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Treating patent as relational data: Knowledge transfers and spillovers across Italian provinces[^]

Mario A. Maggioni[*] Teodora Erika Uberti[*] Stefano Usai[°]

The paper adopts a new perspective to investigate the characteristics of innovation clusters within and across Italian NUTS3 regions (province). Patents are used as relational data connecting inventors to applicants along a dual interpretation of a "knowledge production" and a "knowledge utilization" function.
The paper intends to map and measure the structure and the evolution of a series of innovation sub-systems (both at territorial level and at the industry level) in two different periods of time, 1987-1991 and 1997-2001 to detect how networks of inventors and applicants have changed over time. The paper uses the CRENoS database on regional patenting, built on EPO data, spanning from 1978 to 2001 and uses two complementary analytical tools (network analysis and spatial econometrics) in order to analyse the behaviours of inventors and applicants within 103 Italian NUTS3 regions (*province*) and 5 specific industries chosen according to the Pavitt's taxonomy (Footwear, Textiles, Chemicals, Personal Computers and Machine).
The paper deals with the following research questions. Is the polarisation of the geographical structure of the innovative activity in Italy, replicated both at the inventors and at the applicant level? Which are the relevant changes in the 20 years? Can we distinguish between a "knowledge production function" and a "knowledge utilisation function"? Which is the structure of knowledge flows between inventors and applicants in Italian provinces? Are there industry-specific differences? Which are the determinants of the knowledge flows between Italian provinces?

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Although the paper is a joint effort, sections 1, 2, and 4.4 can be attributed to Mario A. Maggioni, sections 3 and 4.3 to Teodora Erika Uberti, sections 4.1, 4.2 and 5 to Stefano Usai.

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> In this desert of data, patent statistics loom up as a mirage of wonderful plentitude and objectivity. They are available; they are by definition related to inventiveness, and they are based on what appears to be an objective and only slowly changing standard. No wonder that the idea that something interesting might be learned from such data tends to be rediscovered in each generation.
>
> Zvi Griliches (1990)

1. Introduction: innovation networks and innovation systems

The recent literature on the economics of innovation and technological change has witnessed the appearance of two innovative and interrelated concepts which have followed different and distinct paths, being cultivated by different "schools" and streams of thought with very few interactions.

The network approach is based on the assumption that all activities (economic, social, political, etc.) are organized by means of different links between economic actors, i.e. as networks. Networks have three important characteristics (Johansson, 1995; Bramanti and Maggioni, 1997; Cappelin, 2003; Ejermo and Karlsson, 2006a; 2006b): (i) the relationship between two nodes identifies either a mutual relationship or a relationship of control or of dependence of a node with respect to another node; (ii) each node has a specific function, which depends on its internal characteristics, its relationship with other (most proximate nodes, and its position in the overall network; (iii) the relations existing in a specific network are non-ergodic due to the existence of cumulative learning and path dependence.

The starting point for a network analysis of the innovation process is the micro-level of individual agents, these being: individual inventors, firms and other organizations engaged in innovative activities. The relations between these agents may be mapped though direct interviews or, more easily, deducted from patents or joint research programmes. These relations, as explained above, are dependent on the node's attributional and relational characteristics but also on their geographical location. Thus, the interaction between two different nodes in an inventors network depends upon the available capital stock and upon the functioning of existing transport infrastructure and information exchange systems. By aggregating data at a given geographical level (i.e NUTS2 or NUTS3), one may build a geography-based innovators network (see, among others, Ponds *et al.*, 2007, Maggioni *et al.* 2007; Paci and Usai, 2008).

The national systems of innovation (henceforth SI) approach has been developed from the seminal contributions of Lundvall (1988, 1992), Freeman (1982, 1987, 1995), Nelson (1993), Dosi *et al*. (1988). The main idea behind these scholars was to create a framework able to understand, describe and analyse innovation as a process of learning and interacting, based on knowledge, on heterogeneity of organizations and institutions, and on dynamic evolution. In Lundval (2007) words, the SI approach "helps to organize and focus the analysis, it helps to foresee what is going to happen, it helps to explain what has happened and it helps to give basis for rational action" (p. 99).

Indeed, to be philologically correct, one should note that one of the early definitions (Freeman, 1987) described the national SI a "network of institutions in the public and private sectors, whose activities and interactions indicate, import and diffuse new technologies" (p. 1), but in this literature, the network has always been used more as a metaphor than as a proper analytical tool.

In the early nineties it become evident that the SI definition at the national level was too wide to give a sensible framework able to encompass very different situations both from a technological and a geographical perspective. In order to solve these problems a series of ancillary concepts was created by substituting the original "national" adjective with several alternatives: on the one side, "technological" and "sectoral" SI were able to account for industry and technology-specific characteristics; while, on the other, "regional", "transnational" and "global" SI extended the spatial scope of the original concept within and outside national borders.

This paper aims at bridging these two different approaches by looking at the different innovation system as described by the innovators-applicant relationships aggregated at the provincial (NUTS3 region) level in Italy. In this way we are able to show that not only each system is a network in its very nature but also that regional, national and sectoral systems cannot be fully understood without reference to one another.

In order to achieve this aim, after this introduction, section 2 reviews the use of patent as indicators of innovative activities both from an attributional and a relational perspective, section 3 illustrates the construction of the original relational database and presents the research questions, section 4 presents the different analyses (using spatial econometrics, social network analysis and gravity models) and section 5 summarizes the results and concludes the paper.

The different empirical analyses performed in the paper show that, despite their inward-oriented character, local innovation systems are heavily dependent on "external" linkages and that different industries have really different structure of their innovative mechanisms and processes.

2. Treating patents as source of relational data: what has been already done

Patents (and patent applications) are one of the most established output indicators of innovative activities[1]. Since the seminal contribution of Scherer (1965), patents have been used in the economic literature[2] in order to measure different aspects of the innovative process both at the micro and at the macro level (Griliches, 1981).

2.1. Patents as source of attributional data

The early use of patent statistics as economic indicators, to quote the title of a renowned paper (Griliches, 1990) was limited to the attributional side of a patent. Being documents "issued by an authorised governmental or [supergovernmental[3]] agency granting the right to exclude anyone else from the production or use of a specific new device, apparatus or process for a stated number of years" (Griliches, 1990, p. 1662), patens were used to measure the output of the inventive activity (both at the firm and at more aggregated – region, nation, industry – levels) and, sometimes, as proxy of the input side of the inventive activity when no R&D data were available. A further line of research (Griliches, 1981; Hirschey, 1982; Pakes, 1985) investigated the relation between the patents held by a firm and its stock market value; while Pavitt, Patel and Soete (Pavitt and Soete 1980; Soete, 1987; Pavitt and Patel, 1988) used patent data to analyse the relative

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[1] "The measure of patented innovations provides a fairly good, although not perfect, representation of innovative activity. This supports the use of patent counts in studies examining technological change" (Acs *et al.*, 2002, p. 1070).

[2] Not to forget the wide economic geography and regional science literature.

[3] As in the case of EPO for the EU.

'competitiveness' of various countries, to construct a 'revealed technological advantage' index and to describe the international location of inventive activity in different industries.

Something closer to a relational use of patent data came from the work of Jaffe, starting from his Ph.D Thesis (Jaffe, 1983), devoted to the identification and measurement of knowledge spillovers which implied the exploitation of an intrinsically relational information contained in the patent document: the citations list.

However, until 1993 citations were used in an attributional way: the number of citations was used as an index of differential quality of different patents. This literature could be represented by Trajtenberg (1990) which showed that citation weighted patent numbers are more closely correlated with innovative output (consumer surplus derived form the introduction of an innovation), while un-weighted patent counts are more closely correlated to input (R&D expenditure).

2.2. Patents as source of relational data

The "relational revolution" was unintentionally ignited by Krugman who, in his book *Geography and Trade* (1991), stated that knowledge flows are invisible and cannot be properly measured and tracked[4]. But the founding father is surely Jaffe who suggested that indeed knowledge flows leave a "paper trail", in the form of patent citations, which can be measured and used to obtain information on the spatial dimension of the innovation spillovers phenomenon[5] (Jaffe *et al.*, 1993). Papers such as Jaffe and Trajtenberg (1996 and 1998) extended the analysis and became the standard way (known as localized knowledge spillover approach) to exploit the relational content of patents. Other papers used patents citations to measure knowledge flows across regions (see, among others, Jaffe and Trajtenberg,

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[4] " (…) as a matter of principle I think we should focus first on the kinds of external economies that can be modelled other than by assumption. (...) Knowledge flows (...) are invisible; they leave no paper trail by which they may be measured and tracked, and there is nothing to prevent the theorist from assuming anything about them that she likes" (Krugman, 1991a, p. 53).

[5] But knowledge flows do sometimes leave a paper trail in the form of citations in patent. Because patents contain detailed geographic information about their inventors, we can examine where these trails actually lead. Subject to caveats (…) this allows to use citation patterns to test the extent of spillover localization" (Jaffe et al., 1993, p. 578).

1999, 2002; Hall *et al.*, 2001; Lukatch and Plasmans, 2003; Criscuolo and Verspagen, 2006; Maurseth and Verspagen, 2002; Le Sage *et al.*, 2007; Paci and Usai, 2008).

A different approach has been used by Ejermo and Karlsson (2004), Cantner and Graf (2006), Maggioni and Uberti (2006 and 2008) and Maggioni *et al.* (2007). These authors used the information about the multiple inventors of the same patent and exploited it in order to map a network of intentional knowledge exchange between scientists (or, by appropriately aggregating the data, between research institutions, firms, regions). If three inventors, located in three different regions, produce a patent that mean that a flow of both codified and tacit knowledge has been established between these three regions and supported by a series of different relational tools, media and technologies: face to face contact, phone, e-mails, videoconferencing etc, which may be very difficult to map and measure.

Breschi and Lissoni (2001, 2004 and 2006) criticize the localised knowledge spillover approach which is built on the assumption that scientific and technological knowledge is largely tacit, so that face-to-face contacts are the necessary vehicle for its diffusion; and conclude that geographical proximity is in turn a necessary condition for those contacts to take place. They observe that if knowledge is tacit it is also private (Callon, 1994) and therefore is up to the producers to decide with whom sharing, or to whom selling them. Breschi and Lissoni therefore exploit another relational information contained in the patent document: the relation between inventors and applicants (in their jargon: assignees). In this way they are able to show that far from being freely spilled over one firm to another, scientific knowledge is exchanged and sold by inventors working with (or for) different firms. In their papers they argue that the key variable affecting knowledge diffusion is not the geographical but the social distance (social contacts built by scientists' and technologists' cross-firm mobility patterns and/or market activity between patent inventors) which may, or may not, be localized (Moen, 2000; Lamoreaux and Sokoloff, 1999).

In this paper we exploit the relation between inventors and applicants but at a higher aggregated level (NUTS3 regions) in order to link the literature on the regional systems of innovation and the literature on the innovation networks within an encompassing framework.

3. Treating patents as relational data: what we have done

While we leave the technicalities involved in the construction of a region-based "inventor-applicant" patent database to section 3.2, it is useful to discuss here which are its main *pros* and *cons* and which are the research questions which may be fruitfully addressed by such a research approach.

The main advantages deriving from looking at the innovation process described by patents from this twofold perspective lie in the possibility to analyse the process of producing an invention as a different (but interrelated) phenomenon from the process of applying the invention into the marketplace in order to reduce the costs of producing existing products a/o the development of new product and services.

The main drawbacks derives from the formal procedures involved in the process of filling in the patent application. All relevant information come from the applicants (or representative[6]). Therefore, on the applicant side, one may wonder whether, in case of large companies with multiple locations, the patent is assigned to the branch/subsidiary/division where the innovation has been produced (or will be applied), or just left to the parent company headquarter. On the inventor side one may doubt (at least this may be a problem for Italy) whether the legal address of the inventor (*residenza*) coincides with the actual place where the inventor lives[7], and one could be 5worried about the effect of commuting patterns.

3.1. Research questions

This paper address four main research questions:

Is the geographical polarisation of the innovative activity in Italy, replicated both at the inventors and at the applicants level? Which are the relevant changes in the last 20 years?

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[6] "Natural or legal persons having either their residence or their principal place of business in a contracting state can undertake all procedural steps before the EPO on their own and are not obliged to be represented by a professional representative. Others do need to be represented by a professional representative, except when filing an application or paying fees" (EPO website, 2008).

[7] However, this information is nevertheless interesting because it shows where people were born, educated and trained, as well as their intention to maintain a link with their home town.

Can we usefully distinguish between a knowledge production function (henceforth KPF) and a knowledge utilisation function (henceforth KUF)? Do spatial spillovers work differently as regards to inventors and applicants?

Which is the structure of knowledge flows between inventors and applicants located in different Italian regions? Can we find significant sectoral a/o temporal differences? What can we learn about local innovation systems from these networks?

Which are the determinants of the (market mediated) knowledge flows (implied by the relation between inventors and applicants) between Italian regions?

In order to address these research question different methodologies have been applied from descriptive statistics to spatial econometrics, from network analysis to gravity models.

3.2. The methodology

Data on patents are one of the most established output indicators to measure the innovation process, and the constitution of the European Patent Office (EPO) in Munich in 1977 allowed researchers to use a common dataset to analyse the innovative performance of different European countries and regions.

As stressed in section 3, in this analysis we focus our analysis on the Italian innovative activity, at the regional level, respect to "inventors" I^n and "applicants" A^n, i.e. creative people producing innovation and the owners of patent n[8].

These data on Italian "inventors" and "applicants" are disaggregated at NUTS3 level and are extracted by CRENOS files based on the original EPO database.

Since a patent record includes information on the location of inventors and applicants treating appropriately these information, we are able to identify the data on "creators" and "users" of innovation aggregated at NUTS3 level. For example a patent filed by a firm in region r and invented by 5

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[8] Since we are going to detect flows between inventors and applicants, in this analysis we exclude data relative to self-produced patents, i.e. when inventor and applicant are the same person which account for less than 14% of the entire database.

individuals, 2 located in region *x*, 1 in region *y* and 2 in region *z*, is split in regional shares as follows: 0.4 in region *x*, 0.2 in region *y* and 0.4 in region *z*. Finally we sum all these “inventors equivalent numbers” and (if necessary) “applicant equivalent numbers” across all patents in order to calculate our dependent variables for the econometric analyses.

Each patent *n* can be expressed as a square matrix $\mathbf{P_n}$ (whose dimensions are 103 x 103) where on the rows list 103 provinces where the inventors i^n_r, j^n_r, ..., k^n_r may be located and on the columns list 103 provinces where the applicants a^n_s, b^n_s, ... g^n_s may be located.

$$\begin{array}{cccc} & 1 & 2 & 3 \\ 1 & p_{11} & p_{12} & p_{13} \\ 2 & P_{21} & p_{22} & p_{23} \\ 3 & p_{31} & p_{32} & p_{33} \end{array}$$

Having summarised the information on the equivalent numbers of inventors/applicant per regions of locations, we are able to sum this information across all patents in order to describe the streams of knowledge ad information embodied in the patent (and in its “production process”) which flow among Italian regions:

$$P_N = \sum_{n=1}^{N} P_n$$

The main indicators of this interdependent system are as follows:

1) the total “equivalent number” of patents invented by inventors located in region *r* (i.e. the sum by rows in the $\mathbf{P_N}$ matrix):

$$pat_{r\bullet} = \sum_{n=1}^{N} \frac{i_r^n}{I^n}$$

2) the “equivalent number” of patents assigned to applicants located in region *s* (i.e. the sum by columns in the $\mathbf{P_N}$ matrix):

$$pat_{\bullet s} = \sum_{n=1}^{N} \frac{a_s^n}{A^n}$$

3) the "equivalent numbers" of patents invented by inventors located in region *r* and assigned to applicants located in region *s* (i.e. the element p_{rs} in the $\mathbf{P_N}$ matrix):

$$pat_{rs} = \sum_{n=1}^{N} p_{rs}$$

where p_{rs} is the element of each cell in the original $\mathbf{P_N}$ matrix.

4) Similarly to previous section we individuate the "equivalent numbers" of patents invented by inventors located in region *r* and assigned to applicants located in region *s* (i.e. the element p_{rs} in the $\mathbf{P_N}$ matrix) for 5 different sectors:

$$pat_{rs}^{z} = \sum_{n=1}^{N} p_{rs} \quad z = (\phi, \tau, \mu, \pi, \gamma)$$

These "relational" data are relative to the equivalent numbers of patents in *Footwear* (ϕ), *Textiles* (τ), *Machinery* (μ), *Personal Computer* (π) and *Chemicals* (γ) from 1978 to 2003, and we are able to map and differentiate flows of innovation at sectoral level. To identify these manufacturing sectors we used conversion tables from IPC classification to NACE. *Footwear* and *Textiles* are traditional industries strongholds of the Italian manufacturing currently suffering from fierce international competition; *Machinery* is still a successful story in Italy; *Personal Computer* is an industrial sector in which, after an outburst in the70s, the Italian innovation system is now lagging behind; *Chemicals* was a leading sector in the past. According to Pavitt (1984) classification these sectors are classified as follows: *Footwear* and *Textiles* are supply dominated sectors; *Machinery* is a specialised suppliers sector, *Personal Computer* is a science based industry and *Chemicals* is a scale intensive one.

In this paper we are dealing with these 4 different indicators of patenting activity. In particular, to detect KPF and KUF (described in section 4.2), we focus on a total equivalent number of patents according to inventors, from 1997 to 2001, equal to 16,890 patents; similarly for the same time period and respect to applicants, we detect 14,965 patents.

Differently to analyse the network of sector specific total equivalent number of patents, we expanded our period of analysis from 1978 to 2003. This choice was forced by the specificity of the Italian innovation system, mostly characterised by incremental innovations (not patentable) and not radical ones. In fact during 26 years about 555 patents are registered in *Footwear* sector, in *Textiles* about 1,708 patents, in *Machinery* about 261 patents, in *Computer* about 915 patents, and in Chemicals about 4,077 patents.

To detect the evolution of innovation networks, in all sectors, we analysed inventors/applicants for two periods, 1987-1991 and 1997-2001. In these two periods, the total equivalent number increased by 1,5 times, from 8185 to 12517.

Finally to estimate the determinants of innovation flows between Italian provinces, we concentrate our analysis on the total equivalent number of patents for the period 1997-2001, i.e. 12,517 patents.

3.3. The database

In our analysis we are dealing with three empirical analyses: the KPF and KUF are investigated using spatial econometrics techniques and the analysis of knowledge flows is modelled according to a gravity equation framework and is estimated using overdispersion estimation procedures.

The KPF model is based on inventors and detects the total equivalent number of patents for the period 1997-2001 in all sectors, while all regressors are relative to previous years and year 1999[9]. In particular we include the "traditional" input variables for a production function, i.e. R&D intensity of the province r ($R\&D_r$) and number of graduates on scientific fields as percentage of total graduates ($SGra_r$) in 1997.

Since the R&D intensity is not available for the Italian provinces, we calculated it respect to employment in R&D sectors in each province, as follows:

$$R\&D_r = \frac{TotR\&D_R \cdot \dfrac{empl_r^{R\&D}}{empl_R^{R\&D}}}{VA_r} \tag{1}$$

where r indicates the provinces, and R the corresponding administrative region, $TotR\&D_R$ is the total value of R&D in region R, $empl_r^{R\&D}$ and $empl_R^{R\&D}$ are respectively employees in R&D sectors in province r and region R, and VA_r indicates the value added in province r.

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[9] All these data are our elaborations based on Crenos database; Istat, *Sistema di Indicatori Territoriali*; Eurostat; Espon database.

A set of regressors relative to 1999 describes the economic structure of a province r, the socioeconomic environment, the labour market and agglomeration externalities. In particular we specify the average dimension of firms, as ratio of employee and local units in region r, $Size_r$; the openness of province r calculated as the percentage of import and exports respect to the value added of a province r, $Open_r$; fraud crimes per 100.000 inhabitants, $Fraud_r$; residents arriving from other provinces as percentage of resident population, $Mobil_r$, capturing the role played by internal migration; participation rate in province r, $Partic_r$. Finally to detect agglomeration externalities, we calculated an interaction variable, $UrbExt_r$ a measure of urban population respect to the geographical localisation (North-Center and South), calculated as the product of percentage of population living in the administrative capital of province r (*capoluogo di provincia*) respect of population in r, and a dummy variable North-Center and South.

Similarly for the KUF model, based on applicants, we select the total equivalent number of patents for the period 1997-2001 in all sectors, and, except for R&D, all regressors are relative year 1999. $R\&D_s$, $Size_s$, $Open_s$, $Fraud_s$, $Partic_s$ are calculated as defined previously, while $Bank_s$ and $PatDiv_s$ are respectively a measure of financial infrastructure in province s and the propensity of province s to export innovation.

In the regression we used a double-log specification in order to interpret the estimated coefficients as elasticities.

Finally variables for the gravity equation are defined as follows. The flows of knowledge, Pat_{rs}, are relative to the total equivalent number of patents for 1997-2001 in all sectors as defined in section 3.2. Regressors include the scientific and high-tech productive "masses" of region r and s, i.e. number of graduates in scientific fields, $SGra_r$ in the inventor region r, and the percentage of local units in medium and high-tech manufacturing firms on the total fimrs $HTman_s$; three measures of proximities: geographical proximity between provinces r and s, $GeoD_{rs}$, the geographical distance in kilometres; a measure of production proximity, $ProdD_{rs}$, as the correlation between employment in manufacturing sub-sectors; and an innovation proximity $InnD_{rs}$, calculated as the correlation between IPC applications.

$R\&D_r$ and $R\&D_s$ are calculated as defined in equation 1; $Open_r$ and $Open_s$ are the openness of inventing and applicant provinces, as described previously; $Pexp_r$ and $Pimp_s$ are respectively the propensity to export innovation of inventing province r and the importing propensity of province s, calculated as follows:

$$Pexp_r = \frac{pat_{r\bullet} - pat_{rr}}{pat_{r\bullet}} \text{ and } Pimp_s = \frac{pat_{\bullet s} - pat_{ss}}{pat_{\bullet s}}.$$

Concluding we include Acc_{rs} a measures that captures the role of accessibility between the couplet of provinces *s* and *r*, calculated as the minimum between the two accessibility indexes. All these regressors are relative to 1999, with the only exception of R&D calculated in year 1997.

4. The empirical analysis

4.1. Spatial concentration of the innovative activity

Almost every study on the Italian innovation system (Malerba, 1993; Belussi, 2001; Evangelista et. *al*., 2002) points out its double dichotomised structure.

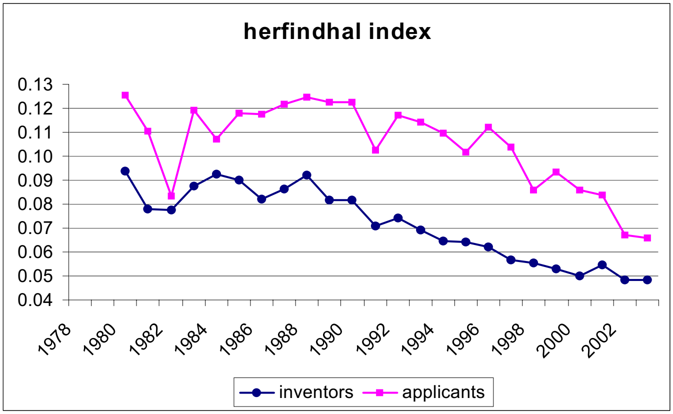
From an industrial perspective there are two distinct innovation systems: one based on networks of export-led SMEs and another based on large firms performing most of the formal R&D activity.

From a geographical perspective around 60% of the innovative activity, measured through input (R&D expenditure and personnel) and output (patents and number of innovations) indicators, is located in 3 regions only (Lombardia, Lazio and Piemonte) and the gap between the Northern and central part of the country as opposed to the South is wide.

This polarisation is replicated at the provincial level with the first 7 provinces recording more than 55% of patents and almost 40% highly skilled workers as opposed to a mere 25% of the total population.

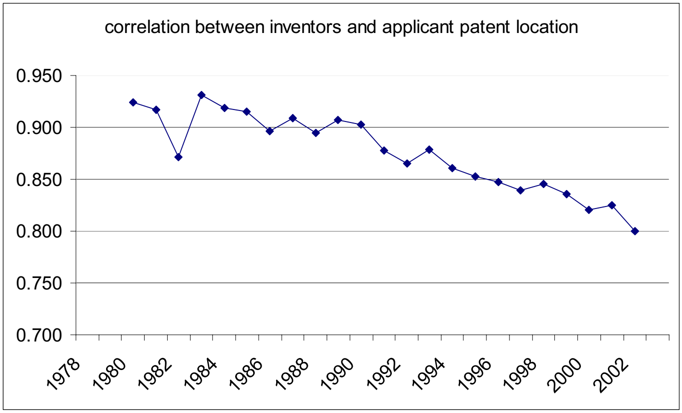
If we look at a measure of spatial concentration, as the Herfindhal index, we find that applicants are more concentrated than inventors (figure 1). However, in the period 1978-2003, one notes an ongoing process of spatial diffusion for both categories. The twofold perspective (inventors-applicants) used in this paper stresses the Italian innovation system at the provincial level allows also to test for the degree of localism of the provincial systems of innovation. On average, across the whole period, the percentage of patent invented and assigned in the same province is equal to 70%, but the inter-industry variance (described in section 3.2) is quite high.

Figure 1: Spatial concentration of inventors and applicants



The innovation capacity of a province seems to be determinant: if a province record a high number of patent assigned, it is very likely that the same province will record a high number of patent invented as witnessed by the high correlation index (being on average about 0.87) between inventors and applicants location (figure 2).

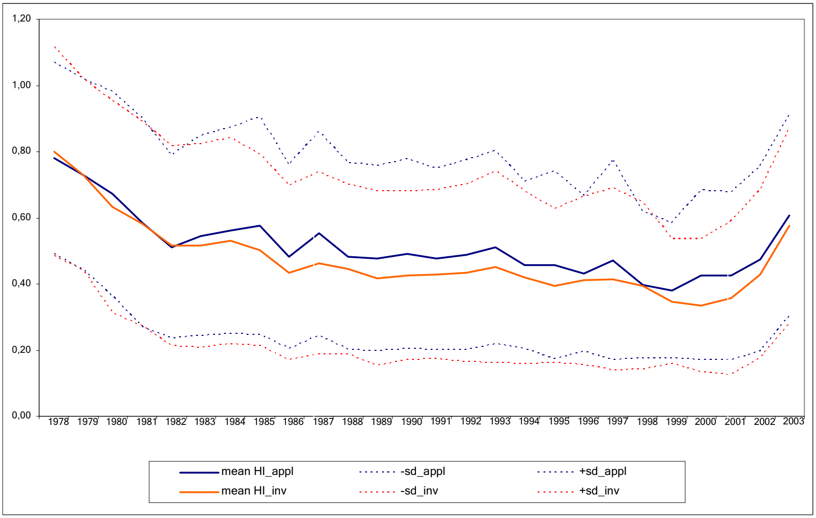
Figure 2: Spatial correlation between inventors and applicants



However in the period 1978-2003 the correlation index is steadily decreasing showing that the above mentioned diffusion process is acting for both inventors and applicants but following two distinct geographical patterns.

Figure 3 shows the evolution of the diversification of the innovative activity in the Italian provinces calculated through an Herfindhal index of patents based on IPC classes. Applicants, on average, are slightly more specialised than inventors; while the general trend is towards differentiation for both categories.

Figure 3: IPC diversification of inventors and applicants



As a final remark, one should remind that, while this paper focuses on the innovation networks stretching between Italian provinces, local innovation systems in Italy are mostly inward oriented.

4.2. Knowledge production and utilisation functions

In section 3.1 we showed that the location of inventors and applicants although decreasing is still highly correlated Nevertheless the use of the inventors-applicants perspective allows to enquire on two different innovative phenomena: the first relates to the process of generating new knowledge: the "classical" knowledge *production* function (KPF)[10]; the second relates to the process of apply this new piece of knowledge to a marketable product or process: we dubbed it knowledge utilisation function (KUF).

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[10] See, for a recent application to European regions, Moreno *et al*. (2005).

These two functions have been modelled (through a double log specification) as linearly dependent on the amount of research and development produced in the region and a series of other variable describing the social and economic characteristics of the region.

More formally KPF (2) and KUF (3) may be specified as follows and estimated through OLS:

$$\begin{aligned} Pat_{r\bullet} &= \alpha + \beta_1 R\,\&\,D_r + \beta_2 Size_r + \beta_3 Open_r + \beta_4 Fraud_r + \beta_5 Partic_r + \\ &\beta_6 SGra_r + \beta_7 Mobil_r + \beta_8 UrbExt_r + \varepsilon_r \end{aligned} \tag{2}$$

$$\begin{aligned} Pat_{\bullet s} &= \alpha + \beta_1 R\,\&\,D_s + \beta_2 Size_s + \beta_3 Open_s + \beta_4 Fraud_s + \beta_5 Partic_s + \\ &+ \beta_6 Bank_s + \beta_7 PatDiv_s + \upsilon_s \end{aligned} \tag{3}$$

where variables are defined as in section 3.3. Once we estimated both functions with OLS we tested for the presence of spatial auto-correlation and through the appropriated test we model the relation as a spatial lag model (Anselin, 1988). The results of both the OLS and the spatial lag model are presented in table 1 and equations 2 and 3 can be written as follows:

$$\begin{aligned} Pat_{r\bullet} &= \alpha + \beta_1 R\,\&\,D_r + \beta_2 Size_r + \beta_3 Open_r + \beta_4 Fraud_r + \beta_5 Partic_r + \\ &+ \beta_6 SGra_r + \beta_7 Mobil_r + \beta_7 UrbExt_r + \rho_r WPat_{r\bullet} + \vartheta_r \end{aligned} \tag{4}$$

$$\begin{aligned} Pat_{\bullet s} &= \alpha + \beta_1 R\,\&\,D_s + \beta_2 Size_s + \beta_3 Open_s + \beta_4 Fraud_s + \beta_5 Partic_s + \\ &+ \beta_6 Bank_s + \beta_7 PatDiv_s + \rho_s WPat_{\bullet s} + \xi \end{aligned} \tag{5}$$

where ρ_r and ρ_s are respectively the spatial autoregressive coefficient for inventors and applicants, and measures the spillover effect connected to the dependent variable, W is the spatial weight matrix based on spatial proximity, ϑ and ξ are the error terms.

Since all variables are in log, we can interpret the coefficient as elasticity and discuss their relative size.

The amount of R&D performed in the province is positive and significant for both KPF and KUF in the OLS specification but become insignificant in the spatial lag models. We interpret this result as a sign of a overall dimension of local innovation systems in Italy whose size, in general, exceeds the provincial border.

Table 1: KPF and KUF

All variables are in log

	KPF, dependent variable: $Pat_{r\bullet}$		KUF, dependent variable: $Pat_{\bullet s}$	
	OLS	**ML**	**OLS**	**ML**
Constant	-5.33	0.76	-22.63***	-16.07***
R&D	0.13*	0.07	0.12*	0.05
Size	0.50*	0.45*	1.53***	1.25***
Open	0.28***	0.16*	0.02	0.02
Fraud	0.40***	0.33***	0.45***	0.37***
Partic	3.58***	2.01**	4.12***	2.78***
SGra	1.04***	1.06***		
Mobil	0.41**	0.17		
UrbExt.	0.01**	0.004		
Bank			0.68***	0.48***
ρ		0.40***		0.33***
Log-Likelihood	-94.62	-84.42	-107.75	-101.32
AIC	207.24	188.85	231.49	220.65
Obs.	103	103	103	103
Moran-I	0.19***		0.06*	
Lm LAG	18.61***		11.31***	
Robust LAG Lm	11.07***		11.40***	
LM Error	7.59***		1.60	
Robust Lm	0.05		1.69	
LR test		22.87***		12.84***

The average size of firms is positively related wit both the inventors and the applicants measure of provincial patenting activity. However it is worth nothing that the coefficient in the KUF is three time higher than the coefficient of the same variable in the KPF, confirming that larger firms do rely more on IPR tools for their innovation strategies, while individual creativity shows a weaker correlation with the level of scale economies.

The degree of openness of the provincial economic system positively affects the inventors performance while it is not influential on the applicants side; while the effectiveness of the labour markets (as measure by the participation rate) records a positive and significant coefficients in all models and specifications.

Different and alternative stories may explain the positive and significant coefficients registered by the fraud variable. The first relies on the interpretation of this variable as a proxy of the social capital endowment of the province (in order to perform a fraud one needs to be in an environment where people trust each other very much). The second relates on the connection between fraud, counterfeit and IPRs (the more the counterfeiting the higher the patenting activity), the third refers to alternative use (one legal: the invention; one illegal: the fraud) of the local degree of creativity.

The human capital endowment positively influence the inventors performance in the province, while both the degree of inter-province mobility and the level of urbanization externalities are not significant in the spatial lag specification. The level of financial intermediation activities, as proxied by the diffusion of bank branches in the province, fosters the applicants performance.

The coefficient of the spatially lagged variable is positive and significant for both functions but it is higher in the KPF than in the KUF, suggesting that knowledge spillovers (i.e. unintentional knowledge transfer between provinces) are more influenced by the behaviours of the individual inventors rather than the strategy of firms.

4.3. Networks structure of inventors-applicants relation

Following the methodology described in section 3.2, here we treat patents as flows of knowledge between inventing provinces and applicant provinces in five different sectors and we analyse these networks using Social Network Analysis (SNA) techniques. This procedure allows us to investigate the presence (or not) of structural differences of innovative activity among different sectors.

We should remind that in all empirical analyses performed in the paper, we excluded patents where applicants and inventors are the same person in order not to overestimate the degree of localism. As already mentioned in footnote 7, this phenomenon is not very relevant but there is a high variance across industries (Chemicals 2%; PCs 6%; Machinery 7%; Footwear and Textiles 12%). These values reflect the different roles played by formal R&D and innovation procedures in these industries.

To apply SNA techniques we have to dichotomise all sectors specific networks according to a threshold value equal to "0", i.e. detecting the presence of an innovative flow irrespective to its intensity.

Computing the average distance of these knowledge flows, we observe that the average distance is increasing reflecting two phenomena: the codification of knowledge and some sector specific characteristics of the Italian innovative system. In fact if the average distance for total patents is 277 km, respect to sectors the average distance is very different: in machine sector the average distance is 80 km, in footwear 122, in textiles 154, in personal computer sector 252 and in chemicals 892 km. These values confirm that when knowledge is becoming more and more codified and innovation is taking places in high-tech sectors, exchange of knowledge could flow easily along Italy. On the other hand these values reflect also the dispersion/concentration of SMEs in the Italian economic structure.

To detect the similarity or not of these innovative networks, we compute a correlation between all networks using Quadratic Assignment Procedure (QAP). Correlations values are always very low (less than 0.1), with an exception, between Personal Computer and Chemicals, whose correlation is nearly 0.3[11]. These values confirm that the inventors/applicant networks are "districts" specific, hence not highly connected, and that in Textiles, Machine and Footwear innovation is more incremental and less patentable.

Before presenting the SNA main results, we should recall that all innovation/applicants networks are highly locally-based: indeed the role of self-loop (i.e. pat_{rr}, patents applied by applicants and inventors located within the same province) is very relevant although changes characterise these 5 sectors. In all traditional sectors (Footwear, Textiles and Machinery)

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[11] We compute these correlations for original networks and for binary ones, and values are confirmed.

self-inventing represents nearly 4/5 of total innovative activity[12] confirming the existence of very tightly knitted local innovation systems at the provincial level (not surprising giving origin to the industrial districts phenomenon). Differently in Personal Computer and in Chemicals, localism is less evident, representing less than 60% of total patenting activity[13].

Since in this analysis we are mostly interested in the flows across provinces, in SNA results, we exclude all loops, i.e. values on the main diagonal pat_{rr}.

SNA, carried out using dichotomised networks with very low threshold value (greater than 0), shows interesting results for different sectors both respect to the whole connectedness and respect to the presence (or not) of pivotal provinces in terms of "creation" of innovation (inventors) and "use" of innovation (applicants) (figures 1-5).

The SNA indexes are summarised in table 2.

Table 2: SNA indexes

Sector	Density	MC	Average degree	Islands	Centralisation	
					OUT (inventors)	IN (firms)
Footwear	0.0056	34	0.573	Sondrio/Lecco	0.083	0.123
Textiles	0.0194	64	1.981	Brindisi/Lecce	0.168	0.337
Machine	0.0040	37	0.408	-	0.055	0.065
PC	0.0145	79	1.476	Prato/Cagliari; Avellino/Salerno	0.064	0.579
Chemicals	0.0507	92	5.175	-	0.335	0.751

Firstly these networks are disconnected since there exist numerous isolated nodes, with the only exception of Chemicals. In addition in Footwear, Textiles and Personal Computer some independent regional-based sub-networks emerge (Sondrio-Lecco in Footwear, Brindisi-Lecce in Textiles

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[12] In footwear sector loop is 81%, in textiles is equal to 72% and in machinery 75%.

[13] In fact in Personal Computer the loop is equal to 56%, in Chemical is even less, 50%.

and Avellino-Salerno in Personal Computer)[14], emphasising the presence of "independent" but "nearby" innovative systems within regions.

Figure 1: Footwear network

(threshold value >0)

The main component (MC) size is extremely heterogeneous: in Chemicals the inventors/applicants MC includes nearly 90% of all Italian provinces, emphasising that this sector is spread over the Italian territory, while on the contrary Footwear and Machinery sectors, whose MCs are less than 40%, strengthen the presence of district specific areas excluding a part of the territory from this innovation process. Finally Textiles and Computer sectors present more similar MCs size, respectively 62% and 77%.

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[14] There is only an exception in Personal Computer sector, Prato and Cagliari, two provinces located respectively in the South of Sardegna and in the middle of Toscana.

Figure 2: Textiles network

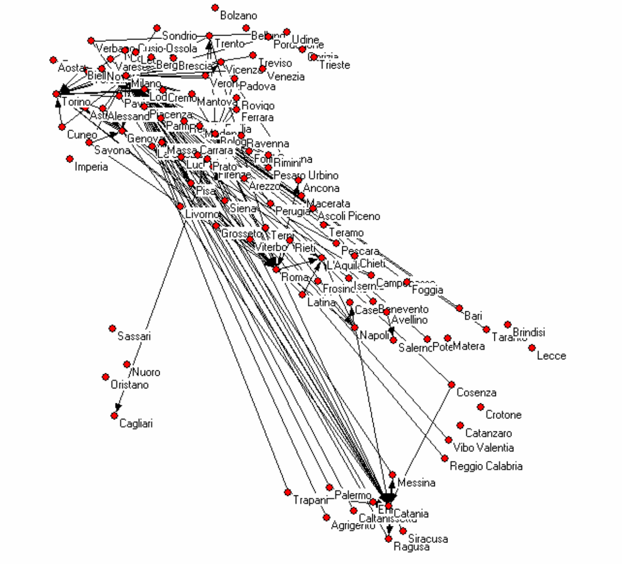
(threshold value >0)

Figure 3: Machine network

(threshold value >0)

Figure 4: Personal Computers network

(threshold value >0)



Accordingly, all networks are relatively sparse with a very low density[15]. The highest density, equal to 0.051, is in Chemicals; in Textiles and in Computer density values are 2.6 and 3.5 times lower than in Chemicals (0.019 and 0.014), while Footwear and Machinery are nearly empty networks, indeed density values are respectively 0.006 and 0.004.

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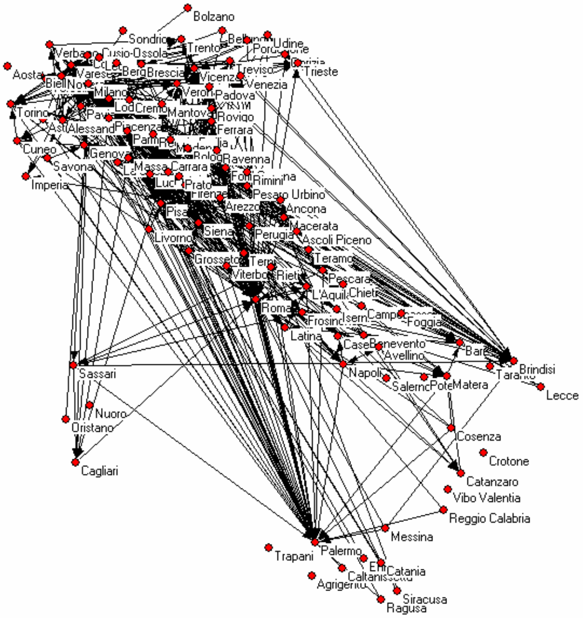
[15] Density, d, in a digraph is calculated as $d = \frac{L}{n \cdot (n-1)}$, where L indicates the total number of links present in the network and n the number of nodes. This value ranges between 0 (empty network) and 1 (full network).

Figure 5: Chemicals network

(threshold value >0)



To identify the presence of pivotal provinces, we calculate the centralisation values both for the inventors (outdegree) and for the applicants (indegree). Centralisation values measure the difference in centrality levels between the most central province and the other ones, and represents the variance of degree centrality and ranges between 0 (high homogeneity among degree of nodes) and 1 (high heterogeneity among degree of nodes)[16].

As density values analysis suggests, average degree values are very low, with the only exception of Chemical, whose value is 5.2. The average degree values in the remaining sectors are much lower: Textiles and

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[16] More formally, centralisation value is calculated as $\bar{\bar{C}}^{i}_{g} = \frac{\sum_{i}(C^*_g - C^i_g)}{(n-1)(n-2)}$ where C^*_g is the centrality value of the most central region in the system, C^i_g is the degree centrality of generic node *i* indicating the number of direct links, and the denominator reflects the maximum level of centrality obtainable in a system of *n* regions.

Computer have average degree respectively equal to 2 and 1.5, and Footwear and Machinery less than 1 (0.6 and 0.4).

If we look at the outdegree centralization index, to detect the presence of a pivotal inventor province, values are always very low (always less than 0.3), confirming that inventors are spread all around Italy, with no particular concentration in some areas.

On the contrary the analysis of the indegree centralization index, to detect the presence of a pivotal applicant province, shows the existence of different industry-specific structural features. In Chemicals and in Personal Computer the indegree centralization values are very high (0.8 and 0.6), with few provinces - Milano and Roma – playing a pivotal role in the network.

Differently in Textiles, the indegree centralization value is much lower (0.3), suggesting a structure of applicants relatively homogeneous.

And finally a completely homogeneous structure, in terms of applicants, is replicated both in Footwear and Machinery sectors, where applicant provinces are almost equal: innovation is very rare and no concentration of innovative firms seems to appear.

Concentrating the analysis on the most central provinces, a district and sector specific map emerges with few exceptions. In fact respect to applicants, three "urban" provinces (Milano, Roma and Torino) are very central in all networks and irrespective to sectors; while other provinces hold central positions because overlapping with the industrial districts: Treviso and Verona in Footwear, Pordenone and Firenze in Textiles; Bologna and Firenze in Machinery; Catania in Personal Computer and Palermo, Brindisi and Vicenza in Chemicals. Conversely respect to inventors, the Italian creativity is spread all over the territory, and no particular areas do emerge.

Finally to detect how the network evolved over time, we considered two periods, 1987-1991 and 1997-2001 and we dichotomised them according to the same procedure described above, i.e. the threshold value is selected irrespective to the intensity.

As shown in table 3, the network of inventors/applicants is becoming more and more connected: in fact in the second period there are no isolated provinces, while in the first there are 7 isolated provinces[17]. Consequently the density is increasing, becoming 1,5 bigger, it still remains very low: only 11% of all possible ties are actually presents. This result confirm that the Italian innovation system is very sparse, although is becoming more and more connected over time.

Table 3: SNA indexes for evolving networks

	1987-1991	1997-2001	Δ
Isolated nodes	7	0	⇓
Density	0.072	0.109	⇑
Average degree	7.350	11.126	⇑
OUT Centralization	0.442	0.543	⇑
St. dev. Outdegree	7.906	9.730	⇑
IN Centralization	0.729	0.840	⇑
St. dev. Indegree	11.721	13.716	⇑
MC	96	103	⇑

The average degree is increasing over time and the centralization measures reflect different structures respect to those depicted at the sectoral level (table 2). Indeed centralisation measures show similar ranking, i.e. centralisation of inventors is always lower than centralisation of the applicants one, but at this aggregation level the role played by few provinces is more pivotal, recalling an “hub and spokes” structure, with a central province concentrating all flows. This result seems to suggest an increasing concentration of innovative activities in very few provinces (as suggested in section 4.1).

A sensitivity analysis conducted on the threshold level, both for sectoral and aggregated level, could help to detect how the structure of the Italian innovation system changes respect to different sectors and over time.

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[17] Among these isolated provinces, only Oristano in Sardegna appears autarchic in its innovation system, since it is isolated, but present a loop, i.e. flows of creation and use of innovation within the region.

Finally the clustering coefficient, while relatively high in both periods, is decreasing probably reflecting a transformation toward a more connected and less clustered structure of the national system of innovation.

4.4. The determinants of knowledge exchange flows

The second econometric exercise aim to explain the determinant of the interregional knowledge transfer implied by the inventor-applicant relationships embodied in the EPO patents registered by Italian applicant in the period 1997-2001.

The estimated model is as follows:

$$Pat_{rs} = f(SGra_r, HtMan, GeoD_{rs}, ProdD_{rs}, TechD_{rs}, Pexp_r, Pimp_s, Acc_{rs}) \qquad (6)$$

where the interregional knowledge flows between inventors and applicants (measured through the number of patent invented by inventors located in region r and assigned to applicants in located region s) is modelled as a function of a series of characteristics of the emitting and of the receiving regions and three distinct measures (geographical, technological and productive) of proximity as explained in section 3.3.

At a first glance, as it has been done in section 4.2, it is tempting to express the relations between inventors and applicants as a log-additive model and estimate the parameters using ordinary least squares procedures.

$$\begin{aligned} lPat_{rs} &= \alpha + \beta_1 lSGra_r + \beta_2 lHtMan + \beta_3 lGeoD_{rs} + \beta_4 lProdD_{rs} + \beta_5 lTechD_{rs} + \qquad (7) \\ &+ \beta_6 lPexp_r + \beta_7 lPimp_s + \beta_8 lAcc_{rs} + \omega_{rs} \end{aligned}$$

However, this approach suffers from two main drawbacks.

First, a logarithmic form of model (7) estimated by OLS assumes observations to be normally distributed. This would only be statistically justified if the inter-regional relations embodied in patents were log-normally distributed with a constant variance, while this is not the case with our data on inventors and applicants. Second, the logarithm of zero is not defined but the number of zeros in the dependent variable Pat_{rs} is very high (more than 90% of the entire sample). The estimation results would thus be inefficient, inconsistent and biased.

To overcome these problems, it is possible to use a Poisson model specification. The Poisson distribution provides the probability of the number of event occurrences in the model, and the Poisson parameters corresponding to the expected number of occurrences[18] are modelled as a function of explanatory variables. Such a specification of the model has no problems with zero flows since $p_{rs} = 0$ is a natural outcome of a Poisson process. A Poisson density function may be represented as follows:

$$f(p_{rs}) = V_{rs}^{rs} e^{-V_{rs}} / p_{rs} \tag{8}$$

where V_{rs} denotes the systemic part of the model that captures the stochastic relationship to other model variables, which are the covariates and refer either to the origin r of the interaction or to the destination s of the interaction or to a function describing the separation between region r and region s.

A Poisson model may be estimated with maximum likelihood. However a Poisson specification is based on the assumption that the independent variables included in the model account for all individual deviations. Unobserved heterogeneity that cannot be captured by the covariates may therefore lead to biased estimates due to overdispersion. As suggested, for instance, by Long and Freese (2001), a way to overcome the problem of unobserved heterogeneity is to introduce a stochastic heterogeneity parameter leading to a Negative Binomial density distribution which may be estimated as well by Maximum Likelihood (see Cameron and Trivedi, 1998).

An LR test for overdispersion (which test the null hypothesis of the stochastic heterogeneity parameter being equal to zero) suggest that this was the case and that the Negative binomial model was correctly fitting the data.

Finally we adopted a zero inflated model estimation strategy to take into account the large number of zeros . A zero inflated count model assume that there are two latent (i.e. unobserved) groups. An individual observation (in our case a single couple of provinces) in the “always 0” group has an outcome of 0 with probability 1, while an individual couple of region in the “not always 0” group might have a zero count, but there is a nonzero probability that it has a positive count.

Since Zero Inflated models exists for both Poisson and Negative Binomial, we tested both Poisson and Negative Binomial specifications and in both cases the Vuong test suggested to use a “zero inflated” specification.

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[18] In order to use a Poisson specification we used an integer approximation of the distribution obtained by the aggregation over all patents of p_{rs}.

Finally a Likelihood ratio test (Long and Freese, 2001) was used to discriminate between a Zero Inflated Poisson (zip) and a Zero Inflated Negative Binomial (zinb). The test showed that the independent variables included in the model were not taking account of all the heterogeneity, thus a zinb specification was used and the results are described in table 4.

Table 4: Knowledge flows across Italian provinces

	Negative Binomial	Logit
Constant	-5.70***	2.86***
$SGra_r$	4914.01**	-7303.32***
$HTman_s$	0.60	9.37
$GeoD_{rs}$	-0.99***	3.79***
$ProdD_{rs}$	2.60***	0.73**
$InnD_{rs}$	0.98***	0.07
$Pexp_r$	-2.23	-1.51*
$Pimp_s$	3.57***	0.60
$R\&D_r$	-10.09***	-17.73***
$R\&D_s$	11.53***	0.81
Acc_{rs}	0.02***	-0.02***
$Open_r$	276.29	-64.46
$Open_s$	2580.07***	-2070.93***
Obs.=10201	932	9269
Log-likelihood	-4484.46	
LR chi2(12)	866.25***	
Vuong of ZINB vs. Negative Binomial	6.02***	
LR of ZIP vs. ZINB	1.3e+04	

The regression analysis shows that, among the couplets of provinces which have the opportunity to transfer scientific knowledge embedded in patents the endowment of specific human capital increase the expected flows of scientific knowledge, while the specialisation in high-tech industries of the receiving region does not play any significant role.

All measures of distance (geographic, sectoral and technological) play a significant negative role by decreasing the number of equivalent patent.

The coefficient of the propensity to "export" patents invented in the province is insignificant in the negative binomial regression while it is significant and negative in the logit specification. The higher the propensity to export innovative ideas, the lower the probability that this export does not really take place.

The R&D performed in a region decreases the outflows of patents invented by local inventors and assigned to "foreign" applicants, while the R&D performed in a region increases the inflows of patents wherever invented.

Accessibility is important on both sides of the exchange while the commercial openness play a significant and positive role only on the applicant side.

5. Conclusion

This paper presents an alternative and complementary way to look at patents as relational data connecting innovators and applicants across and within Italian provinces.

The outcomes deriving from such an approach are twofold: on the theoretical side we are able to connect two streams of literature (the system of innovation and the network of innovators) that, despite their evident complementarities have been rarely intertwined; on the empirical side we are able to use different data extracted form the same patents database to identify a knowledge production and an knowledge utilisation function and to search for the relevant variables influencing these intentional flows of scientific knowledge.

The use of social network analysis technique is used in the paper as a powerful descriptive phenomenon. Further extension of the paper will include the use of longitudinal analysis in order to take into account the fact that, contrary to what it must be assumed in order to perform any kind of statistical and econometric analysis, each province is part of a networks which determines (together with some structural characteristics) its performance.

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