Regional innovation, RD and knowledge spillovers

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1. Regional innovation, R&D and knowledge spillovers: the role played by geographical and non-geographical factors

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1.1 INTRODUCTION

Debates regarding the role played by innovation in driving changes in economic geography, and, conversely, the role played by geography in shaping innovation processes, are multidimensional and varied in nature. Any comprehensive analysis of these interrelationships is likely to include discussions of issues such as the formation of clusters and agglomerations, the role of different types of firms ranging from small and medium-sized enterprises (SMEs) through to multinationals, and the role played by different types of knowledge-related institutions, including private research and development (R&D) centres, universities and research institutes. One of the issues for which there is overwhelming evidence is that R&D is related to productivity (Ortega-Argilés and Brandsma, 2010; Ortega-Argilés et al., 2010, 2011, 2015a, 2015b; Ortega-Argilés, 2012a, 2012b) via a mechanism in which R&D fosters innovation, which itself then drives productivity. However, exactly how these mechanisms relate to geography is far from straightforward.

In economic geography and urban economics there is often a tendency to assume certain types of relationships and mechanisms, and then to develop analytical arguments on the basis of these assumptions, rather than testing the assumptions themselves. For instance, innovation is often assumed to be a key driver of city growth via the positive impact that external knowledge spillovers have on a firm's competitive behaviour, while the existence of such local external knowledge spillovers is often simply assumed. Indeed, the idea that observations of agglomeration-type behaviour are themselves reflective of the existence of local knowledge spillovers is a widespread notion underlying many different models and empirical exercises, even though in many cases there is little or no independent evidence to support such a claim. The result is that the role played by cities in fostering innovation, and the role of innovation in shaping spatial behaviour and in driving city growth, tends to be treated as synonymous with knowledge spillovers. In other words, the existence of innovation processes is treated as being largely equivalent to the existence of local knowledge spillovers, which themselves are assumed to exist locally due to observed processes of local urban growth. Yet, if indeed innovation, knowledge spillovers and clustering are largely synonymous with each other, as urban economists in particular are fond of suggesting, then much of the vast literature on the economics of knowledge technology and innovation appears redundant. We argue that this is not the case, but appears so because of the circularity of the urban economic logic: by avoiding many of the complex issues raised by the non-spatial literature, this logic is ultimately of little help in furthering our understanding of local development processes.

When the relationship between innovation and geography are being discussed, rather than assuming generic patterns it should be the conditions under which innovation, knowledge spillovers and clustering do (or do not) co-exist and are (or are not) consistent with each other that are the point of departure. From this perspective, the vast non-spatial literature on the economics of knowledge, technology and innovation is neither redundant nor superfluous. On the contrary, this literature is essential in order to develop a reasonable and realistic way of understanding these relationships. In particular, while the wider debates as to exactly how innovation shapes geography via market transactions (McCann 2007) or the institutional settings (Shearmur, 2011; Barca et al., 2012) often remains somewhat clouded due to often rather heroic assumptions that underpin the different geographical approaches, a detailed examination of how the non-spatial literature informs the spatial literature is invaluable.

The aim of this chapter is therefore to unpick many of the widely held assumptions within economic geography and urban economics concerning the relationship between knowledge spillovers, technology, R&D and innovation, and to consider how the non-spatial literature can provide sound underpinnings for the more explicitly spatial research. Parts of the chapter draw significantly on Ortega-Argilés (2012a) and though the literature surveyed here is wide-ranging it remains only a small subset of non-spatial and spatial literatures examining innovation and economic geography. The material referred to here, however, does provide a reasonably comprehensive picture of many facets of current evidence and debates, and as such is intended to provide a roadmap through the vast field of analysis. The chapter is organized as follows. The next section reviews the literature on the nature, role and links between R&D, innovation and productivity. Section 1.3 examines innovation from the perspective of the resource-based view of the firm, and Section 1.4 discusses the characteristics of knowledge and technological regimes as shaping the evolution of the firm's innovative behaviour. Section 1.5 sets the insights of these various non-spatial and firm-centred arguments in the context of geography, and discusses spatial behaviour on the basis of prevailing technological regimes. The final section provides some brief conclusions.

1.2 R&D, INNOVATION AND THE DETERMINANTS OF FIRM-LEVEL PRODUCTIVITY

Schumpeter's (1934) basic competition argument is that all entrepreneurial innovations – that is, new or significantly improved combinations of products, processes, raw materials, markets, organizational solutions – will count economically as long as they are not immediately copied. In other words, innovation generates temporary monopoly rents for firms, because market competition is not primarily about prices but about the opportunity to perform better tomorrow than the market leaders do today. This Schumpeterian approach, which is also explicitly formulated in modern evolutionary economic theory (Nelson, 1995), is also consistent with different approaches that allow for heterogeneity and variety among actors regarding information, knowledge, capabilities, as well as among products and processes.

Innovation has traditionally been seen as the outcome of collision between technological opportunities and user needs, an outcome usually embedded in new products: as such, innovation is a critical dimension of economic value creation (Schumpeter, 1934). During recent decades researchers have broadened the concept of innovation to include non-technological innovation, which can include: design innovation (Walsh, 1996; Verganti, 2006), business model innovation (Amit and Zott, 2001; Zott and Amit, 2010) and process innovation (Hammer, 2004). Furthermore, interest in different innovation contexts – service environments as opposed to the well-studied product environments – is increasing (Drejer, 2004).

One strand of the conceptual literature on the link between R&D and firm productivity analyses innovation output as an intermediate step that catalyses the effect of R&D on firm performance, mainly measured by labour productivity or profitability. Schumpeter's (1934, 1942) seminal work describes a largely linear relationship, with R&D investment influencing technological performance, which in turn influences profitability. Innovation is seen as the outcome of the collision between technological opportunities and user needs (Schumpeter, 1934). Alternatively, Nelson and Winter (1982) view the innovation-productivity mechanism as a circular one whereby innovation success influences profits, which influence R&D investment, which influences innovation probability and thereby success (success breeds success).

Capturing these mechanisms empirically, however, is difficult. Building on Griliches's (1958) and Mansfield's (1965) pioneering work, attempts to analyse and quantify the productivity effects of innovative activities have proved to be challenging and controversial. In recent decades this research has been augmented by the new theoretical underpinnings of endogenous growth theory (Romer, 1990; Aghion and Howitt, 1998), which suggests that economic outputs are positively correlated with the flow of new products, whether radical or incremental. Indeed, in emphasizing innovation, it is important to remember that innovation based on imitation or technology transfer can also result in substantial productivity growth of economies (and firms) behind the technological frontier. Technology transfer is not necessarily automatic and is contingent on the levels of knowledge and expertise in the firm, industry or country to which the technology is being transferred. This line of thought is closely linked with the idea that some knowledge is tacit or hard to acquire without direct experience. By actively engaging in R&D in a particular intellectual or technological field, one acquires tacit knowledge that can therefore help in more easily understanding and assimilating the discoveries of others. Even then, the transfer of technology may be far from automatic. While the firm, or more broadly the business enterprise, plays a large role in determining the characteristics of technological change, the firm's ecosystem, including supporting institutions and legal structures, also remains of great importance.

More recent theoretical contributions have therefore focused on opportunities to improve innovation success by opening up the R&D funnel and engaging with ecosystems and firm surroundings. Examples include customer involvement in the early stages of R&D (Von Hippel, 1990), sourcing of innovation ideas and projects externally through licensing, partnerships or intermediaries (Chesbrough, 2006; Chesbrough et al., 2006), as well as the potential use of alternative business models or routes to commercialize promising technology (Chesbrough et al., 2006). Brécard et al. (2006) find that R&D produces its full effects on two forms of innovation, namely, aggregate factor productivity gains and improvements in product quality. However, as Teece (2010) explains, technology-driven firms face the problem of how to manage and integrate the output of highly skilled experts (*literati* and *numerati*) across countries, time zones and organizational boundaries.

All innovations or innovation activities share the common characteristics of being novel or new, of reflecting improvements on existing blueprints and of being undertaken in order to overcome future uncertainty (Gordon and McCann, 2005). In general, innovation can be distinguished along the following dimensions:

- Type: technological – product and process innovation (Hammer, 2004) – or non-technological – organizational innovation (structural, procedural), marketing and design innovation (Walsh, 1996; Verganti, 2006), business model innovation (Amit and Zott, 2001; Zott and Amit, 2010) and managerial innovation, among several others.
- Mode: novel innovator (strategic and intermittent), technology modifier and technology adopter.
- Socio-economic impact: incremental, disruptive or radical.

Within this broad framework, the role of R&D in stimulating innovation has long been viewed as central to economic performance and social welfare. The existing economic literature has indeed found robust evidence for a positive and significant impact of R&D and innovation on productivity at the firm level. This consensus about the existence of a positive and significant impact of R&D on productivity is based on a variety of studies using different proxies for productivity according to the data available. The estimated overall elasticity of productivity with respect to R&D is positive, statistically significant and with a magnitude – depending on the data and the adopted econometric methodology – ranging from 0.05 to 0.25 (Mairesse and Sassenou, 1991; Griliches 1995, 2000; Mairesse and Mohnen, 2001). However, these elasticity estimates tend to be higher from cross-sectional estimators and lower from within or difference estimators. This is consistent with the idea that, given the presence of measurement error, coefficients are biased downwards when 'within' and first difference estimations are performed.

The majority of studies on the relationship between innovation and firms' economic performance use the production function approach, where different measures of firm performance (mainly productivity) are explained by several independent variables such as physical capital, human capital, R&D and other innovation-related investments as well as by firm size and maturity. However, Griliches and Mairesse (1984) point out that estimation results for the majority of models applying production functions, including their own analyses, are likely to be biased due to simultaneity and measurement error. This is because investment in physical capital, R&D expenditures and employment might well be influenced by productivity. To keep simultaneity problems to a minimum, and to take into account the lag between R&D investment and productivity gains, several authors have included R&D stocks in estimated equations using the inventory method, or have estimated a simultaneous equation model, following the landmark Crépon et al. (1998) methodology.

This seminal paper on the analysis of links between R&D, innovation and productivity examines these relationships in the context of French manufacturing. In their work, which builds on Griliches (1986) and Griliches and Mairesse (1984), they examine issues of selection bias, simultaneity bias, specification and estimation. They confirm the presence of a positive relationship between research and innovation and between innovation and productivity. This paper has spawned a whole series of similar papers, and from these we see that the estimated relationships are sensitive to the type of model, estimation method, measures of firm performance, sub-sample of business sectors, type of innovation, data source and specification of the innovation models used. As Hall and Mairesse (2006) explain, in terms of understanding the channels linking investment in knowledge and productivity growth, Crépon et al. (1998) combine the important but largely separate lines of empirical research that had evolved since Griliches's original work.

Crépon et al.'s (1998) improvement and amplification of Griliches's original work has been possible because of better micro-data sources: the construction of surveys for various purposes has facilitated the incorporation of new determinants in the models and the application of more sophisticated techniques. Several microeconometric studies have gathered evidence regarding other channels of the knowledge-productivity link. These studies attempt to replicate the Crépon et al. model with higher levels of sophistication in the measurement of inputs, in the data used, in the methodology applied and in the set of country comparisons. The key results of these studies can be summarized as follows. The probability of doing R&D increases significantly with firm size, captured by the number of employees, and also with their market share and diversification activities (Crépon et al., 1998). However, while evidence from firm-level studies for a range of countries confirms a positive role for R&D expenditure in explaining productivity growth, R&D expenditure has only limited explanatory power regarding differences in productivity rates between firms, sectors and countries (Griliches and Mairesse, 1990). As reported by Nadiri and Prucha (1996) and Mairesse and Mohnen (2001), most studies on R&D expenditure find a positive net effect on both value-added and turnover, although the advantages of R&D decline when its effect is evaluated over time (Klette and Kortum, 2004). Labour productivity increases significantly with the intensity of innovation sales for manufacturing and service sectors (Lööf and Heshmati, 2006). The estimated elasticity of productivity levels with respect to innovation output increases by about 50 per cent when physical capital is not controlled for. The lack of a control for skill increases the elasticity by about 25 per cent (Lööf and Heshmati, 2006). The elasticity of value-added per employee, in levels and growth, differs little between manufacturing and services.

Although these estimated impacts of innovation on productivity are subject to a variety of econometric and other reservations, there is striking similarity between samples of firms, which is not well documented in the literature. Unlike productivity, employment increases with innovation outputs only in service firms (Lööf and Heshmati, 2006). These researchers also find that sales growth increases with the level of innovation output, but only for manufacturing. Innovation productivity is higher for firms sharing knowledge through R&D partnership(s) thanks to internalized spillovers. Innovation productivity is also higher for firms belonging to a group, where R&D costs and knowledge are more likely to be spread across affiliates acting as a natural consortium. Kremp and Mairesse (2004) observe a relationship between innovative performance and four different knowledge management practices within firms, the promotion of a 'knowledge sharing culture', the adoption of incentive policies to retain R&D professionals, the employment of alliances for knowledge acquisition and the adoption of a written knowledge management policy by the firm. Halpern and Muraközy (2009) find that innovative firms are both more productive and more likely to trade and export into more countries.

Foreign firms are more likely to innovate compared to similar domestic firms, but R&D is a weaker predictor of their innovative output. Instead, they find that the exceptional export performance of innovative firms is primarily driven by a diversified export strategy, exporting to more markets rather than exporting more products or at larger intensive margin.

Another important finding is that different types of innovation – product and process innovation in the cases described below – have different determinants. Firm size enhances process innovations more than product innovations. Robin and Mairesse (2008) re-examine the Griffith et al. (2006) results, using more recent data for France, and find a more pronounced effect of innovation on productivity, especially in the case of firms conducting both product and process innovations. Cabagnols and Le Bas (2002) find that economic competition favours process innovations, whereas technological competition (the percentage of innovators in the same sector) stimulates product innovations. They also find that process innovators tend to rely on upstream sources of knowledge and on consortium research, whereas product innovators source their knowledge from downward and horizontal links.

Van Pottelsberghe de la Potterie (1998) concludes that although there have been a considerable number of studies on R&D – productivity linkages – these studies are virtually impossible to compare because they differ with respect to key dimensions such as aggregation level (firm, industry, country, macro-regions such as European Union (EU) versus United States), econometric specification, data source, measurement of R&D, measurement of productivity and period of investigation. Thus, the complexity of innovation processes and the variety of possible components and elements of these processes remain difficult to disentangle econometrically. Our empirical models remain heavily guided by conceptual frameworks, and the result is that, in many ways, the economic theory of the firm is still, as Rosenberg (1982) pointed out, largely a 'black box' when it comes to understanding the processes that result in the creation of new products and services and their profitable commercialization. Given this uncertainty, ideas about the geography of innovation – which assume an understanding of innovation processes that does not reflect the current state of the literature – may need rethinking. We shall return to this in later sections, and now consider the resource-based model of the firm.

1.3 THE RESOURCE-BASED MODEL OF THE FIRM, STRATEGIC MANAGEMENT AND THE IMPLICATIONS FOR FIRM INNOVATION BEHAVIOUR

One way of making progress on these issues is to approach them in terms of the role played by knowledge. The literature on the economics of knowledge (Foray and Freeman, 1993; Foray, 2004, 2009; Swann, 2009) provides various different ways of thinking about innovation, and about the relationships between innovation and economic geography (Iammarino and McCann, 2013). The strategic management literature argues that in innovation-driven economies, intangible assets, including knowledge spillovers and relationship capital, are critical to the creation and production of new goods and services. In such economies, it is argued that how the firm exploits these assets is a key mechanism of technological change (Teece, 2010). Knowledge assets are tacit to varying degrees and costly to transfer. The market for know-how is also riddled with imperfections, which favours internalization to capture strategic value, in that certain assets are more valuable to one firm than another. Assets that have such special value are referred as strategic assets, and these can take the form of 'dynamic capabilities', 'resources' and 'competences'.

Following the seminal contributions of Penrose (1959), the strategic management literature (Teece, 1984) and the systems-of-innovation literature (Lundvall, 1992) frame the analysis of innovation by focusing on the role played by the firm's resources, competences and capabilities.

- Resources are regarded in the resource-based view (Penrose, 1959; Teece, 1984) as being those firm-specific assets that are difficult for other firms to copy or imitate, and the difficulty of imitation means that often they tend to be intangible rather than tangible, although both are possible. In particular, these types of assets tend to display property rights features whose boundaries are somewhat difficult to define and, as such, are both rather fuzzy and idiosyncratic in nature (Teece, 1984), and these characteristics themselves significantly inhibit such resources being traded or transferred to competitor firms (Teece, 1984). Teece (1984) lists various examples of resources that display these features, such as intellectual property, the embodied knowledge and specific skills within groups of specialized workers, customer relationships and process know-how (Teece, 1984). Over many decades the resource-based framework has developed within the management literature, building heavily on the work of Penrose (1959) and Teece (1984) amongst others, and this literature is based on the principle that the firm earns rents from leveraging its unique resources, which are difficult to monetize directly via transactions in intermediate markets. This in turn gave rise to the analysis of learning and knowledge management as the means to develop and augment new, hard-to-imitate resources. However, while resources are a stock not a flow, they can be constantly renewed. The need for renewal is amplified in fast-moving environments such as those characteristic of high-tech sectors (for example, computers), but the need to renew resources can also occur in 'low-tech' industries (for example, life insurance).
- Competences are a particular kind of organizational resource, resulting from activities that are performed repetitively, or quasi-repetitively. Organizational competences require collective effort, and represent distinct bundles of organizational routines and problem-solving skills.
- Dynamic capabilities are defined by Teece (1984) as the firm's ability to build, integrate and reconfigure both external and internal resources and competences in order to respond to and influence the evolving business environments (Teece, 1989, 1996, 2007). According to the resource-based view (Teece, 1984), dynamic capabilities may be embedded in various firm-specific systems and routines for adapting to change, and these may involve, for example, different product development processes, different investment strategies, different managerial approaches or different entrepreneurial initiatives (Teece, 1984). Taken together, these different systems, routines and responses reflect the efficiency and efficacy with which the firm is able to reconfigure its resources to best fit the evolving business environment (Teece, 1984). In other words, dynamic capabilities also reflect the capacity of a firm to

orchestrate and reorganize its activities, resources and assets within the broader system of global specialization and diversification.

The elements in this literature that are regarded as central include organizational schemes, teams, hierarchies, incentive systems and outsourcing. However, the key idea is that resources, competences and dynamic capabilities may be built. Dynamic capabilities are based on the skills, procedures, organizational structures and decision rules that firms utilize to create and capture value. For instance, different innovation activities such as exploration (e.g. research on a potentially disruptive technology) and exploitation (e.g. selling mature products) will require different managerial styles. Whether the enterprise is currently making the right products and addressing the right market segments, or whether its future plans are appropriately matched to consumer needs or to technological and competitive opportunities, is determined by its dynamic capabilities. Managers must be able to sense the opportunities, craft a business model to capitalize on them and reconfigure their organizations, and sometimes their industries, as the business environment and technology shift. Management involves not only motivating talent and ensuring the job gets done, there is also a strategic component – what tasks to assign, what priorities to set, what resources to use and where to get them from. To respond to these challenges, business enterprises need to develop capabilities and deploy them on a global basis (Teece, 2010). Sensing (identification and assessment of an opportunity), seizing (mobilization of resources to address and opportunity and capture value from doing so) and transforming (continuing renewal) are the particular attributes of firms that enable them to evolve and co-evolve with the business environment. Such capabilities are critical to long-term productivity and profitability.

As Teece (2010) points out, R&D is not the only source of productivity gains. The literature has shown that different determinants have a direct influence on firm's performance. In this sense, a firm's inputs can be classified into traditional inputs and new discoveries. Traditional inputs comprise a firm's inputs such as human capital, physical capital, information and communications technology (ICT) and information technology (IT) services and capital, financial capital, materials and energy, while new discoveries comprise new sources of firm growth such as knowledge and innovation management, along with dynamic capabilities. The strategic management and resource-based literatures therefore see major differences between two different generic types of firm model – broadly defined as the 'industrial model' and the 'knowledge model', with the latter reflecting a more modern and innovative model of firm organization (Ortega-Argilés et al., 2005) and management. The term 'knowledge management' is nowadays itself widely used in the literature to refer to the implicit or explicit practices employed by a firm to acquire new knowledge, and to rearrange and diffuse existing knowledge within the firm. It also includes strategies that are intended either to prevent the firm's own knowledge from leaking out or to encourage the diffusion of its knowledge to partner firms and others from whom the firm might benefit via reciprocal knowledge exchanges. Although knowledge management is not identical to innovation, the two are often viewed as closely connected, in the sense that innovation can be viewed as the production of new knowledge, implying that firms which innovate will also be those more concerned with the management of knowledge thus produced. Knowledge management is important for firm productivity and performance because it is directly linked with the firm's products and production processes. In addition, knowledge management plays an important role in setting the short-term and long-term capital strategies of the firm. Knowledge management is also directly linked with managerial strategies related to process outsourcing, diversification and internationalization. This is because knowledge management is linked to the formulation of better combinations of assets and resources, to strategically obtain the highest possible returns.

The strategic management and knowledge management literatures therefore contend that R&D and innovation-related investments can have higher returns when they are complemented with other factors, and this van be understood in two ways. In one way, complementarities will be seen in the firm's core when activities not necessarily considered as R&D investments, such as business services, complement R&D activities and provide higher returns. In parallel, a series of complementarities found in the external environment can also act as a support for the firm's internal R&D effort.[1] These insights imply that to transform invention successfully into innovation requires a range of complementary activities, including internal organizational changes, firm-level training, testing, marketing and design alongside external linkages. Innovation rarely occurs in isolation and is often a highly interactive and multidisciplinary process, which increasingly involves collaboration by diverse networks of stakeholders, institutions and users. In recent years, economists have paid more attention to the idea that new technology requires substantial complementary investments, and there is increasing evidence of their effects.[2] Complementary investments can be of an organizational nature. Technology alliances among competing firms can generate both private and societal benefits (Jorde and Teece, 1990; Teece, 1992; Baumol, 2002). More recently, Bresnahan and Greenstein (1999) describe such complementary investments as co-invention, and Bresnahan (1999) emphasized that firms must adjust their organizational structure and their work processes, which is a long and slow procedure, to take full advantage of new technologies.

In recent years, companies have implemented thousands of large and small ICT-based innovations in software applications, work processes, business organization, supply-chain management and customer relationship management. In the United States and elsewhere, computer investments have contributed to output growth (Brynjolfsson and Hitt, 1995, 1996, 2003; Lichtenberg, 1995; Jorgenson and Stiroh, 2000; Oliner and Sichel, 2000). The contribution of ICT capital (capital deepening) to labour productivity growth has been increasing over time and this effect is widespread across industries. Probably the most important technological input to services are ICT products.

The impact of IT at the industry level is primarily understood by distinguishing between the IT-producing sectors and the IT-using sectors because during the 1990s productivity gains were primarily associated with the former whereas in the following decade productivity gains were much more centred on the latter. Their impact on productivity is greater in ICT-producing and ICT-using industries than in more traditional sectors, but nevertheless there are also significant effects in traditional sectors. In most manufacturing industries ICT has contributed to rationalizing production processes and raising productivity by reducing inputs, in particular, unskilled labour. In many service industries, ICT has had an additional impact on 'product' innovation, in turn implying increased use of high-technology inputs. Indeed, some service industries, and in particular finance and parts of the business service sector, are among the most intensive users of ICT. As such, most current studies emphasize the importance of complementary changes in a variety of other organizational aspects when IT systems and processes are implemented (Brynjolfsson and Hitt, 2000; Bresnahan et al., 2002; Van Leeuwen et al., 2009).

In high-technology industries where the pace of technical change is high and where much of the newly emerging knowledge is tacit and uncodified, the generation of new products and services may have to overcome significant knowledge-related hurdles in order to distinguish themselves from the offerings of competing firms. In such an environment, the knowledge economics literature argues that it is valuable to have a highly skilled, and technically adept workforce, particularly where the firm develops an identity based on the relations it builds with other firms, either directly as suppliers or customers, or indirectly as collaborators and competitors.

The introduction of IT in companies implies more than simple automation and the substitution of workers by computers. IT implementation is associated with complementarities among three distinct kinds of technical change relating to: cheaper more powerful IT capital; organizational change; and new products, services or quality. Implementing these three forms of technical change concurrently transforms companies and leads to substantial changes in labour demand. Since all three involve substantial amounts of invention, the complementarity arises in the long run (David, 1990; Brynjolfsson and Hitt, 2000). Computers are best described as a general-purpose technology whose primary contribution is to make new production methods possible when combined with complementary investments such as new work systems, organizational redesign and business process re-engineering (Milgrom and Roberts, 1990; Malone and Rockart, 1991; Bresnahan et al., 2002).

IT-intensive production processes are based on an organization's strategic goals, such as new products and services, new quality levels, new capabilities or new efficiencies. In many cases they imply a need for complementary activities related to human capital improvements (education mix, skill mix); organizational changes, such as new hierarchies or work operations; new cognitive content of managerial work (Davenport and Short, 1990; Bresnahan et al., 2002); new supply chain management systems (Short and Venkatramen, 1992); and a higher service level for customers. IT computerization processes have therefore implied changes in workers' capabilities, changes in managerial tasks, increases in demand for high skilled human capital and in many cases the substitutability of low skill human work. IT computerization process has primarily affected the tasks of lower level white collar and blue collar workers, because of their repetitive and routinized nature, while managerial and organizational tasks that required judgement, training, autonomy or creativity have been more indirectly affected. On the one hand, the implementation of a new technology requires a high level of cognitive skills that are important in adapting to change and exploiting data. As a result, there is increased demand for workers with skills to process and synthesize accumulated data associated with the implementation of new IT-intensive processes. On the other hand, there are more opportunities for managers and professionals to assess this increased information when designing organizations and new products. These new managerial activities thus require new managerial abilities – both quantitative skills and business knowledge. Therefore, complementarity between machinery and human capabilities leads to a wide variety of organizational structures that adapt better to the new requirements of communication and coordination. Additionally, because of the new skills requirements, there is the potential for implementing training or screening policies to analyse the improvements of existing workers and increase their cognitive skills. Productivity should be higher in firms that successfully find complementary matches between IT, organizational structures and human capital investments than in those firms that cannot make such complementary matches. Yet, the importance of complementary assets makes it more difficult to determine the appropriate rate of return to R&D than many traditional econometric approaches suggest. If downstream complementary investments are substantial, it becomes very difficult to determine how much of the observed downstream returns are attributable to indirect R&D and how much is due to the many different forms of complementary investment.

These observations also underlie the importance of complementarities that are external to the firm, and an important literature (Teece, 2010) addresses factors in the firm's external environment that impact firm-level innovative performance. The common argument of this literature is that firm-level innovation depends on the supply of skilled workers (who are not entirely mobile internationally), universities (for access to both highly educated faculty and research), financial institutions (especially venture capital), the legal system (especially intellectual property law and employment law), the supply base (including complementors), the domestic market and the presence of other firms in the same or related industries. In industries characterized by tacit knowledge that is not easily transferred over large distances, human capital practices are of particular importance to performance strategy because worker knowledge cannot easily be interchanged. Following this logic Cohen and Levinthal (1990, 1996) developed the concept of the 'absorptive capacity' of firms to adapt and acquire external and internal knowledge. Its premise is that the firm needs prior related knowledge to assimilate and use new knowledge. The embodied knowledge contained in a firm's workers also represents previous processes of knowledge accumulation and learning that should be preserved by industries that have a non-codified knowledge component. Cohen and Levinthal (1990, 1996) argued that the long-run activity learning processes that firms acquire are difficult to transfer or acquire from elsewhere. Moreover, these learning processes have also themselves been subject to enormous transformations over the last three decades due to the presence of modern ICTs described above.

1.4 THE PROPERTIES OF KNOWLEDGE, TECHNOLOGICAL REGIMES AND THE EVOLUTIONARY FIRM

At the industrial level, the evolutionary literature has proposed that sectors and technologies differ greatly in terms of the knowledge base and learning processes related to innovation. Knowledge differs across sectors in terms of domains. One knowledge domain refers to the specific scientific and technology fields at the base of innovative activities in a sector (Nelson and Winter, 1982; Dosi, 1988). The second domain refers to the applications, the users and the demand for sectoral products. In addition, other dimensions of knowledge may be relevant for explaining innovative activities in a sector. Concepts such as accessibility, appropriability, opportunity and cumulativeness are argued to be key dimensions of knowledge. These are related to the notion of technological and learning regimes that differ across firms and sectors and help to understand why some firms benefit from their innovations while others do not capture the benefits of incurring R&D costs. Malerba and Orsenigo (1997) argue that different patterns of innovative activity in a sector can be explained as the outcome of different technological regimes implied by the nature of technology and knowledge. The notion of technological regime provides a synthetic representation of some of the most important economic properties of technologies and the characteristics of learning processes involved in innovative activities. The main elements of the idea that patterns of innovative activities are related to technological regimes (Nelson and Winter, 1982; Malerba and Orsenigo, 1993, 1997) can be summarized as follows:

- Appropriability conditions reflect the opportunities on the part of knowledge investors for protecting their innovations from imitation by competitor firms, and the greater these opportunities, the higher the likelihood of the knowledge-investing firm capturing the maximum profits from its innovative activities (Nelson and Winter, 1982; Malerba and Orsenigo, 1993, 1997). Appropriability conditions are thus linked directly with the features and characteristics of the firm's internal knowledge, and especially the degree to which this knowledge can be codified and standardized (Nelson and Winter, 1982; Malerba and Orsenigo, 1993, 1997). High appropriability conditions typically exist in the context where knowledge is both complex and difficult to codify, whereas low appropriability conditions reflect a business and economic environment characterized primarily by simple knowledge that can be easily standardized, routinized and codified (Nelson and Winter, 1982; Malerba and Orsenigo, 1993, 1997). In order to protect their innovations and knowledge investments, firms use a variety of different means, although the effectiveness and use of these different approaches tends to differ between industries according to the features of the knowledge. This, in turn, generally affects both the scale and the nature of knowledge externalities. Among the means employed to enhance appropriability are the use of patents, secrecy, lead-times, non-disclosure employment contracts, non-competition clauses, organizational arrangements and long-term contracts with employees, customers or suppliers (Nelson and Winter, 1982; Malerba and Orsenigo, 1993, 1997).
- Cumulativeness and progressiveness conditions in the resource-based view of the firm reflect the contribution that current innovations and innovative activities have as the springboard or the starting point for tomorrow's innovations (Malerba and Orsenigo, 1993, 1997). The cumulativeness argument is that today's innovative firms are more likely to innovate in the future in specific technologies and along specific trajectories, and this is especially the case if these firms experience internal learning processes and dynamic increasing returns at the technology level. Such cumulativeness driven by learning processes may be associated with organizational or human resource issues as much as with technological issues (Nelson and Winter, 1982; Malerba and Orsenigo, 1993, 1997).
- The knowledge base in the resource-based view of the firm refers to the properties of the knowledge upon which firms' innovative activities are based. The nature and properties of the firm's knowledge can be parsimoniously described according to the quatro-partite classifications of: generic versus specific knowledge; tacit versus codified knowledge; complex versus simple knowledge; independent versus systemic knowledge (Nelson and Winter, 1982; Malerba and Orsenigo, 1993, 1997). The innovation behaviour of the firm in response to these various knowledge

characteristics is also heavily shaped by the means and agents of knowledge transmission and communication activities available to the firm (Nelson and Winter, 1982; Malerba and Orsenigo, 1993, 1997).

- The opportunity conditions in the resource-based view of the firm reflect the ease of innovating for any given amount of resources. Technological opportunity conditions are related to the characteristics of the market and environment in which firms operate, such as: barriers to entry; the nature of the innovation and the knowledge base internal or external to the firm and sector; the appropriability of the returns to knowledge investments; and the orientation of the innovation activities and systems.

The sources of technological opportunities, in other words, the varying ease of innovation across technological fields, differ across sectors (Scherer, 1965; Rosenberg, 1974). For example, Freeman (1992) and Rosenberg (1982) have shown that in some sectors the conditions governing opportunities are related to major scientific breakthroughs in universities. In other sectors, opportunities to innovate may come from advancements in R&D, equipment and instrumentation. Moreover, external sources of knowledge in terms of suppliers or users may play a crucial role. Not all external knowledge may easily be used and transformed into new products or services: in particular, if advanced integration capabilities are necessary in order to absorb this external knowledge (Cohen and Levinthal, 1990), then the industry is likely to be rather concentrated and dominated by large established firms. In contrast, if external knowledge is easily accessible and transformable into new products and services, then innovative entry into markets is likely to be widespread (Winter, 1984).

The cumulativeness of knowledge in terms of the degree to which the generation of new knowledge builds upon current knowledge (Nelson and Winter, 1982; Malerba and Orsenigo, 1993, 1997) also differs between industries. Cumulativeness at the technological and firm levels can create first mover advantages and tends to generate high levels of firm concentration. Regarding the sources of the cumulativeness of knowledge, three main ones can be identified (Nelson and Winter, 1982; Malerba and Orsenigo, 1993, 1997), namely: learning processes and dynamic increasing returns at the technology level; organizational capabilities that are firm-specific and can be improved only gradually over time; feedbacks from markets, such as success breeds success processes in which innovative success yields profits that can be invested again in R&D (Nelson and Winter, 1982). In general, a high degree of cumulativeness implies a high degree of appropriability. When returns to innovation remain largely with the knowledge-investor innovating firm, this encourages more internal R&D and innovation. In contrast, low cumulativeness and low appropriability on the part of the knowledge-investor reduces returns to internal R&D and incentivizes free-rider behaviour on the part of other firms (Nelson and Winter, 1982; Malerba and Orsenigo, 1993, 1997).

Malerba and Orsenigo (1997, 2000) analyse the relationship between technological regimes and the specific patterns of innovative activities in a sector. Knowledge that is accessible may be internal or external to the sector, and external knowledge in particular may be different in terms of its degrees of accessibility (Malerba and Orsenigo, 2000). This is important because greater knowledge accessibility decreases industrial concentration and monopoly power. This is in part determined by the nature of the knowledge itself. The degree to which knowledge about an innovation varies between being tacit or easily codified also affects the ease of imitation and hence inversely reflects its level of appropriability on the part of the knowledge-investor. In particular, greater knowledge accessibility and appropriability by other firms implies low appropriability on the part of the knowledge-investor because competitors may more easily imitate the innovations of the knowledge-investing firm. Patents can in some cases be used to slow rivals' imitation activities and generate internal profits. However, patents rarely confer strong appropriability to the innovator outside certain special cases such as new drugs, chemical products and rather simple mechanical inventions (Levin et al., 1987), and they are especially ineffective in protecting process innovations. The reason is that, ironically, the more complex a product, the easier it often is to re-engineer while introducing a number of incremental differences, thereby avoiding patent legislation.

The conditions under which the implications of cumulativeness and appropriability tend to diverge are when spillovers operate. Spillovers tend to be important where knowledge accessibility is high. As such, cumulativeness may exist at the level of the sector or the region even though appropriability at the level of the individual knowledge-investing firm may be low. Following this line of argument, the ways in which innovative activities take place in sectors, technologies, firms and regions may therefore be quite different (Iamamrino and McCann, 2013). For example, in certain technologies innovative activities tend to be concentrated among a few major innovators, while in others they are distributed among larger numbers of firms. In some industries or in some regions large firms undertake the bulk of innovative activities, while in other sectors or regions small firms are very active. Meanwhile, in some regions innovation is dominated by firms that are highly clustered together whereas in other regions this is not the case.

For our purposes in this chapter, the technological regime approach is found to be especially useful for discussing the links between innovation and economic geography (Iammarino and McCann, 2013). Indeed, one of the most important ways for firms to enjoy returns from their knowledge investments is to protect their innovations, and as we have already seen, companies use different means for ensuring the cumulativeness and appropriability of their own knowledge investments and assets (such as patents, copyrights, trademarks or other forms of intellectual property, non-disclosure employment contracts and so on). These systems are essential in many contexts because if a firm's knowledge and its diffusion are in part tacit and informal as well as complex and part of a larger system, the most relevant means of knowledge transmission is via face-to-face contacts and employment mobility of personnel. If, on the other hand, the firm's knowledge is largely standardized, codified, simple and independent, the most relevant means of knowledge transmission are formal means, such as via routines, templates and blueprints. The former transmission and diffusion processes tend to be geographically constrained whereas the latter are not (Iammarino and McCann, 2013), and the characteristics of the knowledge will therefore have an influence both in the transmission of returns of knowledge investments into productivity gains and on the geography of firm behaviour (McCann, 2007). Taken together, the characteristics of knowledge – defined by notions such as its cumulativeness and appropriability, the degree of standardization or routinization of knowledge operations, and also the technological opportunities arising – provide a robust underpinning for discussing the links between innovation and economic geography. In particular, we can interpret the conditions under which clustering or agglomeration is more advantageous than spatial dispersion from the vantage point of what types of knowledge are being generated, transacted or transmitted. Yet, quite how these interrelationships play out and exactly how they are to be understood requires us to reinterpret these approaches in an explicitly geographical setting. These are the issues to which we now turn.

1.5 ECONOMIC GEOGRAPHY, INNOVATION, KNOWLEDGE SPILLOVERS

There is a large literature on the geography of knowledge and spillovers. Jaffe (1986, 1988; Jaffe et al., 1993) was one of the first to examine the effects of knowledge spillovers between firms, finding in general that in the United States patents are likely to be cited by firms at a location close to the inventor, while cross-border citations are less likely than domestic citations. As such, certain types of knowledge spillovers are taken to be geographically bounded (Moretti, 2004). Indeed, widespread subsequent evidence also supports the idea that knowledge spillovers, where they exist, are mediated via geography, the more tacit the knowledge, the more spatially concentrated its spillovers. An additional aspect of clustering common to all forms of clusters is that local competition and mutual visibility also foster imitation and innovation (Porter, 1990). Innovation and entrepreneurship are therefore often associated with cities (Acs, 2002), and evidence from the United States also suggests that regions that are more sectorally diversified (Glaeser et al., 1992) and structurally disaggregated (Duranton and Puga, 2001) exhibit higher knowledge spillovers, although the international evidence on this is not at all clear-cut (Beaudry and Schiffauerova, 2009; De Groot et al., 2009; De Melo et al., 2009). In particular, the European context appears to be rather more mixed than the United States, with neither specialization nor diversity playing a decisive role in the geography of growth and innovation (De Groot et al., 2009). Similarly, although there is some evidence that cities exhibit higher rates of entrepreneurship and innovation, there is also a great deal of heterogeneity across European observations (Sternberg, 2011). In addition, as well as the links between industry structure and geography, other researchers have studied knowledge interactions between firms and universities or research institutes (Anselin et al., 1997; Mansfield, 1965; Darby and Zucker, 2003; Adams, 2004), and again evidence points to localization effects of knowledge spillovers (Jaffe et al., 1998; Adams et al., 2003), although the nature and magnitude of these effects appear to vary significantly as the nature of university linkages with the wider economy range from human capital-mobility effects (Faggian and McCann, 2009) to R&D activities. While the available econometric evidence is broadly – but only weakly – supportive of these knowledge- and innovation-related localization, clustering and agglomeration arguments, there are still numerous exceptions to these trends. Following the cumulativeness and appropriability arguments, spatial dispersion rather than spatial concentration will often be an appropriate strategy in cases where firms prioritize secrecy. In order to avoid knowledge spillovers many highly innovative firms working at the frontiers of technology have major knowledge facilities located in relatively isolated locations (Simmie, 1998) or they used corporate organizational structures and legal systems to enforce secrecy (Arita and McCann, 2002; Arita et al., 2002).

Part of the problem here is that industrial clustering of activities does not necessarily imply that widespread local knowledge spillovers are evident. The knowledge-related arguments discussed above imply that innovation that is heavily driven by local knowledge spillovers will only in reality be evident in certain circumstances and where certain knowledge-related conditions are fulfilled. As such, our argument goes somewhat against the standard agglomeration-spillover assumptions popular in urban economics, which often treat agglomeration and clustering as independent evidence of the widespread existence of such spillovers. Indeed, we argue here that the links between knowledge, innovation and economic geography are in reality more complex than the 'learning, sharing, matching' (Duranton and Puga, 2004) assumptions widely advocated. Indeed, from the arguments outlined above we may ask: learning about what? sharing what? matching what? We can learn about knowledge, we can share knowledge, we can match knowledge; we can learn about technology, we can share technology, we can match technology; we can learn about human capital, we can share human capital, we can match human capital. Moreover, we can apply these arguments to other issues, such as, for example, organizational systems, which can be shared, matched and learned about. Indeed, these arguments could be extended to institutional systems, training systems, financial systems, marketing systems, transport systems, legal systems. The list goes on, but importantly for our purposes here, these various learning, sharing and matching processes are likely to differ substantially depending on what is being learned, shared or matched. As such, the geographical advantages or disadvantages of clustering or agglomeration are likely to differ substantially depending on the issues at hand, and clustering or agglomeration cannot be taken itself as de facto evidence of the existence of knowledge spillovers.

One of the key reasons why knowledge spillovers and clustering are not synonymous is that while clustering offers possible benefits from inward knowledge spillovers, it also implies costs associated with outward spillovers. Clustering increases knowledge accessibility and appropriability on the part of other firms via spillovers, while at the same time reducing knowledge cumulativeness and appropriability of the firm making knowledge investments. Therefore, while, on the one hand, the arguments favouring clustering and agglomeration are based on the premise that clustering allows for knowledge spillovers in a form that largely provides a common public good, on the other hand, the arguments of Grindley and Teece (1997) imply that firms must always consider the costs associated with unintended knowledge outflows. In other words, the problem associated with the inability of the firm to earn maximum returns to internal investments due to unintended knowledge outflows means that in a cluster it must either find ways to protect its knowledge investments by inhibiting knowledge spillovers or by relocating away from a cluster. In some cases, firms use legal and organizational strategies to limit knowledge spillovers, and the greater the degree of clustering, the greater the need for such strategies. In some cases, these legal and organizational systems will be used in tandem with dispersed location strategies, particularly in cases where utmost secrecy is essential for the firm's technological progress.

Following on these arguments, and building on the earlier work of Gordon and McCann (2000) and McCann and Mudambi (2004, 2005), Iammarino and McCann (2006) develop a Pavitt (1984)-type classification of different types of industrial clusters – namely, pure agglomeration, industrial complexes and social networks – based on their innovation and knowledge characteristics. This classification is then extended and updated (Iammarino and McCann, 2013) to allow for different types of social networks.

The Iammarino and McCann (2006, 2013) approach argues that clustering primarily associated with local knowledge spillovers, in the sense of externalities, occurs in situations of pure agglomeration in which markets are largely: monopolistic and stochastic in nature; knowledge exhibits low cumulativeness and appropriability; and external sources of market-based knowledge dominate. These situations are most relevant where knowledge is diversified and broadly based and also largely codified into information. They are evident in many types of service industries. These cases tend to be supplier dominated and while the technological opportunities vary, technological trajectories tend to be primarily related to problem-solving processes and organizational innovations.

In contrast, where local industries are primarily oligopolistic, knowledge transactions within industrial complexes are mediated via long-term legal contracts between groups of firms: the benefits of these knowledge exchanges remain internal to the group of firms. This allows all firms in the group to appropriate all of the rents associated with their internal investments and to maximize returns to their R&D, much of which is focused on basic science. Knowledge spillovers, in the sense of pure externalities, are almost entirely absent, and the knowledge base is specialized, narrow and focused on complex products and cost cutting, although firms do benefit from innovations embodied both in intermediate demand and also in the R&D investments of other firms in the group. Levels of cumulativeness and appropriability are high, and industry dynamics are strategic rather than stochastic in nature, since the routinized and specific activities internal to the firm are primarily governed by hierarchies rather than markets. These spatial-organizational arrangements are typical in sectors such as petro-chemicals, pharmaceuticals and automobiles, as well as in the ICT hardware products and the medical instruments sectors.

Some spatial-organizational arrangements are primarily mediated via social networks: these tend to be of two types, namely, trust-based or competence-based. These knowledge spillover systems operate either on the basis of a shared longstanding history, a 'community of practice' that gives rise to trust-based relationships – typical in many traditional craft-based, touristic and heritage industries – or in the rather newer social network systems based on cognitive relations typical in high-technology clusters of SMEs, where tacit knowledge flows via informal exchanges between firms (Von Hippel, 1994). The science-driven knowledge base in competence-based networks tends to be broader than the more specialized and traditional knowledge base of trust-based networks. However, in both cases social bonds foster reciprocal and frequent face-to-face contacts: physical proximity may often facilitate knowledge transmission, and these proximity effects are especially important in trust-based networks. All social networks exhibit low levels of appropriability, and sources of innovation tend to be external to the firm. Yet, there are also major differences between the innovation characteristics of these two types of social networks. The degree of cumulativeness is low in competence-based networks, and the uncertainty and disruption involved in radical new product development mean that the innovation and technological opportunities tend to be high. In contrast, in trust-based networks that are primarily incremental and process driven, technological opportunities are low as levels of knowledge cumulativeness are high.

These knowledge-related lines of enquiry allow us to make sense of many different types of spatial organization. Moreover, they allow us to make sense of situations where firms will disperse or will disperse various functions. We may safely assume that all firms enjoy experiencing inward knowledge spillovers, and all else being equal this supports a tendency towards clustering. However, we also know that many firms are keen to avoid unintended outward knowledge spillovers, as these may undermine the cumulativeness and appropriability of their internal knowledge assets. To partially counter such threats, spatial dispersion makes sense. Spatial dispersion also makes sense in situations where a firm's markets are themselves dispersed or where a firm wishes to use location as a means to access new knowledge. However, in either of these cases spatial dispersion is still only viable where the firm is able to use organizational, technical or legal systems to ensure the cumulativeness and appropriability of its own internal knowledge while it is transacting knowledge across large spatial distances. Indeed, the provision and operation of such organizational, technical and legal systems designed to prevent knowledge outflows and maintain the appropriability and cumulativeness of knowledge are the specialist preserve and *raison d'être* of multi-plant and, in particular, multinational firms (Iammarino and McCann, 2013).

At the same time, these systems are used to enable such firms to cluster while limiting or inhibiting unintended outward knowledge spillovers. More specifically, if sufficient protection against unintended outward knowledge spillovers is available, then a firm will be able to make knowledge-related location decisions on the basis of the ongoing transactions costs associated with face-to-face interactions (McCann, 2007), weighed against classical location-specific factor cost considerations. These decisions will relate to, for example, the siting of individual facilities relative to core central business districts, or alternatively to the location of various multi-plant and multinational facilities in different locations. In such situations, the ongoing costs and opportunity costs of face-to-face interactions, whose importance to the firm depends on the degree of standardization of the knowledge being acquired, can be analysed in a manner consistent with orthodox location theory. On the other hand, if firms are unable to ensure the cumulativeness and appropriability of their knowledge investments, then their location strategies will tend towards patterns of spatial dispersal rather than clustering and concentration.

1.6 CONCLUSIONS

The arguments and analysis outlined in this chapter suggest that in terms of underpinning innovation processes, the observation of agglomeration and geographical clustering only makes sense under certain knowledge conditions. On the one hand, where the knowledge base is distributed and where the knowledge itself displays both low appropriability and low cumulativeness, then agglomeration-related behaviour is indeed suggestive of local knowledge spillovers. On the other hand, in other knowledge-related conditions, industrial clustering does not necessarily imply the existence of local knowledge spillovers, and other explanations must be sought for such spatial behaviour. As such, the common approach adopted in many urban economic studies, whereby the observation of spatial clustering is taken itself as de facto evidence of knowledge spillovers, cannot be upheld unless other empirical evidence is also available to substantiate these claims. Firm-specific microeconometric evidence is ideally suited to play this role, and the available micro-survey-based evidence that is emerging from various countries does not point unequivocally to these simple local spillover-learning narratives (Shearmur and Doloreux, 2008, 2013; Simonen and McCann, 2008, 2010; Doloreux and Shearmur, 2012; Shearmur, 2012). As consistent with the different issues raised in this chapter, the relationships between innovation, knowledge spillovers and geography are complex and varied and depend on the nature and roles of the knowledge being generated and transacted. In addition, there are also other debates regarding the extent to which knowledge and innovation is context-dependent or otherwise (Shearmur, 2011; Barca et al., 2012), although these are issues for another analysis.

NOTES

1. Evidence in support of this argument also comes from Cassiman and Veugelers (2006) who conducted pioneering work addressing the complementarity between R&D activities and its context. They argue that complementarities do exist between internal R&D and external knowledge acquisition, although the channels via which complementarities operate are firm-specific and context-specific. Later research tried to deepen the discussion suggested by Cassiman and Veugelers (2006) by sub-dividing corporate R&D. Schmiedeberg (2008) divided R&D activities into three categories: internal R&D, R&D cooperation and R&D contracting, and found empirical evidence that strongly indicates complementarities between internal R&D and R&D cooperation. Catozzella and Vivarelli (2007) included in-house and commissioned R&D, and embodied and disembodied technological acquisition. They stressed the catalysing role of in-house R&D and showed that internal R&D is complementary to all other innovation activities.
2. Los and Verspagen (2000) introduce the notion of indirect R&D available to the firm, by taking the unweighted sum of all other firms' R&D stocks (Bernstein, 1988). The idea behind this is that technology produced by some firms is more relevant than that produced by other firms. Many firms nowadays derive benefits from different external R&D sources by following an 'open' innovation model (Chesbrough, 2006), and therefore in order to capture these complementarity effects other approaches have been developed. Limiting inter-industry rent effects to technology, Terleckyj (1974), Sveikauskas (1981), Wolff and Nadiri (1993) and others utilize input-output or capital flows matrices to construct weights assuming that an industry that buys relatively more from a certain industry will benefit relatively more from (product-oriented) R&D in that industry. A related approach is chosen by Griliches and Lichtenberg (1984), Sterlacchini (1989) and Mohnen and Lépine (1991), who use matrices in which either patents or innovations are classified according to their industry of manufacture and origin of use, using the patent indicator as a measure of rent spillovers.

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