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Heterogeneous foreign direct investment and local innovation in Italian Provinces

Andrea Ascani[a,b], Pierre-Alexandre Balland[a,c], Andrea Morrison[a,d,*]

[a] Department of Human Geography and Planning, Utrecht University, Princetonlaan 8A, 3584 CB Utrecht, The Netherlands
[b] Department of Geography and Environment, London School of Economics, Houghton Street, London WC2A 2AE, UK
[c] Collective Learning Group, The MIT Media Lab, Massachusetts Institute of Technology, 77 Mass. Ave., E14/E15, Cambridge, MA 02139-4307, USA
[d] ICRIOS - Department of Management and Technology, Bocconi University, via Roentgen 1, 20136 Milano, Italy

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ABSTRACT

Locations all over the world compete to attract Foreign Direct Investment (FDI) in order to access knowledge, technology, and boost economic development. Although the literature shows a positive impact of FDI, little is known about (1) its effect on neighbouring regions and (2) the type of FDI generating the strongest learning effects. To fill this gap, we investigate the FDI-innovation relationship in Italian provinces. By adopting the Pavitt taxonomy of manufacturing sectors, we suggest that only specific categories of FDI benefit local economies, whilst other types may produce negative outcomes. The evidence on the spatial implications of FDI remains limited.

1. Introduction

All over the world, countries and regions compete to attract foreign direct investment (FDI). The presence of multinational enterprises (MNEs) in the domestic economy is supposed to boost the performance of local firms, mainly through the diffusion of new knowledge and technologies (Iammarino and McCann, 2013). Little is known, however, on the link between FDI and innovation. To shed light on this issue, we study the relationship between FDI and the innovation capacity of Italian provinces (NUTS3) by considering a fundamental issue that has received scant attention despite its academic and policy relevance: namely, the inter-industry effects of FDI that depend on the sectoral nature of the innovation process. In this sense, we consider the inter-sectoral linkages between foreign MNEs' activity and the local industrial structure of recipient economies, in order to understand how the relationship between FDI and local innovative activities vary according to the diverse nature of innovation in different branches of manufacturing. In parallel, we also account for the geographical dimension of this relationship, as the sectoral patterns of this link can be more or less bounded in space. This is a relevant additional aspect to consider, since the implications of FDI can transcend local administrative boundaries, thus potentially affecting other local economies, as envisaged in Antonietti et al. (2015). Hence, starting from the traditional question on whether FDI and the innovation capacity of local economies are connected, we extend the research horizon on the effects of FDI in these directions.

Exploring these aspects is also of utmost importance for policymaking and public measures for FDI attraction at the local level. First, FDI attraction initiatives should consider potential heterogeneous effects associated to the diverse sectoral and technological nature of different inward FDI. In fact, FDI-induced benefits and/or costs can be non-uniformly associated with foreign activities that are characterised by very diverse knowledge sources. Second, regional policies to attract foreign MNEs can require more strict coordination in presence of inter-regional effects in order to avoid

* Corresponding author.
E-mail address: a.morrison@uu.nl (A. Morrison).

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ineffective or even wasteful policies connected to detrimental territorial competition (Cheshire and Gordon, 1998).

In order to capture the heterogeneity of FDI in terms of knowledge inputs, we will apply the well-established categorisation of manufacturing sectors by Pavitt (1984) to inward FDI within Italian provinces, thus accounting for the nature and sources of knowledge in different sectors where foreign MNEs are active. This represents an interesting perspective because foreign activities are inherently industry-specific, and categorizing FDI allows us to focus on how the industrial specialization of foreign affiliates relates to indigenous innovation in different technological fields. Hence, based on this categorisation, we are able to conceptually identify key interdependencies in the innovation process across industries and to position FDI and local innovative activity in this framework.

Notwithstanding the large number of empirical studies searching for evidence on the knowledge-related effects from FDI (see Rojec and Knell, 2018), the existing literature offers mixed results and scarce attention has been devoted to these key elements, as the bulk of works mainly regards the intra-industry effects of FDI. A limited number of studies, instead, investigate productivity effects by developing input-output analyses to account for inter-industry interactions between foreign MNEs and domestic companies (e.g. Javorcik, 2004). Nevertheless, in our investigation of innovative activities, rather than productivity, we depart from this approach and we directly focus on the sectoral features of the innovation process and its inter-industry interactions. Therefore, the present work aims at contributing to the academic debate by adopting an approach which explicitly concentrates on the inter-sectoral effects of FDI depending on the nature of innovation across different industries. A further original aspect of this article regards the data. We make use of provincial patent data as a measure of recipient locations' innovation performance while the literature mainly focuses on more traditional indicators, such as total factor productivity (TFP), or aggregate regional measures of innovation (e.g. Aghion et al., 2009; Antonietti et al., 2015; Ascani and Gagliardi, 2015; Cheung and Lin, 2004; Qu and Wei, 2017). Furthermore, we are able to distinguish 605 IPC technological classes in which patents are filed and to connect these to manufacturing sectors. We are also able to identify inward FDI by provinces and industries. Therefore, we can empirically link FDI to patent classes at the territorial level for the period 1999–2006, thus explicitly and systematically investigating which specific typologies of FDI can be considered as a relevant source of knowledge inputs and whether these heterogeneous effects are spatially-bounded. Not only are these original additions to the recent strand of literature connecting inward FDI and domestic innovation, but investigating the inter-industry role of FDI also allows to look into the composition of the aggregate effects that are usually detected in extant works.

2. Conceptual background

2.1. FDI as a sector-specific source of knowledge

Most studies on the relationship between FDI and host economies' performance entail that foreign MNEs exhibit technological advantages over domestic companies. As a consequence, inward FDI is generally considered to carry benefits to local firms, including novel technical skills, new organisational and managerial routines as well as the opportunity to access new and distant markets. In this respect, the seminal contribution by Hymer (1976/1960) suggests that MNEs must have certain advantages to operate overseas, considering that local companies are plausibly better informed about local demand and regulations than foreign actors. Therefore, MNEs become competitive within 'alien' contexts because they have developed firm-specific or ownership advantages before internationalisation (Dunning, 1980), among which the ability to develop new knowledge and technologies play a prominent role (Cantwell and Iammarino, 2003). Hence, corporate firm-specific advantages mainly occur in the form of knowledge-based assets that are embodied into firms' know-how (Markusen, 1995). On these premises, inward FDI can reasonably be a channel for the international diffusion of MNE-specific advantages to the benefit of domestic companies. Thus, the presence of MNEs within a territorial context could plausibly foster local innovative activities if MNEs' know-how represent a source of knowledge for domestic companies. In fact, the specific technological content of foreign activities represents a crucial factor in shaping the relationship between local innovativeness and foreign MNEs operations (Cantwell, 1989). Nevertheless, most existing empirical studies tend to consider FDI as a whole in technological terms, differentiating foreign engagement only on the basis of other characteristics such as national origin, mode of entry or economic motivation for investing abroad (see Barba Navaretti and Venables, 2004; Dunning and Lundan, 2008).

Recent empirical evidence on the case of Italy suggests that the linkage between greenfield FDI and local patenting activity is not statistically significant within the manufacturing sector as a whole (Antonietti et al., 2015). However this aggregate result can plausibly hide a more articulated set of relationships depending on the sectoral nature of the innovation process and the composition of inward FDI. Only a limited number of works explore the role of FDI technological heterogeneity more or less explicitly, although results remain extremely mixed. For instance, Castellani and Zanfei (2003) suggest that beneficial effects on domestic firms are present in most manufacturing sectors where the knowledge gap between foreign and domestic firms is large. Their argument implies that foreign investors carrying more sophisticated knowledge offer the largest opportunities for lagging-behind local economies in terms of technological upgrading. Nevertheless, Alvarez and Molero (2005) report that FDI induces larger beneficial effects in industries with low technological content and where the technological gap between domestic and foreign companies is more limited. On the contrary, Benfratello and Sembenelli (2006) do not detect any statistically significant difference between the effect of foreign ownership in high-technology versus low-technology sectors on domestic firms' productivity. For China, Hu and Jefferson (2002) show instead that FDI spillovers significantly differ across sectors. They find that while a 'market-stealing' effect prevails in the electronics sector, textile domestic firms seem to be unaffected by the presence of FDI. Moreover, in the long-run the negative effects observed in electronics tend to disappear, indicating that local firms need time to accrue the benefits of technology introduced by foreign firms.

In this literature, scant attention is devoted to the nature of the linkages connecting foreign MNEs to local innovative activity. Rather, the prevalent idea is that FDI in sectors in which more advanced technologies are adopted can generate substantial beneficial effects in terms of local innovativeness. In fact, hosting this type of FDI may imply a transfer of relevant MNE-specific advantages from the MNE headquarter to its foreign affiliates within the local economy through non-market internalisation mechanisms (Buckley and Casson, 2009).

However, it is unlikely that all MNEs carry the same type of knowledge assets with their investment, as the process of new knowledge generation and pace of technological change radically differ across economic sectors of activity (Klevorick et al., 1995; Castellacci, 2008 and 2009). At the same time, local economies are diverse in their production and knowledge structures, mostly depending on the regional industry mix and its technological antecedents (Cantwell and Iammarino, 2003). Taken together, these two dimensions of heterogeneity imply that a key filter in the relationship between FDI and local innovation pertains to the sectoral linkages that foreign MNEs can plausibly establish with the local industrial structure.

Therefore, specific manufacturing industries in which foreign MNEs invest can be particularly prone to produce knowledge assets that are adopted or are jointly developed with other sectors (Lau et al., 2010; Baldwin and von Hippel, 2011). In other words, if and to what extent FDI represents a source of knowledge inputs for local economies depend on the heterogeneous composition of inward FDI in terms of the nature of the innovation process within sectors. In this sense, the well-established sectoral categorisation of manufacturing industries elaborated by Pavitt (1984) provides a very useful conceptual framework to inspect which types of FDI can be a systematic source of knowledge inputs and/or a source of detrimental competition for local innovative activities. The literature on the trajectories of technical change and innovation (see Castellacci, 2008; Bogliacino and Pianta, 2016) has widely discussed and applied this categorisation of manufacturing activities in four groups, according to the nature of their innovation process: namely, (i) "Science based" industries, (ii) "Supplier dominated" industries, (iii) "Scale-intensive" industries and (iv) "Specialised supplier" industries.

(i) "Science based" industries, such as electronics and chemicals, tend to be characterised by large companies that innovate based on strong internal R&D investment. Their knowledge-base is complex and they also contribute to produce innovations in other industries. At the same time, "Science based" industries can also innovate based on the knowledge transfer from "Specialised suppliers" of specific equipment and machinery.
(ii) "Supplier dominated" industries, which include traditional sectors such as textiles and food products, represent the least technologically advanced segment of the manufacturing sector. Companies in these industries usually do not generate new knowledge internally, but mainly adopt innovations and technologies developed within sectors that provide them with equipment and machinery. Hence, these sectors generally depend on external technological trajectories to improve their internal production process.
(iii) "Scale-intensive" industries, such as automotive and plastics, are characterised by a rather complex knowledge-base and interdependent production system. They are fundamentally constituted of large companies exploiting economies of scale on the basis of strong organisational capabilities. These industries extensively interact with other branches of the manufacturing sector, by providing knowledge inputs to "Supplier dominated" industries, and innovating based on a combination of internal and external knowledge inputs. The latter mainly consists of specific capital goods and instruments from "Specialised supplier" industries, but also scientific advances from "Science-based" industries.
(iv) Finally, "Specialised supplier" industries, such as machinery and equipment, are fundamentally constituted of small and specialised companies. These tend to develop a relatively high proportion of their own innovation internally through engineering and design competences. Their technological trajectory also interacts with external actors in order to both complement their knowledge-base and supply external advanced users of technologies with equipment and machinery, including "Science based" and "Scale-intensive" industries.

Importantly for our purposes, a fundamental element of this taxonomy regards the focus on inter-sectoral relationships between a well-defined set of industrial groupings. This set of systemic linkages and interactions between firms in different industries is thought to provide the cornerstone of innovation and competitive advantage (Porter, 1990; Laursen and Meliciani, 2002).

In this framework, FDI-induced linkages across industries can be established in terms of technological collaborations and alliances between sectors (Broekel and Brachert, 2015), market transactions such as backward and forward relationships (Roper et al., 2008), user-producer interactions for the development of customised technologies that respond to user-specific needs (Baldwin and von Hippel, 2011; Laursen, 2011). MNEs may also need to directly upgrade the technical and managerial capabilities of their local suppliers in order to maintain a certain level of quality in production (Ernst and Kim, 2002). This can lead MNEs to play an active role in enhancing the knowledge capabilities of their vertically-linked local suppliers by offering technical support, introducing new technologies, training their labour force and upgrading their organisational and managerial skills (Crespo and Fontoura, 2007). Local innovative activity in the upstream sector can also be induced by more intense competition among local companies wishing to supply an MNE. Similarly, MNEs may make technology available to a wide number of suppliers in order to stimulate competition, lower the price of inputs and avoid situation of monopoly in the supplying sector (Blalock and Gertler, 2008). Inter-sectoral linkages can also feature MNEs as knowledge suppliers of local firms in downstream sectors. In these circumstances, as MNEs are supposed to produce more sophisticated goods than domestic suppliers, the innovative potential of domestic firms in downstream industries can be fostered whenever a specific input or intermediate good provided by MNEs require a technological improvement in the domestic production process (Crespo and Fontoura, 2007). Similarly, knowledge diffusion is reinforced by the technical support that foreign firms in upstream sectors provide to local customers with the aim of increasing their demand (Marcin, 2008).

While a parallel stream of literature on the effects of FDI on domestic productivity has investigated the role of vertical interactions, its focus is entirely centred around input-output linkages between MNEs and domestic companies (e.g. Javorcik, 2004; Rojec and Knell, 2018). Instead, we believe that, in order to understand the relationship between FDI and local innovative activity, a careful and dedicated consideration of the specific sources of knowledge inputs for specific sectoral innovation activities is needed. Previous research, however, has hardly adopted the lenses of this taxonomy to investigate the relationship between innovation and inward FDI, although other strands of literature clearly acknowledge that FDI can be a carrier of knowledge (see Iammarino and McCann, 2013). Most contributions at the industry level have, instead, adopted the taxonomy to investigate innovation and market share dynamics (Laursen and Meliciani, 2000), the location of industries (Heidenreich, 2009) and the sectoral patterns of innovation (Castellacci, 2009) among others. A relevant exception is represented by Resmini (2000), who applies the taxonomy of manufacturing sectors to study the determinants of FDI in Central and Eastern European Countries.

2.2. Spatial implications of inward FDI

Generally, evidence on the relationship between FDI and domestic performance remains mixed with studies often reaching opposite results (Rojec and Knell, 2018). Furthermore, while the literature offers important insights on the nuances of the relationship between FDI and domestic performance, some key aspects have received more limited attention, including the geographical dimension of the link between FDI and local innovation, especially when considering FDI as a source of sector-specific knowledge. One the one hand, incorporating a geographical perspective of analysis is relevant as most inter-sectoral linkages that are thought to mediate the relationship between FDI and local performance can transcend a single local economy. For instance, in the case of industries producing tradable goods, competition effects can operate at a larger scale than the local one. Similarly, the territorial impact of MNEs can vary along industrial and technological lines (Yeung and Coe, 2015). In this respect, the economic geography literature offers interesting conceptual insights. As far as the spatial nature of knowledge diffusion is concerned, there is wide consensus among scholars that distance decay effects play a remarkable role (Jaffe et al., 1993; Audretsch and Feldmann, 1996; Figueiredo et al., 2015), in contrast with statements about the death of distance associated with the sheer fall in communication costs worldwide (Cairncross, 1997). This entails that geography space poses a serious limit to knowledge diffusion (Iammarino and McCann, 2006). This can be due to the highly localised nature of the mechanisms of knowledge transmission discussed in the previous section, which can be both market- and non-market-mediated (Breschi and Lissoni, 2001). Recent evidence indeed indicates that FDI effects on domestic performance occur mainly at regional level (Crespo et al., 2009; Driffield, 2006; Girma and Wakelin, 2007; Wang and Wu, 2016). However potential effects can easily overcome the spatial boundaries of the local economy if, for instance, labour mobility or business interactions between foreign and domestic firms occur within larger spatial markets. Nonetheless, based on the notion that distance adversely affects knowledge diffusion, the inter-regional FDI-induced knowledge transfer should be limited to the closest neighbouring locations of those receiving inward FDI.

3. Data description

According to the combined availability of statistics, we consider a panel of 103 Italian provinces (NUTS3) for the period 1999-2006.

Innovation: following standard approaches we use the number of patent applications to the European Patent Office (EPO) counted according to the inventor's place of residence (Balland et al., 2018), normalised by provincial per capita GDP, as dependent variable. This measure allows to consider the innovativeness of researchers and laboratories located in each province[1] . Although patent data are not able to catch innovations that are not officially registered at EPO, the choice of using this proxy is justified by the fact the patents provide a direct measure of innovation output. In contrast, the commonly used TFP is just a "derived measure of technology, as it is computed from data on inputs and outputs" (Keller, 2004, p.758). Another limitation of our measure of innovation is that we cannot distinguish patents by foreign MNEs. Therefore, our analysis is not strictly on spillover effects, as some provincial patents can be filed by the foreign firms undertaking FDI. Nevertheless, we are also confident that by considering patents by inventor (rather than applicant) should slightly alleviate this concern by limiting this issue to a small number of provinces, given that MNEs tend to concentrate their patents in their headquarter locations. Our data contains information on 605 IPC classes at the provincial level that we link to 2-digits manufacturing sectors by means of the Eurostat concordance tables (Van Looy et al., 2014). Therefore, we obtain the number of patents by sector in each province. Considering our interest in spatial dynamics relating innovation and FDI, we explore provincial patent data by running a test for the existence of global and local spatial autocorrelation[2] . The Moran's I presented in the scatterplot in Fig. 1 is about 0.08, thus suggesting that there is no spatial dependency on average.

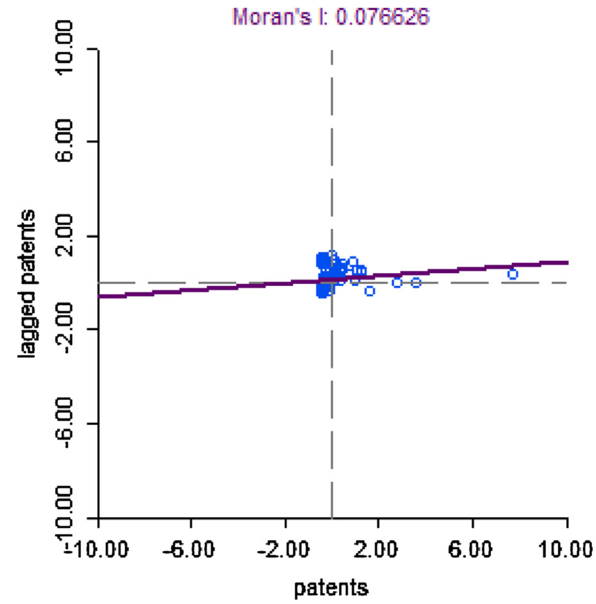

Fig. 1. Patent Moran's I scatterplot, 1999–2006.

However, testing for local spatial association (Anselin, 1995) reveals the existence of some hot- and cold-spots of clustered provinces. Fig. 2 shows the cluster map with the associated significance map for patent data over the time period considered. We notice that clusters of high patenting activity occur in Northern provinces, especially in the North-West. In the North, however, a notable group of provinces exhibits an innovation capacity below the average of their neighbours. The considerable number of such provinces can be due to the proximity to the province of Milan which notably raises the average number of patents in the area. As far as the South of Italy is concerned, the period under scrutiny is characterised by clusters of provinces with low innovative performance. Finally, the province of Rome is, not surprisingly, characterised by a high innovation capacity with neighbours with low patenting activity.

FDI: We employ a unique dataset concerning the inflow of FDI collected by the Bank of Italy for the national Balance of Payments. The dataset contains the amount of FDI for provinces and sectors. The majority of studies on the effects of FDI use proxies such as the number of foreign firms into the host economy, the volume of sales or the number of workers employed by foreign subsidiaries. Rather, we use a direct measure for FDI since we consider the amount of foreign capital flowing into each territorial unit of analysis. Nevertheless, considering that annual FDI flows can be subject to strong volatility, especially at a highly detailed territorial scale, such as the provincial one, we construct a stock measure by taking into account the last three years of inward FDI flows into each province. This amount of FDI in then normalised by provincial GDP and taken as logarithm.

We run a test to detect spatial autocorrelation for both periods as presented in the scatterplots of Fig. 3. The Moran's I indicates no spatial dependency on average.

At the local level, Figs. 4 suggests that Southern provinces form clusters of weak inward FDI. In the North, the map suggest the existence of a cluster of provinces with an FDI inflow below the average of their neighbours. Again, this may be due to the proximity of the province of Milan which receive a dramatically high amount of FDI when compared to neighbouring provinces.

[1] Instead, the number of patents counted according to the applicant's region does not consider the location where the invention takes place. In fact, it just measures the degree of control of regional actors on patents. As such, patents can be assigned to regions where firms have their headquarters regardless of the location of their research laboratories.

[2] The weight adopted for this test is a k-nearest neighbours weight where k is equal to 15.

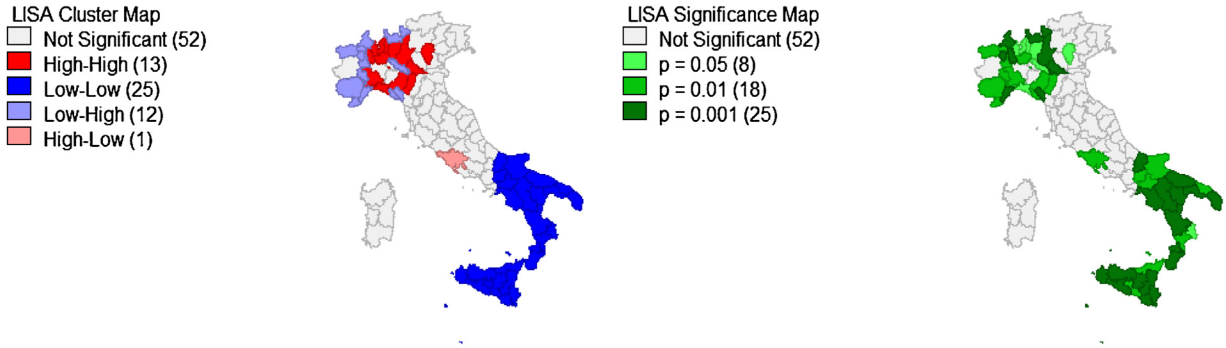

Fig. 2. Patent Local Indicator of Spatial Autocorrelation, 1999–2006.

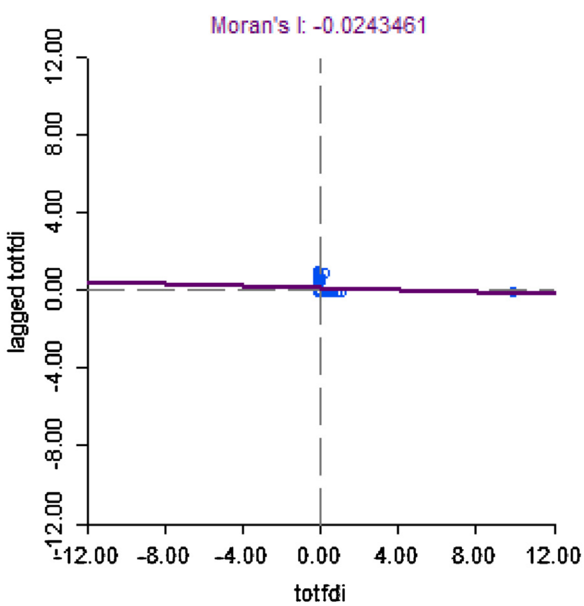

Fig. 3. FDI Moran's I scatterplot, 1999–2006.

With respect to the industrial sectors of inward FDI, our data includes information on 2-digits manufacturing sectors. We categorise these manufacturing sectors according to the revised Pavitt taxonomy of Bogliacino and Pianta (2016). Table 1 describes sectors and their categorisation.

Table 2 reports the top- and bottom-five provinces according to inward FDI by type of industry. Not surprisingly, across the various FDI typologies, the top-five destinations of FDI tend to be exclusively in the North of Italy, with the exception of Rome, while the bottom-five are concentrated in the Centre and South of the country.

Table 1
Categorisation of the manufacturing sectors of inward FDI.

Science based
Manufacture of office machinery and computers
Manufacure of chemicals and chemical products
Supplier dominated
Manufacture of food products, beverages and tobacco
Manufacture of textiles and textile products
Manufacture of leather and leather products
Manufacture of fabricated metal products, except machinery and equipment
Scale-intensive
Manufacture of pulp, paper and paper products
Manufacture of other non-metallic mineral products
Manufacture of basic metals
Manufacture of rubber and plastic products
Manufacture of coke, refined petroleum products and nuclear fuel
Manufacture of transport equipment
Specialised supplier
Manufacture of machinery and equipment
Manufacture of electrical equipment
Manufacture of other transport equipment

Source: adapted from Bogliacino and Pianta (2016)

Education: the level of human capital is expected to influence directly the productivity of workers and the capacity to innovate. In fact, educated workers are more likely to create new technology (Romer, 1990). Moreover, a higher level of education allows to adopt and implement domestically the innovation created abroad (Nelson and Phelps, 1966). In order to take into account this effect, we use information about tertiary education (ISCED 3–4) as provided by OECD for Italian regions (NUTS2). We weight this measure by provincial population.

R&D: we employ data from OECD on the total regional (NUTS2) expenditure in R&D activities. Such a variable is expected to have a positive impact on innovation since it represents the main input for technology creation (Keller, 2004) and it is directly connected with

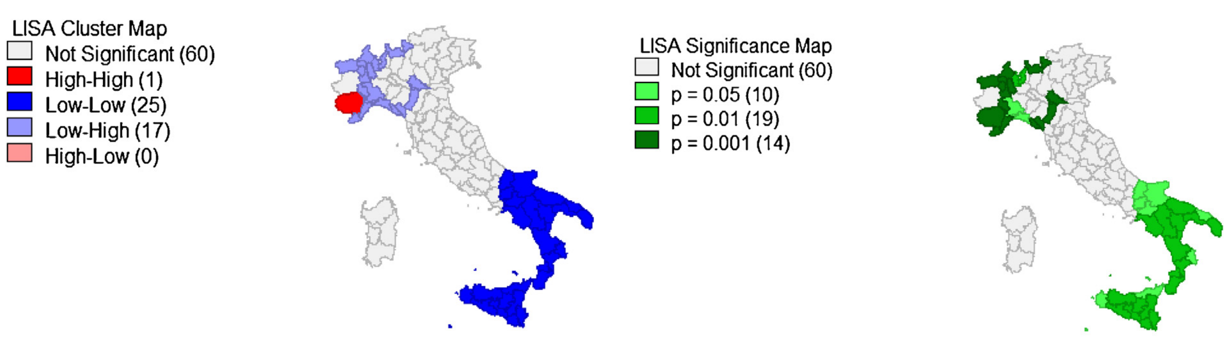

Fig. 4. FDI Local Indicator of Spatial Autocorrelation, 1999–2006.

Table 2
Top- and bottom-five provinces by different types of inward FDI, 1999-2006.

Rank	Science-Based	Supplier Dominated	Scale-Intensive	Specialised Supplier
1	Milan (Lombardy)	Milan (Lombardy)	Turin (Piedmont)	Milan (Lombardy)
2	Rome (Latium)	Rome (Latium)	Milan (Lombardy)	Florence (Tuscany)
3	Turin (Piedmont)	Bologna (Emilia-Romagna)	Terni (Umbria)	Bologna (Emilia-Romagna)
4	Treviso (Veneto)	Vicenza (Veneto)	Rome (Latium)	Rome (Latium)
5	Varese (Lombardy)	Cuneo (Piedmont)	Rovigo (Veneto)	Turin (Piedmont)
99	Oristano (Sardinia)	Rieti (Latium)	Isernia (Molise)	Enna (Sicily)
100	Agrigento (Sicily)	Enna (Sicily)	Caltanissetta (Sicily)	Vibo Valentia (Calabria)
101	Vibo Valentia (Calabria)	Catanzaro (Calabria)	Potenza (Balisicata)	Foggia (Apulia)
102	Catanzaro (Calabria)	Vibo Valentia (Calabria)	Agrigento (Sicily)	Agrigento (Sicily)
103	Potenza (Balisicata)	Oristano (Sardinia)	Enna (Sicily)	Oristano (Sardinia)

Notes: the name of the region (NUTS2) is reported in parentheses.

the regional innovative performance. We normalise this measure by provincial GDP.

Labour market: we use the provincial unemployment rate to consider the impact on innovation of the existence of individuals without recent work records. In fact, the persistence of the unemployed status plays a deteriorating role on the individual occupational profile and on the possibility to find new jobs (Gordon, 2001). As such, unemployment tends to reduce productivity and the innovation capacity of local economies. Data for unemployment is collected from the OECD.

Agglomeration: We use data on the number of registered companies in each province as a proxy for agglomeration forces. The presence of a larger number of firms can produce positive externalities that facilitate the diffusion of knowledge and local innovative activity, due to spatial proximity (Jacobs, 1969; Glaeser et al., 1992). Data on the number of registered companies is collected from ISTAT.

New firms per capita: We consider the number of new companies in a province on total population to proxy for the rate of investment at the territorial level. In fact, local innovative activity can also be fostered by new domestic firms, rather than foreign MNEs, and including this covariate should allow us to better disentangle the effect of FDI. Data is taken from ISTAT.

Exports and imports: We consider the openness of local economies also in terms of their trade linkages, by including the provincial logs of exports and imports in our empirical exercise. In fact, it is possible that this type of internationalisation, rather than FDI, generate novel opportunities for local innovation, through learning-by-exporting and learning-by-importing mechanisms (Salomon and Shaver, 2005; Vogel and Wagner, 2010). Data on both exports and imports comes from ISTAT.

FDI in neighbouring regions: We elaborate a matrix of weights **W** in order to consider spatial effects of FDI from one region to another, by calculating the following equation for every province:

$$\hat{m}_i(x) = \sum_j w_{ij} x_j = \mathrm{w'}_i \mathrm{x} \quad (1)$$

where $m_i(x)$ is the weighted average of the values of x in the provinces that are considered as spatial neighbours of province i, w_{ij} are the spatial weights that relate province i to all other provinces j, and x_j is the sequence of values of a variable in all provinces j. With respect to the present work, x is represented by FDI. As such, Eq. (1) represents one row in the spatial weighting matrix **W**. The notation for the whole vector of spatial averages is the following:

$$\hat{m} = Wx \quad (2)$$

We adopt a mixed method of determination of w_{ij} which takes into account both spatial proximity and contiguity between regions. First, we start by calculating different matrices of weights based on a k-nearest neighbours representation with k equal to 15, 10 and 5, so that:

$$w(i,j) = \begin{cases} 1 & \text{if} j \text{ is one of the k nearest neighbourstolocation} i \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

Therefore, relying on spatial proximity, the above-mentioned matrix of weight indicates that region i has k neighbour provinces with value equal to 1. However, such a representation does not necessarily imply that all bordering provinces of i are considered in k. Indeed, since the proximity between provinces is based on the distance between their geographical centres, some large bordering provinces of i are excluded from k because their centre is farther from the centre of i than that of a smaller province nearby, although the latter does not share any border with province i. Therefore, in order to consider also geographical contiguity we add to the number of provinces of i all provinces bordering i which were excluded from the k-nearest neighbours. With respect to the two island regions (NUTS2) of Italy, we consider that Sicily as bordering the mainland due to its proximity to Calabria. Therefore, provinces in Sicily can be neighbours of provinces in Calabria. We adopted, instead, a special arrangement for provinces in Sardinia. Some of the nearest neighbours of provinces in Sardinia are provinces in regions such as Liguria, Tuscany, Umbria and Latium, especially when considering larger values of k. We eliminated provinces in Umbria since it is a landlocked region in central Italy. Instead, the other three regions share the Tyrrhenian Sea with Sardinia. We base the choice of considering the Tyrrhenian Sea as a border between Sardinia and its neighbours not only in terms of geographical proximity but also because these regions host some of the largest Italian commercial ports in terms of Twenty-Foot Equivalent Units (TEU)[3] (Assoporti, 2010) and thus they are supposed to be well connected with Sardinia[4] .

The next step after the determination of w_{ij} is to normalise the spatial weights as follows:

$$\sum_j w_{ij} = 1 \quad (4)$$

By doing this, we obtain a sequence of normalised spatial weights where the value of each w_{ij} is:

$$w_{ij} = \frac{1}{k+l} \text{ if} j \text{ is aneighbour of} i \text{, 0otherwise} \quad (5)$$

where k is still the number of nearest neighbours and l is the number of provinces added on a contiguity basis. Hence, by pre-multiplying the whole matrix of normalised weights **W** by the vector **x** representing FDI in each province, we obtain a vector with the average

[3] This is a standard measure for the capacity of container terminals.

[4] This operation is not performed for values of k equal to 15, as with this larger spatial lag we consider that Umbria can plausibly be connected with Sardinia through other coastal regions.

Table 3
Provincial effect of inward FDI on local innovation.

	(1)	(2)	(3)	(4)	(5)	(6)
Dep Var: ln Patents						
Ln Patents$_{t-1}$	0.161***	0.140***	0.140***	0.140***	0.144***	0.534***
	(0.047)	(0.039)	(0.039)	(0.039)	(0.040)	(0.073)
FDI stock	0.026*	0.051***	0.050***	0.045***	0.059***	0.032**
	(0.015)	(0.014)	(0.015)	(0.015)	(0.015)	(0.016)
Tertiary education$_{t-1}$		0.259*	0.258*	0.259*	0.248*	0.025
		(0.153)	(0.154)	(0.153)	(0.153)	(0.125)
R&D expenditure$_{t-1}$		0.162**	0.160**	0.159**	0.168**	0.199***
		(0.077)	(0.078)	(0.077)	(0.077)	(0.066)
Unemployment rate$_{t-1}$		−5.009***	−5.027***	−5.057***	−5.041***	−8.052***
		(1.187)	(1.191)	(1.188)	(1.186)	(1.803)
Agglomeration		−0.070	−0.067	−0.077	−0.029	0.449*
		(0.471)	(0.472)	(0.471)	(0.471)	(0.255)
New firms p.c.		−0.018	−0.019	−0.016	−0.012	0.642*
		(0.143)	(0.143)	(0.143)	(0.143)	(0.342)
Exports		−0.032	−0.033	−0.036	−0.032	0.107
		(0.054)	(0.054)	(0.054)	(0.054)	(0.086)
Imports		0.057	0.057	0.055	0.059	0.025
		(0.044)	(0.044)	(0.044)	(0.044)	(0.155)
Neighbouring FDI stock (k = 15)			0.005			0.055
			(0.025)			(0.058)
Neighbouring FDI stock (k = 10)				0.019		
				(0.019)		
Neighbouring FDI stock (k = 5)					−0.020	
					(0.013)	
Observations	824	824	824	824	824	824
Number of provinces	103	103	103	103	103	103
R-squared	0.215	0.256	0.256	0.257	0.258	
Provincial Fixed Effects	YES	YES	YES	YES	YES	
Year dummies	YES	YES	YES	YES	YES	YES
Hansen test						101.47
AR(1)						−2.96***
AR(2)						0.45
Number of instruments						128

Notes: Standard errors in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

amount of FDI in neighbouring provinces for every single province. Finally, we use data about per capita GDP to normalise this measure.

The appendix contains both descriptive statistics and the correlation matrix.

4. Methodology

Our empirical model is based on an equation where a measure of innovation depends on an indicator of FDI into the host provincial economy, as customary in the literature. We estimate this relationship by exploiting the panel nature of our data, thus including provincial fixed effects, which should alleviate all concerns related to time-invariant unobserved heterogeneity at the provincial level. We also include time dummies in order to control for time-specific shocks affecting innovation. Hence, we specify the empirical model as follows:

$$Pat_{it} = \mu Pat_{it-1} + \beta x_{it} + Z\gamma_{it} + \vartheta Wx_{it} + \tau_t + p_i + \varepsilon_{it} \quad (6)$$

Where:

Pat_{it} is the logarithm of patent applications at EPO in province *i* as a share of provincial per capita GDP at time *t*;

x_{it} is the logarithm of the last 3-years stock of FDI received by province *i* as a share of provincial GDP at time *t*;

Z_{it} is a vector of covariates for province *i* at time *t-1*, including:

(i) the logarithm of people with tertiary education in province *i* on total provincial population at time *t-1*;
(ii) the logarithm of R&D total expenditure in province *i* as a share of provincial GDP at time *t-1*;
(iii) the unemployment rate of province *i* at time *t-1*;
(iv) the number of registered companies in province *i* at time *t* as a proxy for agglomeration;
(v) the number of new firms per capita in province *i* at time *t*, as a proxy for local investment.
(vi) the logarithm of exports of province *i* at time *t*.
(vii) the logarithm of imports of province *i* at time *t*.

Wx_{it} is the logarithm of the last 3-years stock of FDI received by the neighbouring provinces of province *i* as a percentage of neighbouring regions' GDP at time *t*;

τ_t is a set of time dummies;

p_i represents provincial fixed-effects;

ε_{it} is an error component.

The inclusion of the lagged dependent variable on the right-hand side of Eq. (6) reflects the fact that the innovation process is intrinsically incremental and cumulative in nature, whereby the development of new technology builds on previous knowledge in a persistent and path-dependent way (see Rosenberg, 1976; Malerba et al., 1997).

The spatial-x model in Eq. (6) is specified not only for FDI as whole, but also for the Pavitt categories of manufacturing sectors, as they are indicated in Table 1 above. With respect to spatial autocorrelation, controlling for fixed-effects should limit the impact of the dependency between the residuals of neighbour provinces. Moreover, the adoption of a spatial-x model reduces spatial dependency since this association is explicitly expressed as a relationship between the dependent variable of a province and the weighted average of the explanatory variables of its neighbours. In methodological terms, the provincial fixed-effects eliminate a substantial endogeneity bias associated with the time-invariant determinants of innovation. Hence, by alleviating the unobserved heterogeneity of provincial economies, our results can provide a clean picture of the relationship between the geography of inward FDI and the geography of innovation in Italy, thus clarifying whether any spatial linkage exists between these two dimensions and whether this relationship is heterogeneous across industrial activities. Moreover, in a robustness check we extend the empirical analysis to implement a dynamic panel regression, where the endogeneity of the lagged dependent variable in the right-hand side of Eq. (6) is accounted for and inward FDI are internally instrumented with multiple lags of inward FDI (Arellano and Bond, 1991).

5. Results and discussion

5.1. Baseline results for aggregate FDI

We start by considering a version of Eq. (6) that is limited to the inclusion of lagged innovation, inward FDI, time dummies and provincial fixed-effects. Column 1 of Table 3 shows that the stock of FDI within a region is positively and significantly associated with local innovation, even if only at the 10% level. Even with only one regressor, the adoption of the fixed-effects model with year dummies allows us explaining slightly more than 20% of the variation in provincial patenting activity, thus suggesting that a relatively large portion of new knowledge generation is associated with unobserved time-invariant local characteristics. Therefore, controlling for these omitted determinants of provincial innovation with fixed-effects is important to clean our estimate of β in Eq. (6) and alleviate potential estimation biases. Also, as expected in consideration of the very nature of the innovation process, past values of patenting activity are strongly associated with current realisations of the dependent variable. In Column 2, we extend our model to the inclusion of the traditional factors influencing local innovativeness. The coefficient on FDI stock remains rather stable in terms of sign and magnitude, but it is more precisely estimated, thus gaining statistical significance. The inclusion of these covariates reveals that provincial innovation is positively and significantly associated with education and local R&D expenditure, as widely accepted in the existing literature (Freeman, 1982), and negatively related to the unemployment rate, thus suggesting that local economies with more rigid labour markets are less prone to innovate. The number of companies within provinces, as a proxy for local agglomeration, as well as the number of new firms per capita, capturing the investment level of local economies, do not exhibit any statistically significant association with patenting activity. Similarly, the coefficients related to the internationalisation of provinces through exporting and importing linkages remain insignificant.

These baseline results tend to be in line with the idea that foreign MNEs can foster local innovative activity, as well as with existing works identifying a positive spillover effect induced by inward FDI (e.g. Haskel et al., 2007). This may suggest that once foreign MNEs undertake an investment within Italian provinces they transfer specific knowledge resources to local incumbent firms, along the lines discussed in the conceptual section above. In Columns 3–5 of Table 3, we present the results for the estimation of the full version of Eq. (6), where the spatial lags of FDI stock alternatively consider a varying number of neighbours k, as explained in the data section. Hence, these results provide a first test for the potential spatial implications of FDI. In these set of regressions, results remain in line with previous specifications, as far as the relationship between aggregate FDI and local innovation is concerned. Nevertheless, this relationship does not seem to transcend the administrative boundaries of provincial economies, as evidenced by the statistically insignificant coefficients on the spatial lags of FDI stock, irrespective of the definition of the spatial weights in Eq. (3). This latter finding confirms previous evidence showing the highly localised nature of FDI effects (e.g. Crespo et al., 2009; Driffield, 2006; Girma and Wakelin, 2007).

Column 6, finally, reports the estimates for the dynamic panel regression explained in the previous section, where we consider inward FDI as an endogenous variable internally instrumented with lagged levels. The coefficient on inward FDI remains very stable, thus suggesting that controlling for provincial fixed-effects in the previous estimates provides a reliable picture of the relationship between innovation and FDI. As expected, the coefficient on lagged patents is larger in the dynamic panel regression as compared to the fixed-effects regression, as the latter produces a lower bound estimate (Arellano and Bond, 1991). The main difference between column 6 and the fixed-effects regressions regard the education level of provinces, which turns to be insignificant. Previous works on patenting activity in the Italian case have also identified insignificant effects related to education variables (e.g. Crescenzi et al., 2013). This is often motivated in terms of the substantial mismatch between high educational attainment of workers and their actual occupational profile, especially in the South (Iammarino and Marinelli, 2011). Also, the dynamic panel specification shows that agglomeration forces and the creation of new companies in a province are weakly associated with local innovation. In terms of diagnostics of the dynamic panel model, the tests for first- and second-order autocorrelation of the residuals reject the hypothesis that the errors are serially correlated. Also, the Hansen test for the null hypothesis that the over-identifying restrictions are valid is not rejected.

Based on this preliminary set of estimations where FDI is treated as an aggregate flow, results are in line with previous studies. Nevertheless, we cannot find any evidence on spatial effects since the geographical extent of the positive association between FDI and innovation remains limited within each provincial economy. Also, we do not find any negative significant link between foreign MNE activities and local innovation in aggregate.

5.2. Inter-sectoral FDI effects

Next we turn to considering the inter-sectoral effects of FDI by grouping inward FDI by province in the four categories discussed above: namely, “Science-based”, “Supplier dominated”, “Scale-intensive” and “Specialised supplier” sectors. We also exploit the information on patent IPC classes by linking them to manufacturing industries as previously explained. This allows generating a sector-specific measure of innovation. Finally, we categorise such a sector-specific innovation indicator into the same types of Pavitt sectors. We employ this disaggregation to re-estimate Eq. (6) by regressing sector-specific patents on FDI stocks unpacked according to the Pavitt taxonomy. We also include the spatial lags of FDI stocks, categorised on the same criteria. However, at this more disaggregate level, we are forced to include the most geographically wide definition of lag (i.e. $k = 15$), as more limited lags of FDI exhibit high collinearity with provincial FDI. Results for the estimation of Eq. (6) according to these amendments are presented in Table 4. The different specifications are associated with dependent variables that alternatively consider patents in the different Pavitt categories of manufacturing sectors. Results suggest that once FDI heterogeneity is taken into account, in terms of the sectoral nature of new knowledge generation across manufacturing industries, the relationship with local innovative performance becomes more articulated than highlighted in the aggregate results above and in most existing studies. This is in line with the expectations that the nature of the innovation process differs across sectors and that the effect of FDI depends on the inter-industry linkages through which technology is produced and used.

Inward FDI in “Science-based” sectors contributes to innovation within the local “Science-based” realm, thus suggesting the exis-

Table 4
Inward FDI by Pavitt (1984)'s sector category, panel fixed effects estimates.

Dep Var: ln Patents	(1) Science Based	(2) Supplier Dominated	(3) Scale-Intensive	(4) Specialised Supplier
Ln Patents$_{t-1}$	0.524***	0.097	0.407***	0.516***
	(0.155)	(0.086)	(0.087)	(0.163)
SciBas FDI stock	0.007***	0.002	0.005***	0.004
	(0.0026)	(0.0015)	(0.001)	(0.003)
SupDom FDI stock	0.014	−0.036*	0.010	−0.014
	(0.017)	(0.019)	(0.010)	(0.018)
ScaInt FDI stock	−0.018	−0.046*	−0.023**	−0.033*
	(0.018)	(0.026)	(0.010)	(0.019)
SpeSup FDI stock	−0.008	0.010	0.002	0.096**
	(0.015)	(0.009)	(0.009)	(0.046)
SciBas Neighbouring FDI stock (k = 15)	0.028	0.027	−0.003	0.080
	(0.048)	(0.027)	(0.027)	(0.051)
SupDom Neighbouring FDI stock (k = 15)	0.026	−0.004	−0.001	0.027
	(0.034)	(0.009)	(0.019)	(0.036)
ScaInt Neighbouring FDI stock (k = 15)	−0.055	−0.014	−0.013	−0.033
	(0.047)	(0.010)	(0.028)	(0.050)
SpeSup Neighbouring FDI stock (k = 15)	−0.040	−0.032	0.004	0.015
	(0.044)	(0.024)	(0.025)	(0.016)
Tertiary education$_{t-1}$	1.023*	0.544*	0.832***	0.610
	(0.570)	(0.316)	(0.321)	(0.599)
Unemployment rate$_{t-1}$	−3.820	4.124	4.661*	−12.376**
	(4.943)	(2.739)	(2.786)	(5.195)
R&D expenditure$_{t-1}$	0.629**	0.196	0.131	0.492*
	(0.287)	(0.160)	(0.163)	(0.293)
Agglomeration	0.853	−0.077	0.588	0.949
	(1.823)	(1.012)	(1.030	(1.920)
New firms p.c.	0.906*	−0.045	0.208	−0.018
	(0.551)	(0.306)	(0.310)	(0.579)
Exports	0.352*	0.006	0.139	−0.117
	(0.212)	(0.117)	(0.119)	(0.222)
Imports	0.138	−0.111	−0.080	0.093
	(0.165)	(0.091)	(0.930)	(0.174)
Observations	824	824	824	824
Number of provinces	103	103	103	103
R-squared	0.080	0.089	0.137	0.121
Provincial Fixed Effects	YES	YES	YES	YES
Year dummies	YES	YES	YES	YES

Notes: Standard errors in parentheses. Significance levels: *** p < 0.01, ** p < 0.05, * p < 0.1.

tence of an intra-industry mechanism in this case, through which foreign MNEs in this type of activities can stimulate local incumbents within the same sectors.This positive relationship remains highly localised, as FDI in "Science-based" within neighbouring economies does not exhibit a significant coefficient (Column 1). Inward FDI in "Science-based" sectors also benefit innovation within "Scale-Intensive manufacturing industries. In other words, inward FDI in industries with a strong scientific knowledge-base can support local innovative activity in industries based on large and complex organisations exploiting economies of scale, such as automotive and plastics. This finding is in line with the insight derived from the Pavitt taxonomy that the inter-sectoral linkage between these two types of industries is rather relevant. In fact, the innovation process within "Scale-intensive" industries is often underpinned by "Science-based" activities providing key knowledge advances for the development of new technologies (Pavitt, 1984).

With respect to FDI in "Supplier dominated" manufacturing activities, this typology of foreign knowledge source cannot provide neither intra-sectoral nor inter-sectoral knowledge inputs, according to the taxonomy of sectors adopted here. In fact, these traditional activities tend to rely on external knowledge sources, mainly embodied in machinery and equipment coming from other sectors (Pavitt, 1984). In line with this argument, we do not detect significant coefficients on inward "Supplier dominated" FDI, with the only exception of a weak negative relationship in Column 2, with the provincial innovation performance in "Supplied dominated" activities. We interpret this negative relationship in the light of the possible detrimental effects of competing FDI envisaged in the literature (Aitken and Harrison, 1999). The same type of result emerges for "Scale-intensive" inward FDI, with the crucial difference that the many inter-sectoral linkages of the activities categorised in this group represent a transmission channel of competitive dynamics also in "Supplier dominated" and "Specialised supplier" sectors. Therefore, inward FDI in a sector exhibiting strong interconnections with other branches of manufacturing could also have negative implications in a wider set of industrial activities.

For instance, when a foreign MNE operating in a "Scale-intensive" industry enters a provincial economy by acquiring a pre-existing company, local "Specialised suppliers" can experience a decrease in the intensity of the linkages and the technological collaborations with the new foreign ownership of the "Scale-intensive" company if the latter starts relying on international suppliers via its global production chains. This could be very much the case of MNEs operating in "Scale intensive" industries in consideration of their complex global organisation, which may push them to exploit internal economies of scale via global vertical integration, rather than relying on local partners for technology development and supply chains. This mechanism echoes the notion of *enclave* foreign MNEs, suggested in some previous studies (Rodriguez-Clare, 1996; Iammarino et al., 2008; Phelps et al., 2015). Interestingly, the negative association between "Scale-intensive" FDI and the innovation performance of other sectors is limited within provinces, thus indicating that wider possible detrimental effects of these foreign activities are limited by geographical distance. Finally, "Specialised

Table 5
Inward FDI in the North of Italy by Pavitt (1984)'s sector category, panel fixed effects estimates.

Dep Var: ln Patents	(1) Science Based	(2) Supplier Dominated	(3) Scale-Intensive	(4) Specialised Supplier
Ln Patents$_{t-1}$	0.0108*	0.001	1.009***	0.061
	(0.545)	(0.075)	(0.355)	(0.525)
SciBas FDI stock	0.008**	0.001	0.005**	0.006**
	(0.003)	(0.002)	(0.002)	(0.003)
SupDom FDI stock	−0.011	−0.046	−0.148*	0.065
	(0.042)	(0.030)	(0.085)	(0.048)
ScaInt FDI stock	−0.016	−0.037*	−0.005	−0.045
	(0.033)	(0.020)	(0.022)	(0.029)
SpeSup FDI stock	−0.032	0.016	0.042**	0.029**
	(0.031)	(0.022)	(0.021)	(0.014)
SciBas Neighbouring FDI stock (k = 15)	0.153	0.154	0.150	0.072**
	(0.174)	(0.123)	(0.159)	(0.029)
SupDom Neighbouring FDI stock (k = 15)	−0.103	0.019	0.106	−0.066
	(0.125)	(0.088)	(0.118)	(0.114)
ScaInt Neighbouring FDI stock (k = 15)	−0.048	−0.218*	−0.049	0.034
	(0.090)	(0.127)	(0.087)	(0.116)
SpeSup Neighbouring FDI stock (k = 15)	−0.185	−0.008	−0.138	−0.083
	(0.133)	(0.095)	(0.091)	(0.122)
Tertiary education$_{t-1}$	0.511	1.409	0.620	0.814
	(1.847)	(1.313)	(1.255)	(1.683)
Unemployment rate$_{t-1}$	−12.112	−3.564	24.95	−88.90**
	(40.62)	(28.66)	(27.53)	(36.90)
R&D expenditure$_{t-1}$	0.924*	0.352	0.360	0.014
	(0.487)	(0.386)	(0.372)	(0.505)
Agglomeration	−0.231	0.128	0.003	−6.760
	(4.739)	(3.341)	(0.015)	(4.285)
New firms p.c.	−1.351	−0.664	−3.078	−1.167
	(1.333)	(0.942)	(3.192)	(1.213)
Exports	0.053	0.206	0.101	0.480
	(0.624)	(0.441)	(0.427)	(0.569)
Imports	−0.432	−0.206	−0.192	−0.370
	(0.630)	(0.443)	(0.429)	(0.572)
Observations	296	296	296	296
Number of provinces	37	37	37	37
R-squared	0.197	0.134	0.228	0.148
Provincial Fixed Effects	YES	YES	YES	YES
Year dummies	YES	YES	YES	YES

Notes: Standard errors in parentheses. Significance levels: *** p < 0.01, ** p < 0.05, * p < 0.1.

supplier" FDI is positively associated with innovation within the same typology of sectors, suggesting that local incumbents can learn from foreign MNEs in sectors where machinery, instruments and specific equipment represent the core business activity (Column 4). In this sense, it is surprising that "Specialised supplier" FDI does not affect innovation in other industries, considering the strong vertical orientation of companies in this type of economic activity. Other interesting aspects regard the (weakly) significant coefficients of exports and the creation of new firms for the innovation activities in "Science based" industries. Hence, this sector may be particularly stimulated by the internationalisation of local companies and by a high rate of local investment. In line with previous studies, moreover, R&D expenditure is also very relevant for innovation in both "Science based" and "Specialised supplier" sectors, which in fact heavily rely on this type of knowledge input for their internal process of innovation.

Taken together, these results suggest that the relationship between inward FDI and local innovative performance is crucially dependent on the heterogeneous nature of the innovation process within the manufacturing sectors where foreign MNEs invest. Therefore, behind the simple positive association estimated by employing the aggregate figure of FDI in the baseline analysis, we uncover a plethora of linkages between inward FDI and local innovativeness with different signs and implications. This adds an original and informative analytical perspective to the existing literature on the effects of FDI, which has generally overlooked this dimension.

5.3. FDI heterogeneity and the Italian economic geography

Finally, we extend our empirical study of FDI heterogeneity to considering the dichotomy of the Italian economic geography, thus exploring whether the relationship under analysis varies according to the location of FDI. It is well-known that the North of Italy represents the economic engine of the national economic system and that most manufacturing activities are located in this area of the peninsula (Aiello and Cardamone, 2012; Giunta et al., 2012). On average, instead, the Centre and South of Italy tend to be less economically dynamic, even if there are notable exceptions.

For our purposes, we geographically split our sample between the North and the rest of Italy[5] and re-run Eq. (6) by considering the role of FDI heterogeneity within these different areas. We expect that the effects detected in the results of Table 4 could be more pronounced in the North rather than the rest of the country, due to the more solid structure of the economy in this wide geographical area. This would be the case if the inter-sectoral linkages between the various Pavitt categories of manufacturing industries are more consolidated and frequent in Northern provinces as compared to the other areas.

In terms of the signs of the relationships, we do not have an *a-priori* expectation on whether one specific area of the country can systematically experience positive or negative FDI-induced effects

[5] We consider provinces in the following regions (NUTS2) as part of the North: Valle d'Aosta, Piedmont, Liguria, Lombardy, Veneto, Trentino Alto Adige, Friuli Venezia Giulia and Emilia Romagna.

Table 6
Inward FDI in the Centre-South of Italy by Pavitt (1984)'s sector category, panel fixed effects.

Dep Var: ln Patents	(1) Science Based	(2) Supplier Dominated	(3) Scale-Intensive	(4) Specialised Supplier
Ln patents$_{t-1}$	0.482**	0.0411	0.341***	0.470**
	(0.211)	(0.0530)	(0.088)	(0.203)
SciBas FDI stock	0.0259*	0.002	0.024***	0.0102
	(0.0156)	(0.002)	(0.006)	(0.0157)
SupDom FDI stock	0.008	0.006	0.0143	−0.010
	(0.032)	(0.009)	(0.0130)	(0.013)
ScaInt FDI stock	0.0255	−0.063**	−0.026	−0.037
	(0.043)	(0.029)	(0.018)	(0.041)
SpeSup FDI stock	−0.017	0.028	−0.003	0.057**
	(0.034)	(0.031)	(0.013)	(0.026)
SciBas Neighbouring FDI stock (k = 15)	0.075	−0.004	0.0201	0.113
	(0.100)	(0.025)	(0.039)	(0.092)
SupDom Neighbouring FDI stock (k = 15)	−0.022	−0.001	−0.019	0.068
	(0.079)	(0.019)	(0.034)	(0.101)
ScaInt Neighbouring FDI stock (k = 15)	0.027	−0.016*	−0.032	−0.144
	(0.102)	(0.008)	(0.047)	(0.0.99)
SpeSup Neighbouring FDI stock (k = 15)	0.111	0.015	0.001	0.060**
	(0.110)	(0.033)	(0.041)	(0.025)
Tertiary education$_{t-1}$	0.981	0.311	1.451***	−0.901
	(0.940)	(0.278)	(0.392)	(0.912)
Unemployment rate$_{t-1}$	−8.591	−2.123	1.118	−19.21**
	(8.444)	(2.029)	(3.297)	(8.868)
R&D expenditure$_{t-1}$	0.949*	0.112	−0.301	0.570
	(0.503)	(0.123)	(0.249)	(0.590)
Agglomeration	4.572	−1.598	5.543	0.225
	(4.286)	(1.936)	(4.280)	(1.250)
New firms p.c.	0.477	0.226	0.057	0.413
	(0.992)	(0.447)	(0.986)	(0.289)
Exports	0.640*	0.179	−0.426	0.119
	(0.360)	(0.161)	(0.354)	(0.104)
Imports	0.534**	0.008	0.228	0.117*
	(0.231)	(0.102)	(0.225)	(0.066)
Observations	528	528	528	528
Number of provinces	66	66	66	66
R-squared	0.206	0.151	0.263	0.203
Provincial Fixed Effects	YES	YES	YES	YES
Year dummies	YES	YES	YES	YES

Notes: Standard errors in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

as compared to the other. On the one hand, the strength on the Northern economy, as compared to the rest of Italy, could provide more opportunities to local incumbents to take advantage of inward FDI. On the other hand, the entry of foreign MNEs in this part of the country could generate higher competitive pressures than those produced in the Centre-South of Italy, thus penalising local firms more.

Table 5 and 6 present the estimation results for the North and the Centre-South of Italy, respectively. What emerges from Table 5 seems to generally drive the results at the national level, as innovation in Northern provinces seems to respond to inward FDI heterogeneity in line with the nation-wide estimates of Table 4. The main differences first regard a larger positive role for "Specialised supplier" inward FDI (columns 3 and 4). The inter-sectoral linkages between foreign suppliers of machinery and equipment and local innovation in large companies based on the exploitation of scale economies is consistent with the predictions of the Pavitt taxonomy that the technological trajectory of "Scale intensive" industries crucially depends on the knowledge inputs provided by "Specialised suppliers". This pattern is more evident in the Northern Italian provinces as a result of the strongest and more dynamic inter-sectoral ties of this area of the country. A second relevant difference with the national results is that, we detect some spatial implications of "Science-based" FDI that have not emerged in the previous analysis Not only this FDI seems to benefit "Specialised supplier" innovation activity within each province, but the inter-sectoral linkage between these two branches of manufacturing transcends local administrative boundaries. This implies that foreign MNEs operating in sectors generating scientific advances, which can be used by vertically-connected specialised firms producing specific instruments and machinery, may establish connections in a larger geographical area than the provincial economy.

As far as inward FDI in the Centre-South of Italy is concerned, Table 6 shows that the inter-sectoral linkages within this broad area do not produce the same variety of relationships between FDI and local innovation observed before.

The positive scope of "Science-Based" FDI remains more limited than in the North as well as that of FDI in "Specialised Supplier" sectors. The latter, however, embodies some beneficial spatial effects on innovation within the same typology of sectors (Column 4). Nevertheless, the relatively strong competitive pressures of FDI in "Scale-intensive" activities detected in previous regressions are also present in the Centre-South of Italy. Interestingly, local innovation in the Centre and South of Italy seems to be related also to other international linkages than FDI. Import and export activities, in fact, may be relevant channels for innovation in "Science based" and, to a lesser extent, "Specialised supplier" industries, according to our results. This may be the case if local sources of knowledge inputs for this type of patent classes are weak or if the inter-sectoral linkages in the local economy are not entirely functional to the local transmission of knowledge.

This set of results suggest that while the main relationships emerging from the nation-wide estimates are persistent when the split between North and Centre-South is implemented, some differences emerge. In fact, the inter-sectoral linkages of the Northern economy provide more opportunities for knowledge transfer across

Table A1
Descriptive Statistics.

Variable	Obs	Mean	Std. Dev.
FDI stock	824	13.538	2.599
Neighbouring FDI stock (k = 15)	824	0.636	2.239
Neighbouring FDI stock (k = 10)	824	0.627	2.321
Neighbouring FDI stock (k = 5)	824	0.727	2.236
Tertiary education$_{t-1}$	824	−1.293	0.651
Unemployment rate$_{t-1}$	824	0.036	.023
R&D expenditure$_{t-1}$	824	−2.653	1.162
Agglomeration	824	10.41	0.746
New firms p.c.	824	−5.07	0.203
Exports	824	20.85	1.478
Imports	824	20.74	1.383

different categories of manufacturing activity as compared to other areas in the country. Consistently, the Northern regions are typically considered as being characterised by denser configuration of inter-organisational connections than the rest of the country, for historical and institutional reasons, and this has favoured the emergence of a path-dependent and systemic set of economic networks through which new knowledge is generated and easily transferred (Iammarino, 2005). On the contrary, the detrimental competition generated by foreign FDI tends to remain relevant across the country.

6. Conclusions

This article investigated the relationship between inward FDI and the innovative capacity of Italian provinces (NUTS3), by building on and expanding recent empirical evidence on the case of Italy (e.g. Antonietti et al., 2015; Ascani and Gagliardi, 2015). Combining data on different patent classes with FDI, our contribution to the academic debate stands in the investigation of the inter-sectoral linkages through which FDI can affect local innovative activity. These linkages fundamentally pertain to the nature of the innovation process and the technological trajectories characterising different manufacturing industries and their interactions. In this perspective, we also considered the spatial dimension of the relationship between FDI and local innovation, by evaluating whether the inter-sectoral linkages under analysis go beyond single local economies. Baseline regression results suggested that while FDI and local innovation are generally characterised by a positive and statistically strong correlation, this relationship does not transcend local administrative boundaries on aggregate.

Nevertheless, the articulated nature of the relationship under analysis strongly emerged once FDI is broken down according to the Pavitt taxonomy of manufacturing sectors. This adds a key layer of complexity to an academic debate that has often underestimated these aspects, and allows us to go beyond aggregate estimates and reveal a mosaic of relationships between inward FDI and local innovation that has not emerged in other studies. Consistently, our results suggest that some of the superior knowledge that constitutes the advantage of MNEs may diffuse to local actors and enhances their innovative capacity only for some specific typologies of inward FDI, such as that in “Science-based” sectors and to a lesser extent in “Specialised supplier” activities. These, in fact, represent the branches of manufacturing that can provide knowledge inputs to other sectors via inter-industry linkages. Nevertheless, inward FDI in different sectors can produce, instead, possible negative outcomes in terms of local innovation, as in the case of FDI in “Scale-Intensive” activities, where the presence of foreign MNEs seemed particularly penalising for local knowledge generation. This also has spatial implications that have not emerged in the aggregate analysis. The focus on inter-sectoral linkages also suggests that innovation in specific sectors, such as traditional “Supplier dominated” activities, that more heavily rely on external knowledge inputs, may more frequently be penalised by inward FDI.

In terms of policy considerations, our results suggest that strategies to attract FDI may promote economic development in terms of the innovativeness of the local economy. However, inward FDI is not beneficial *per se*. Indeed, the differentiated effect of FDI on innovation across sectors and their interactions implies that not all investments benefit the host economy. Hence, tailor-made policies to attract FDI in “Science-based” or “Specialised Supplier” sectors can be justified in terms of the potential benefits produced by such foreign activities. Therefore, identifying the heterogeneous composition of FDI is a crucial step to design effective industrial and regional policies that embody FDI attraction measures. Furthermore, the (limited) evidence in favour of inter-provincial FDI effects is relevant as this can suggest that FDI-induced benefits and costs have a relatively wider impact in geographical terms. This evidence should help preventing wasteful strategies of FDI attraction that generate detrimental inter-regional competition dynamics (Rodriguez-Pose and Arbix, 2001). Hence, a suitable regional and industrial strategy for FDI attraction should focus on the dedicated promotion of FDI in the activities that can provide other sectors with knowledge inputs for local innovation. This should be accompanied by measures aimed at reinforcing the inter-sectoral linkages between different typologies of sectors. In particular, traditional “Supplier dominated” sectors, that in the Italian economy are important, especially in some specific geographical areas of the country, should be supported in terms of the generation of linkages with industries that more likely generate knowledge inputs or develop technologies that can be adopted in their production process.

These results open two main future lines of research. First, it is important to go beyond the connection between different types of FDI and patent intensity and focus on the direction of technological change (Balland et al., 2018). A key issue for future research is to understand how FDI can be a way for regions to jump into new technological areas and re-structure their economy (Alshamsi et al., 2018; Uhlbach et al., 2017). Second, future analyses need to

Table A2
Correlation matrix.

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1)	FDI stock	1										
(2)	Neighbouring FDI stock (k = 15)	0.61	1									
(3)	Neighbouring FDI stock (k = 10)	0.67	0.82	1								
(4)	Neighbouring FDI stock (k = 5)	0.58	0.79	0.89	1							
(5)	Tertiary education$_{t-1}$	0.72	0.36	0.41	0.37	1						
(6)	Unemployment rate$_{t-1}$	−0.67	−0.59	−0.62	−0.60	−0.34	1					
(7)	R&D expenditure$_{t-1}$	0.59	0.47	0.45	0.44	0.61	−0.20	1				
(8)	Agglomeration	0.23	−0.37	−0.30	−0.37	0.21	−0.07	−0.34	1			
(9)	New firms p.c.	0.41	0.28	0.37	0.39	0.31	−0.44	0.07	0.24	1		
(10)	Exports	0.58	0.14	0.20	0.14	0.30	−0.63	−0.03	0.62	0.38	1	
(11)	Imports	0.53	0.02	0.10	0.04	0.33	−0.47	−0.04	0.70	0.30	0.89	1

investigate how FDI impact spatial disparities. In a global context in which economic inequality between and within regions is growing, it is key to understand from a policy perspective to what extent FDI foster or reduce the gap between and within regions.

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Contributors

A. Ascani and PA Balland built the dataset and wrote Section 3 of the manuscript. A.Ascani carried out the statistical analysis and wrote Sections 2, 4 and 5 of the manuscript. A. Morrison and A. Ascani wrote Sections 1 and 6. A. Ascani conceived the idea of the study. All three authors designed the study, reviewed, and approved the manuscript.

Appendix A

Table A1 and A2,

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