation gains little significance at the 10% level. This result however does not turn out to be robust. Put differently there seems to be no association between a change in cooperation and later growth of innovation for this subsample of regions.

On the very left of Table 4 the results can be found for those regions with the lowest cooperation propensities. An inverted U-relationship implies a positive coefficient in this subsample. Indeed this is what the results reveal. This time the coefficient for the first lag of growth of cooperation is insignificant whether or not the second lag or the control variables are included. The coefficient for the second lag, instead, is positive and highly significant. Accordingly growth of cooperation in the *Machinery and Equipment* industry (MACH) is associated with growth of innovation two years later if and only if the cooperation propensity in the region is low. Accordingly the results confirm the validity of hypotheses 1 and 2 for the industry MACH.

Summarising this section one must admit that the results cannot actually proof the existence of a general inverted U-relationship between cooperation and regional innovation activity. Nonetheless the results are affirmative. Hypothesis 1 can be confirmed for the *Machinery and Equipment* industry (MACH) as well as for the *Radio, Television and Communication Equipment* industry (COMM).

Industry <i>i</i> NACE code Coop level	MACH 29								
	low			medium			high		
$\Delta App_{i,r,t-1}$	-0.4478*** (-4.02)	-0.4833*** (-6.33)	-0.5269*** (-6.19)	-0.4820*** (-6.31)	-0.5945*** (-6.65)	-0.5639*** (-6.17)	-0.3204*** (-8.36)	-0.4463*** (-8.41)	-0.4719*** (-10.53)
$\Delta App_{i,r,t-2}$	-	-0.3456*** (-4.01)	-0.3880*** (-4.05)	-	-0.1094 (-1.14)	-0.0679 (-0.69)	-	-0.1766*** (-3.42)	-0.1911*** (-4.49)
$\Delta Coop_{i,r,t-1}$	-0.0151 (-0.52)	-0.0092 (-0.50)	-0.0099 (-0.47)	-0.0158 (-0.88)	-0.0394* (-1.70)	-0.0388 (-1.63)	-0.0323*** (-3.22)	-0.0362** (-2.58)	-0.0309*** (-2.61)
$\Delta Coop_{i,r,t-2}$	-	0.0435** (2.38)	0.0465** (2.29)	-	-0.0272 (-0.89)	-0.0225 (-0.99)	-	-0.0252* (-1.68)	-0.0234* (-1.93)
$GDP_{r,t}$	-	-	0.0031 (0.58)	-	-	-0.0014 (-0.45)	-	-	0.0026 (1.36)
$Pop_dens_{r,t}$	-	-	-0.0000 (-0.48)	-	-	0.0000 (-0.33)	-	-	0.0000 (-0.33)
$Students_{r,t}$	-	-	0.0005 (0.38)	-	-	-0.0012 (-0.93)	-	-	-0.0014* (-1.92)
<i>Year dummies</i>	yes	yes	yes	yes	yes	yes	yes	yes	yes
Obs	188	152	152	193	169	169	386	332	332
Pseudo R ²	0.243	0.336	0.338	0.322	0.352	0.360	0.228	0.273	0.280

Table 4: LAD estimation of equation 2 for the industry MACH regarding regions with low, medium and high cooperation propensities; *t*-statistics are given in parentheses; *, **, *** indicates significance at the 10%, 5%, and 1% level, respectively

Hypothesis 2, instead, seems to hold at least for the industry MACH. Hence one can conclude that regarding MACH as well as COMM regions with low cooperation propensities benefit from a growth of cooperation in terms of innovative output. Regions with high cooperation propensities, instead, suffer from a further increase in cooperation regarding the innovative output of the machinery industry.

VI Conclusion

The paper examined the relationship between growth of cooperation and subsequent growth of innovation for four industries and 97 German regions. Patent data was used in a two-fold way. First, it served as an indicator of innovative activity. Second, it was used to construct a measure of the regional cooperation propensity. For each industry regional growth of patent applications was regressed on the first and the second lag of regional growth of cooperation propensity. Because of the heavy-tailed tent-shape distribution of the dependent variable LAD estimation was preferred over OLS.

The results reveal a positive relationship between growth of cooperation and later growth of innovation for regions with low cooperation propensities in the *Machinery and Equipment* industry as well as in the *Radio, Television and Communication Equipment* industry. For the *Machinery and Equipment* industry growth of cooperation is moreover associated with a decrease in total innovation in regions that already exhibit high cooperation propensities. Thus the results support the idea of an inverted U-relationship between cooperation and innovation at the regional level.

None of these results are found for the *Chemicals and Chemical Products* industry or the *Medical, Precision and Optical Instruments* industry. This finding might be interpreted in different ways. On the one hand it may indicate that the industries' innovative output does not depend on cooperative activities. This explanation, however, is rather doubtful as both industries show a relatively high average cooperation propensity. A more reasonable explanation therefore is that the effect of a change in cooperative activity in both industries becomes effective beyond the two-year period considered in this study. Alternatively one may argue that it is not the yearly growth of regional cooperation propensity but the variables long-term growth rate that might influence regional innovativeness in both industries.

These results yield interesting implications for regional innovation policy. In the past policy makers launched initiatives in order to promote cooperation and thereby to foster

innovation (see, e.g., Lo et al., 2006). Based on the findings from this study, however, one can conclude that an increase in cooperation does not necessarily turn out to be advantageous for regional innovativeness but can also lead to a decrease in a region's innovative output. The level of cooperation in a region appears to be decisive for how regional innovativeness is affected by a change in regional cooperation behaviour. Moreover it has been shown that industries respond differently to a short-term change in regional cooperative activity. It thus appears to be advisable carefully considering the regional dimension as well as industry characteristics when designing the respective regional innovation policies.

Furthermore it is important to emphasise that the methodology applied does not allow resolving any issues of causality. Therefore it is uncertain whether or not an exogenous stimulus to regional cooperation behaviour would have the corresponding effect on regional innovative output. The results should rather be interpreted as a description of the regional development of both variables over time.

Appendix

Industry NACE code Model version	CHEM 24		MACH 29		COMM 32		INST 33	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
$\Delta App_{r,t-1}$	-.4428*** (-9.54)	-.4926*** (-7.31)	-.5594*** (-11.64)	-.5264*** (-12.08)	-.3085*** (-4.80)	-.4367*** (-8.38)	-.5551*** (-11.01)	-.5354*** (-11.45)
$\Delta App_{r,t-2}$	-.0678 (-1.40)	-.1955*** (-2.92)	-.2097*** (-3.96)	-.1921*** (-4.33)	-.1339** (-2.06)	-.2036*** (-3.95)	-.1206** (-2.40)	-.2090*** (-4.68)
$\Delta Coop_{r,t-1}$.0095 (0.54)	-.0041 (-0.17)	-.01120 (-1.01)	-.0215* (-1.93)	.0395* (1.95)	.0479*** (2.94)	.0159 (0.84)	.0065 (0.37)
$\Delta Coop_{r,t-2}$.0199 (1.12)	.0115 (0.46)	-.0128 (-1.07)	-.0052 (-0.46)	.0468** (2.31)	.0102 (0.61)	.0190 (1.05)	.0004 (0.02)
$GDP_{r,t}$	-	.0001 (0.04)	-	.0029* (1.71)	-	-.0007 (-0.24)	-	-.0013 (-0.56)
$Pop_dens_{r,t}$	-	-.0000 (-0.75)	-	-.0000 (-1.54)	-	-.0000 (-1.52)	-	-.0000 (-1.41)
$Students_{r,t}$	-	-.0010 (-0.67)	-	-.0004 (-0.68)	-	.0003 (0.27)	-	.0010 (1.11)
<i>Year dummies</i>	no	yes	no	yes	no	yes	no	yes
Obs	498	498	653	653	392	392	575	575
Pseudo R ²	0.070	0.275	0.133	0.280	0.068	0.255	0.110	0.271

Table 5: LAD estimation of equation 2 for the four industries CHEM, MACH, COMM and INST regarding the whole sample of regions; *t*-statistics are given in parentheses; *, **, *** indicates significance at the 10%, 5%, and 1% level, respectively

	CHEM	MACH	COMM	INST
1998	0.0852 *	-0.0095	-0.0942	0.0251
1999	-0.0502	-0.032	-0.0619	-0.0021
2000	0.0056	-0.0159	-0.0283	-0.1485
2001	-0.0444	0.0733 *	-0.0505	-0.0188
2002	0.0729	0.0945 *	0.0382	0.0278
2003	-0.0078 **	0.1454 ***	0.0256	-0.0024
2004	0.0241	0.0091	-0.1018	-0.1035
2005	-0.0133	0.007	-0.1609	0.1792 ***

Table 6: Moran's I

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