Open innovation, Triple Helix and regional innovation systems

Exploring CATAPULT Centres in the UK

Christopher Kerry and Michael Danson

Abstract: *Through the lens of UK CATAPULT Centres this conceptual paper presents an examination of the links between open innovation, the Triple Helix model and regional innovation systems. Highlighting the importance of boundary-spanning intermediaries, the combined role of these concepts is explored in detail. A conceptual model is then proposed which shows how the Triple Helix model of innovation occurs within regional innovation systems, and how it is underpinned by open innovation principles. Finally, areas requiring further research are discussed, with a call for further emphasis on and exploration of the overlapping nature of the concepts.*

Keywords: *CATAPULT Centres; innovation intermediaries; open innovation; regional innovation systems; Triple Helix*

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Over the years the importance of developing national and regional innovation systems to generate economic growth has gained considerable traction in academic and policy making circles. To this end, the recent emphasis of the UK government's policy initiatives has been on assisting activities that generate innovation through the formation of publicly funded technology and innovation centres. Dotted around the UK, CATAPULT Centres are the offshoot of a report by Hermann Hauser (Hauser, 2010) for the Department of Business, Innovation and Skills on the current and future role of technology and innovation centres. These intermediary organizations represent a concerted effort to bring together the three helixes of science, industry and government (the Triple Helix – see Etzkowitz and Leydesdorff, 1995), creating an infrastructure that bridges the spectrum of activities between research and commercialization of technology. They have been created for UK industries that have global markets, world leading research capabilities and the ability to exploit technology and finance investment (Technology Strategy Board, 2012). Such links – between science, industry and government – have been widely discussed in relation to regional innovation, performance and development (for example, Audretsch *et al*, 2012; Hewitt-Dundas and Roper, 2011; Lawton Smith and Bagchi-Sen, 2010).

This paper posits that there is a considerable theoretical overlap between literature on the Triple Helix model/systems and literature on open innovation. Nakwa and Zawdie (2012) have highlighted that intermediary organizations act as brokers and boundary-spanners in the Triple Helix model, forging linkages between universities, industry and government agencies through fostering engagement in collaborative schemes. This process is synonymous with the principles of open innovation. Here, we argue that both the regional innovation systems research stream and the Triple Helix stream are rooted in open innovation thinking, and that these concepts need to be explored cohesively. Currently there is a lack of any published discussion on how these related concepts theoretically intertwine; in addition, how open innovation, the Triple Helix and regional innovation systems play a combined and equal role in driving economic growth needs further consideration. Open innovation has now become the *de facto* term for activity that involves the innovation process of organizations interacting with their external environment through exploring, exploiting and expanding knowledge (Lichtenthaler, 2011). Because this single label is assigned to a multitude of academic concepts it has often become an umbrella term, coinciding with a booming interest in outsourcing, networks, collaboration, technology and the Internet (Huizingh, 2011). Therefore, through the lens of UK CATAPULT Centres this conceptual paper aims:

- To highlight and discuss the theoretical overlap between regional innovation systems, the Triple Helix and open innovation; and
- To add to our understanding of how CATAPULT Centres help drive and support innovation activities at a regional level, connecting science, industry and governmental organizations.

The paper is structured as follows. First, we introduce the concept of regional innovation systems. Then, citing CATAPULT Centres as an example, we establish the link between the need for 'public policies' supporting regional innovation systems and the Triple Helix model of innovation. We discuss the role of innovation intermediaries, outlining their importance in organizational boundary spanning activities; and then we explain the relevance of open innovation, highlighting how it underpins both concepts, and propose a conceptual model that shows these overlaps. Finally, we outline areas for further research.

Regional innovation systems

The consensus of academics, entrepreneurs and policy makers has long been that innovation is a crucial factor in generating economic growth and development. Increasingly there is evidence to suggest that levels of innovation differ between different geographical areas, particularly at a regional level. As a result, the importance of regional innovation systems has steadily entered academic consciousness over time, increasing attention on regions as designated sites of innovation and competitiveness and focusing on the interrelationships between technology, innovation and location (D'Allura *et al*, 2012). According to Archibugi *et al* (1999), work on innovation systems arose from a desire among academics for a conceptual construct of the innovation process and a reinterpretation of the 'structural economics' of Dahmen (1970), Hirschman (1958) and Perroux (1969), with much of the early research in innovation systems coming from the IKE (Innovation, Knowledge and Economic Dynamics) Group at Aalborg University in Denmark. It was argued that studies such as those of Andersen *et al* (1981) highlighted the strength of Danish exports of machinery in agriculture, confirming the role of the home market in export specialization and establishing that trade statistics can provide for the comparison and characterization of production systems. This led Lundvall (1985) to coin the term 'innovation systems' in his work on product innovation and user–producer interaction (use of this latter term has steadily evolved, to encompass the variety of related concepts that we see today), accelerating studies which analysed uniqueness and stability of national systems, explored the theoretical assumptions behind the approach, and highlighted the importance of relationships and interactions between agents (Archibugi *et al*, 1999).

In fact, such was the interest in and support for this movement that research on the competitiveness of different systems, the importance of home markets and the importance of government and related industries in providing competitive advantage started to become mainstream in the early 1990s, as a result of Porter's (1990) introduction of the diamond model outlining why particular industries become competitive in certain locations. Work on 'national systems of innovation' has, however, proven to be far more difficult to conceptualize than was first anticipated, particularly in relation to what exactly constitutes a 'national' system. Initially, national systems were seen as having two dimensions – a national–cultural element and an étatist–political dimension – but in reality such an abstract notion is difficult to find (Archibugi *et al*, 1999). As a result, the conceptualization of national systems of innovation has since been widened to include systems of innovation that are sectoral and those at different geographical scales, such as local, regional and continental levels (Freeman, 1995). Authors such as Bo Carlsson and Franco Malerba have, respectively, also introduced concepts such as 'technological systems' and 'sectoral systems of innovation'. Complementing this, studies by, for example, Asheim and Isaksen (2002), Doloreux (2002), Doloreux and Parto (2005) and Cooke

(2008) have gone to great lengths to further the regional aspect of innovation system research – the focus of this paper – with regional innovation systems becoming a widely used approach to explain patterns of innovation and its processes (Fiore *et al*, 2011).

The concepts of knowledge and learning (Archibugi *et al*, 1999) lie at the heart of all work on innovation systems. According to Asheim *et al* (2003) the underlying idea behind regional innovation systems is that territorial agglomeration provides the best context for an innovation-based economy, because knowledge is 'sticky' and grounded in social interaction, with interactive learning processes operating at a localized level. Fiore *et al* (2011, p 1401) argued that several factors determine the emergence and prosperity of regional innovation systems:

- The presence of high-tech industries, potentially oriented towards international markets;
- Relationships between firms and university system;
- A specialized labour market and labour force, with readily available, highly skilled human capital;
- Local traditions of cooperation and entrepreneurial approaches;
- Supporting agencies and organizations (Asheim and Isaksen, 2002);
- The presence of social capital: shared norms, values and trust, which facilitate relationships and mutual understanding and learning (Lorenzen, 1998; Landry *et al*, 2002); and
- Financial capacity.

As D'Allura *et al* (2012) suggested, appropriate 'public policies' are necessary in order to overcome market failures. While regional innovation systems emphasize both the importance of geography in the development of technology and that support of such systems provides localization and spatial concentration benefits, the presence of local actors is often not sufficient to support the process of sustainable growth. To ensure the prospect of success, therefore, there are times when government must ensure the full deployment of regional innovation system development factors.

The UK has often failed to take full advantage of its scientific capability, falling short on translating scientific discoveries into leading positions in new industries (Hauser, 2010). The UK government, in attempting to address this failing, has supported the creation of CATAPULT Centres. These centres are intended to increase the level and success of innovation generating activities and of those involved with them. As will be discussed below, in essence the centres act as functions of a science and innovation strategy that is based on a Triple Helix methodology, aiming to broker interaction between science, industry and government. Thus the centres are a notable example of the role of intermediaries fostering interaction between science, industry and government within a regional innovation system.

Triple Helix model and intermediary organizations

Regional innovation systems often involve organizations working together to enhance their innovation efforts. These interactions often occur between organizations from differing backgrounds. One prominent theory that depicts this interaction is the Triple Helix model. Introduced by Etzkowitz (2003),

> '. . .the Triple Helix model describes interaction among three institutional actors Science (S), Industry or Business (B), and Government (G). These three sub-dynamics, reflecting three selection mechanisms, exchange among themselves functions of knowledge production, wealth creation, and normative control.' (Ivanova, 2014, p 359)

As a conceptual framework for exploring the complex dynamics of the knowledge society, the Triple Helix model was, according to Etzkowitz (2003), developed from his earlier work on the concept of the 'Triple Helix of university–industry–government' relationships introduced in the 1990s. Since then an extensive body of literature has arisen which examines various Triple Helix configurations in both national and regional contexts (see Boardman and Gray, 2010; Lawton Smith and Bagchi-Sen, 2010; Saad and Zawdie, 2011).

It has been argued that Triple Helix interaction between science, industry and government is key to innovation and resultant economic growth (Etzkowitz, 2010). According to Ivanova (2014), previously independent institutional actors from the spheres of science, business and government have been required to react to changing societal boundaries, forming overlapping areas within which the functions of each actor participating in the intersection become interchangeable. It is in these overlapping areas that bilateral interaction occurs. According to Ranga and Etzkowitz (2013), the systematic nature of Triple Helix interactions is emerging from two complementary perspectives – (neo) institutional and (neo) evolutionary – of the Triple Helix literature. These perspectives outline a Triple Helix system as a set of

- 'Components, consisting of the institutional spheres of university [Science], industry and government), each with a wide array of actors';
- 'Relationships between components (technology transfer, collaboration and conflict moderation,

collaborative leadership, substitution, and networking)'; and
- ' "Functions", described as processes taking place in what they call the "Triple Helix spaces" – the "knowledge, innovation and consensus spaces" ' (Ranga and Etzkowitz 2013).

Actors in a Triple Helix system include R&D (for example, interdisciplinary research centres, company R&D departments, public research organizations) and non-R&D innovators (for example, design, production, marketing, acquisition of patents and licences, consultancy services); individual and/or institutional innovators, with Triple Helix systems equally acknowledging the importance of individual innovators and entrepreneurs and their role in initiating and consolidating institutional processes; and/or – and, with regard to this paper, most importantly – single or multi-sphere institutions.

Multi-sphere institutions operate at the intersection of the university, industry and government institutional spheres and synthesize elements of each sphere in their institutional design, in what is known as a 'balanced' Triple Helix regime. Ranga and Etzkowitz (2013) outlined how Triple Helix 'spaces' perform numerous functions, from knowledge generation and diffusion, the creation and development of intellectual and entrepreneurial potential, to bringing together the Triple Helix system components to brainstorm, discuss and evaluate proposals for advancement towards a knowledge-based regime. These multi-sphere institutions will sound familiar to many; that is because there is an established body of work on innovation intermediaries which analyses some of these types of institutions. Innovation intermediaries (organizations such as CATAPULT Centres) operate at the overlapping areas of the three helixes and are known to help facilitate innovation (Nakwa and Zawdie, 2012). Their research has stemmed from the various analyses of systems of innovation, innovation and scientific networks, and the increasingly open nature of innovation (Howells, 2006). Authors such as Watkins and Horley (1986) and Shohet and Prevezer (1996), initially interested in diffusion and technology transfer, identified and explored the role of intermediaries and examined, speculatively, where intermediaries might become involved. Subsequently, interest shifted to analysis of intermediaries as organizations and the types of activities in which they were involved (see Hargadon and Sutton, 1997; McEvily and Zaheer, 1999). All these developments were undertaken while the literature on systems of innovation was also recognizing the existence of intermediary organizations, paying particular attention to policy formulation (Howells, 2006). Intermediaries have also been explored in the context of service activity and service innovation, mainly through the discussion of knowledge-intensive business services (see Miles, 2000; Wood, 2003)

Historically, work on innovation intermediaries has predominantly linked science and industrial sectors, often as science-based non-profit organizations, created when structural holes exist, bridging and closing the gap between disconnected actors and stimulating network dynamics (Kirkels and Duysters, 2010). Structural holes arise when actors neglect information flow outside their groups, generating gaps in information and knowledge flows. This in turn creates a 'moral hazard' problem, rendering the system dysfunctional (Ahuja, 2000). Intermediaries act as sponsors, brokers and boundary-spanners in the expansion of the domain of activities in the three helixes and by blurring boundaries following interactions between their actors. As a result, networks are formed by these brokering intermediaries which play an important role in the forging of links between science, industry and government through engaging them in collaborative schemes (Nakwa and Zawdie, 2012) – see Figure 1. By closing these structural holes opportunistic behaviour is minimized and opportunities for social capital formation arise through the potential for brokerage (Burt, 2004). Innovation intermediaries thus often assume the role of coordinator, gatekeeper or representative, depending on both the nature of their organization and resources and the environment in which they finds themselves (Fernandez and Gould, 1994).

Organizations and/or initiatives that broker links between industry, science and government therefore help develop the conditions for a successful regional innovation system. Policies that foster and stimulate formal relationships between higher education and industry stimulate a broader awareness of the benefits of direct cooperation and help them draw on their corresponding fields of knowledge (Fernandes and Ferreira, 2013). Each helix can play a larger/smaller role in some regional systems than in others. For example, the roles and impact of universities often vary within any regional helix space (Martinelli *et al*, 2008). Despite this, however, as authors from a wide range of fields have shown, organizations and/or initiatives that bridge the three helixes are in general particularly useful for satisfying some of the outlined criteria of successful regional innovation systems. They can:

- Provide support for high-tech industries through building relationships between firms and the university system;
- Facilitate local cooperation and an entrepreneurial approach; and

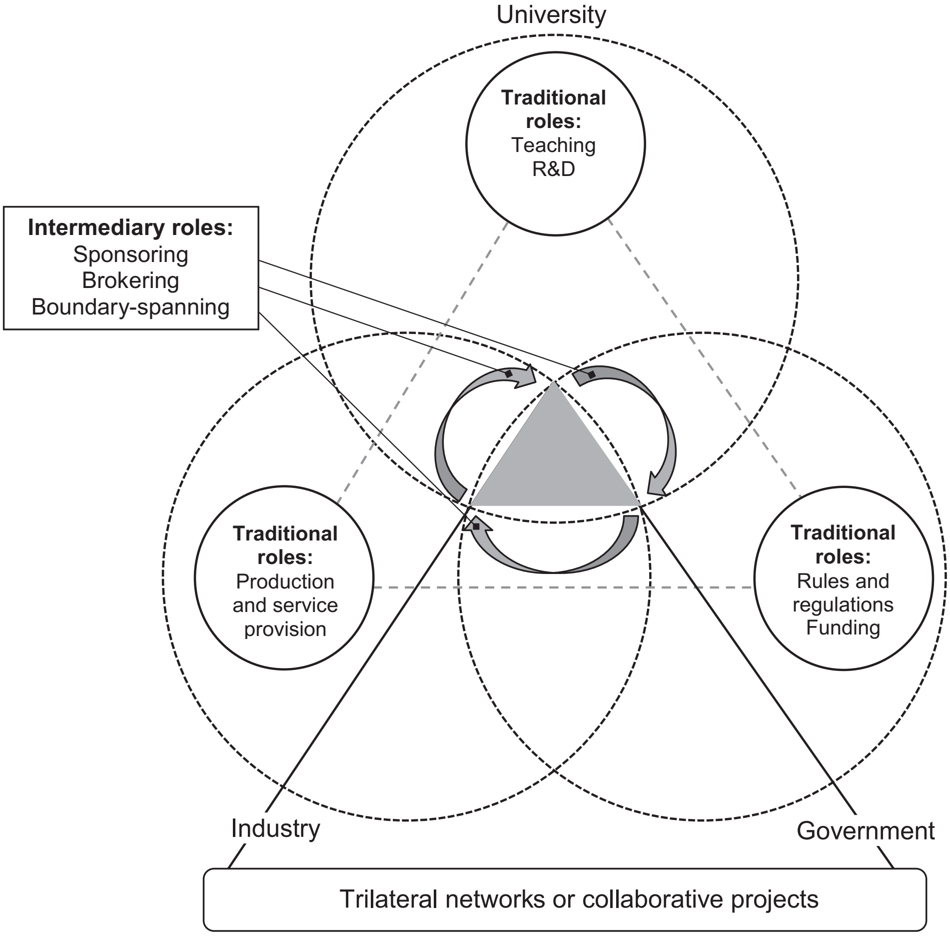

Figure 1. Intermediaries in the Triple Helix model.
Source: Nakwa and Zawdie, 2012.

- Facilitate knowledge spill overs which help support and inform a specialized labour market and labour force, with readily available, highly skilled human capital.

In some cases intermediary organizations can also provide the financial capacity for the development of technology that would otherwise remain latent, such as through the use of publically funded research centres (see Hewitt-Dundas and Roper, 2011).

Various examples from the literature support such claims. For example, Lawton Smith and Bagchi-Sen (2010) illustrated the importance of the Triple Helix network on regional development in their analysis of the biotech-intensive region of Oxfordshire. Together with various regional initiatives designed to provide capacity through funding networks, Lawton Smith and Bagchi-Sen highlighted the key role of boundary-spanning organizations established by both a local charitable trust (Oxfordshire BiotechNet, now OBN) and more recently in a public–private partnership (DiagnOx). These organizations provide networks that support and promote biotechnology business and research enterprise across Oxfordshire. Crucially, not only do these help support cross-helix engagement between universities, firms and government, but also they contribute to the relocation of many organizations into the area, promoting regional innovation activity.

Underpinning Triple Helix and regional innovation systems: open innovation

Something often overlooked is that at a theoretical level these models of innovation are underpinned by a shift in thinking from a closed method of research, development and commercialization to a more ‘open’ one. It is this shift that has been one of the major driving forces behind the emergence of Triple Helix systems and intermediary organizations, and the subsequent impact on regional systems of innovation.

‘Open Innovation’, first proposed by Henry Chesbrough (2003) and a relatively recent development, has grown rapidly in prominence in the academic discourse. This change reflects how, in the current global marketplace, organizations from a variety of settings are increasingly acknowledging that to gain a competitive advantage they need to capitalize on resources that are beyond the boundary of the firm (Chesbrough, 2003; Lichtenthaler, 2011; Tödtling *et al*, 2011; Abuhamad and Shaltoni, 2013). This has been driven by changes in the global social and economic background, prompting developments in the wider innovation environment, the growth of individual forces such as globalization, improved market institutions, and the rise of new technologies in communications (Huizingh, 2011; Chesbrough, 2003).

As Chesbrough stated, 'Open Innovation is the use of purposive inflows and outflows of knowledge to accelerate internal innovation and expand the markets for external use of innovation' (Chesbrough, 2006, p 1). In practice, researchers have tended to use a range of definitions, as a result of open innovation's variety of applications, so that it has become much more difficult to identify a coherent body of knowledge. For example, Christiansen *et al* (2013) emphasized how open innovation had been discussed as a management practice (Dahlander and Gann, 2010), as a conceptual construct (Euchner, 2010; Huizingh, 2011), as a strategy (Igartua *et al*, 2010; Bowonder *et al*, 2010), and as a research field (Elmquist *et al*, 2009). Those difficulties aside, perhaps the clearest way to visualize open innovation is as the opposite of 'closed' innovation:

> '[In a closed model] companies must generate their own ideas, and then develop them, build them, market them, distribute them, service them, finance them, and support them on their own.' (Chesbrough, 2003, p 20)

Closed innovation principles were at the core of innovation models throughout the 1950s, 1960s, 1970s and the 1980s, particularly in the technology-push and market-pull models, but also in the coupling model and the interactive model. Such models focused on the sequential research and development process, relying on internal R&D, and this simply varied depending on whether innovation was driven by market or supply-side forces or, in some instances, a combination of both (Trott 2008). Innovation projects under a closed model can only enter the innovation process at the very beginning of a development cycle, be developed using a firm's internal resources and competencies, and then can only be commercialized via a firm's own distribution channels (Herzog and Leker, 2011). Open innovation, however, describes the opposite process, that of knowledge permeating organizational boundaries. According to Gassmann and Enkel (2004), as a process it can be broken down into three core archetypes:

(1) The *outside-in process* – enriching an organization's own knowledge base through the integration of suppliers, customers and external knowledge sourcing, which can increase a company's innovativeness;
(2) The *inside-out process* – earning profits by bringing ideas to market, selling IP and multiplying technology by transferring ideas to the outside environment; and
(3) The *coupled process* – coupling the *outside-in* and *inside-out* processes by working in alliances with complementary partners in which give and take is crucial for success. (Gassmann and Enkel, 2004, p 6: see also Figure 2)

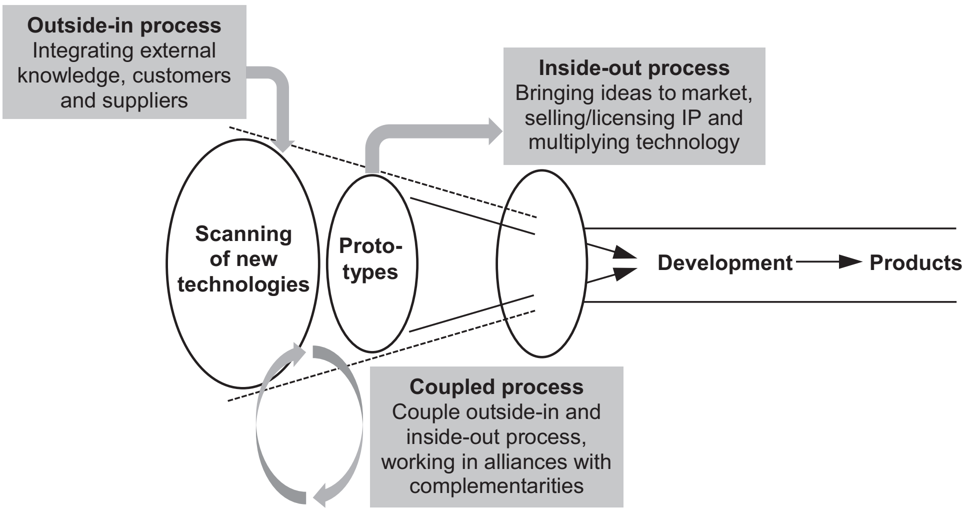

Figure 2. Open innovation model.
Source: Gassmann and Enkel, 2004, p 7.

Most organizations now adopt open innovation principles in their innovation generating activities. They can become a customer or supplier of their former internal projects (creating value generating opportunities that otherwise would not exist); this in turn can allow others to develop a firm's non-strategic initiatives, make a firm's intellectual property (IP) work harder for both their own business and that of another, grow the entire eco-system to the benefit of the firm, reduce costs, and expand participation (Chesbrough and Crowther, 2006). Globally renowned organizations such as Cisco Systems, Intel, Microsoft and Nokia rose in prominence often doing little or no research of their own (Chesbrough, 2003), being eager to take advantage of the benefits of an open approach.

It is successes like these that have spurred the rise of open innovation not only as an academic subject but also in its application in practitioner circles (such as CATAPULT Centres). Despite this, many organizations still require further support in their open innovation efforts. Whilst acknowledging the need for governments to support a Triple Helix and regional system of innovation, it has been argued (Chesbrough *et al*, 2011; Wang *et al*, 2012) that innovation policy makers should also formally promote and support open innovation processes and activities. According to Levy and Reid (2011), the UK at that time still had a long way to go to take advantage of the 'open goal' of benefits that can be secured through supporting open innovation. Levy and Reid argued that in addition to encouraging innovation practices in organizations to enable them to become more open the UK government should also contemplate developing markets that support innovation through the generation of infrastructures which support open innovation practices in key industries aligned with the UK economy's strengths. In addition, authors such as Chesbrough *et al* (2011) have highlighted where European innovation policy makers should focus their efforts in the near future: on improved education and human capital development; improved financing for open innovation; a balanced approach to IP; the promotion of cooperation and competition; and the expansion of open governments.

Wang *et al* (2012) have championed the use of the national system of innovation as a potential driving force behind the adoption of open innovation, arguing that any system of innovation should seek to develop technology markets, foster linkages between organizations, develop regimes for knowledge appropriation with regard to protection of IP, support basic research, and increase the supply of high quality labour. Because open innovation practices are also said to be positively affected by a continuous supply of outside knowledge, highly educated personnel, financial resources and effective legal systems (Wang *et al*, 2012), what is clear is that an effective system of innovation requires public bodies to support fully activities that foster the preconditions of open innovation, and to support activities that activate and maintain the purposeful inflows and outflows of knowledge among the various actors (Chesbrough *et al*, 2011; Levy and Reid, 2011; Westergren and Holmström, 2008).

The pre-conditions of open innovation include ensuring that organizations and networks are aware of the importance of openness, that they thoroughly examine external ties and trust constructs, ensure that there is mutual trust between organizations, containing risk and managing co-dependencies, and ensure that information technology is fully enabled in organizations (because it is a fundamental part of the communication and exchange landscape) (Westergren and Holmström, 2008). Open innovation practices are also dependent on the availability of external knowledge and resources; thus a system of innovation which provides the supply of such knowledge is crucial (Wang *et al*, 2012).

Illustrating the link between the three concepts: CATAPULT Centres

Innovation intermediaries such as CATAPULT Centres are ideally placed to play a role in helping drive the adoption of open innovation at a regional level. The Centres aim to 'de-risk' innovation by providing a range of services throughout the research and development cycle, acting as both an anchor and a catalyst for new markets, innovative sectors, clusters and networks. They act as enablers in the transfer of knowledge, resources, IP and skills between the private, public, educational and political sectors, providing all the while an element of financial stability through the use of multiple sources of funding (Andersen and Le Blanc, 2013). Operating at higher technology readiness levels (TRL 3–8) than other institutions such as public research centres (TRL 1–3), there are currently seven Centres.[1] These deal with cell therapy, the connected digital economy and future cities (based in London); high value manufacturing (based in Warwick, Sheffield, Strathclyde and Bristol); offshore renewable energy (Glasgow and Northumberland); satellite applications (Oxford); and transport systems (Milton Keynes). These Centres, despite a national remit, often work closely with organizations from science, industry and government in the region in which they are based.

For example, the high-value manufacturing (HVM) CATAPULT, through the Advanced Manufacturing Research Centre, has worked with TATA Motors 'to identify areas where automation can be introduced to reduce manual intervention, that could be retrofitted to existing systems of work for the annealing of large steel bars in the rolling mills at the Stocksbridge [Sheffield] site' (CATAPULT.org.uk, 2013a). Similarly, in recognizing that 'the development of offshore renewable energy presents significant economic opportunities for local and regional economies', the offshore renewable energy (ORE) CATAPULT works with local enterprise partnerships (LEPs) such as Humber LEP, North Eastern LEP and Tees Valley LEP (all within CORE Centres of Offshore Renewable Engineering areas) to identify how they '. . .can collectively work together to deliver relevant aspects of LEP Strategic Economic Plans . . . and also ORE CATAPULT's objectives of generating economic benefit for the UK economy and lowering the price of offshore renewable energy' (CATAPULT.org.uk, 2014a). Interestingly, the LEPs closely related to the ORE centre are all based in England; as such, the question of how this body interacts with the devolved government, and enterprises and universities, in Scotland (where there is a particular emphasis, independent of the British Parliament at Westminster, on renewables across all three helixes) and, similarly, with the Welsh Assembly, is worthy of further analysis.

The activities of CATAPULT Centres, particularly those cross-helix interactions in a given regional innovation space, display numerous open innovation characteristics. Organizations display both outside-in processes and inside-out processes. A typical example is the recent development of new thread-rolling processes for the aerospace industry, where Arrowsmith Engineering worked closely with the Manufacturing Technology Centre (MTC, part of the HVM CATAPULT), sharing ideas, information and knowledge. Working through the development process from start to finish, using ideas and expertise gained from employees of the MTC, techniques were developed that resulted in manufacturing processes in which quality was kept high and manufacturing costs were reduced (outside-in) (CATAPULT.org.uk, 2015a). Conversely, technologies traditionally used mainly in the automotive and aerospace industries are being developed as a result of knowledge spill-overs from other sectors (inside-out). For example, the Centre for Process Innovation (CPI, part of the HVM CATAPULT) is applying the knowledge gained in previous projects in the automotive and aerospace industries to a joint-industry project involving the Peacocks Medical Group and a number of academic and industrial partners, commercializing additive manufacturing for customized orthotics (technology multiplication) (CATAPULT.org.uk, 2015b). Furthermore, CATAPULT Centres – the ORE CATAPULT is one – are running activities such as innovation challenges in wave, tidal and offshore wind energy generation in an attempt to broaden their resource pool of knowledge and ideas. These follow a three-step process: first, the CATAPULT Centre asks interested parties to respond to individual challenges with innovative ideas; second, these are then assessed for suitability; and, third, there is engagement with successful entries, in an attempt to foster a collaborative relationship. Unsuccessful applicants are offered support, including introduction to contacts in support agencies, funding bodies and industry (CATAPULT.org.uk, 2015c).

In addition, it is generally the case that organizations active in these centres come from all three helixes. For example, science-based organizations that have worked with the HVM CATAPULT include the Universities of Sheffield and Warwick and non-university organizations such as the Centre for Process Innovation and the Argonne National Laboratory. As well as being funded by the UK government, these centres also engage with government-supported organizations such as NESTA, LEPs, government departments and individual Members of Parliament. Organizations from industry such as Rolls-Royce, SSE and Jaguar Land Rover also routinely work with these CATAPULT Centres.

This cross-helix collaboration has already resulted in a number of innovation-generating outputs. For example, UK design studio Cohda worked with the Centre for Process Innovation on the integration of printed electronics to enhance significantly the functionality of their 'Crypsis Lighting' product and to develop the product from prototype to full commercial manufacture (CATAPULT.org.uk, 2014b). Similarly, the capabilities of the Warwick Manufacturing Group's Energy Innovation Centre (a centre within the high-value manufacturing catapult) were used to support Drayson Racing Technologies in achieving the world land speed record, testing and developing the e-motors that would be used in the world record attempt (CATAPULT.org.uk, 2013b).

Examples such as these indicate how CATAPULT Centres can contribute to a regional innovation system. Centres such as the HVM CATAPULT certainly support the presence of high-tech industries in their locality: Drayson Racing is located some 50 miles from the WMG Energy Innovation Centre and is at the forefront of high-speed automotive engineering. There are other related organizations in the automotive industry, including Lotus F1, Vision Motorsport, Arden International Motorsport and Prodrive, in the same vicinity. These sorts of centres provide an outlet in which academic knowledge and research can be applied in an industrial setting, strengthening the link between universities and firms, providing a specialized labour force able to assist in the development of complex technologies, and developing social capital between those involved. In addition there are often opportunities for the centres to provide access to facilities that would otherwise be unavailable or prohibitively expensive.

Conclusions

As the above shows, it is clear that CATAPULT Centres not only involve organizations from science, industry and government, but also operate as intermediaries brokering collaboration between combinations of the three helixes, resulting in innovation generating activities: the Triple Helix model of innovation. These intermediaries thus act not only as brokers but also as sponsors and boundary-spanners. We would argue that intermediary organizations operating in the overlapping areas of the three helixes can influence positively the factors that contribute to a successful regional system of innovation. The emergence of this regional innovation system is underpinned by changes in the business environment such that the organizations involved embrace the principles of open innovation (see Figure 3).

We have highlighted here research which has identified factors contributing to a successful regional innovation system. These include 'the presence of high-tech industries, potentially oriented towards international markets; relationships between firms and university system; a specialized labour market and labour force, with readily available, highly skilled human capital; local traditions of co-operation and entrepreneurial approach; and supporting agencies and organizations'

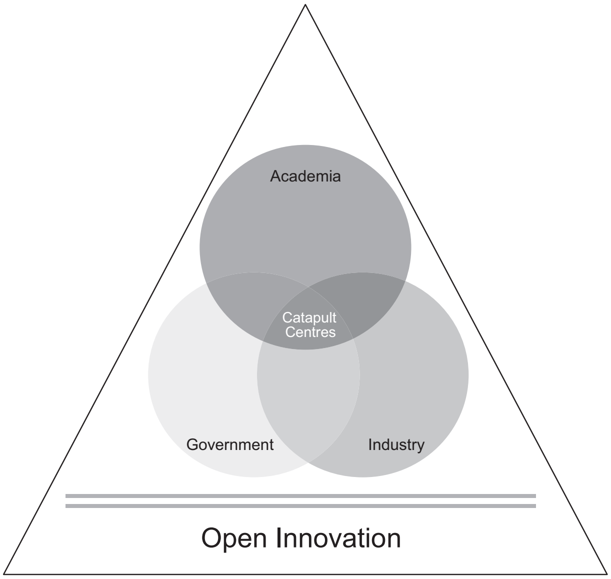

Figure 3. Conceptual model of regional innovation system, Triple Helix and open innovation integration.

(Asheim and Isaksen, 2002); 'the presence of social capital: shared norms, values and trust, which facilitate relationship and mutual understanding and learning' (Lorenzen, 1998; Landry *et al*, 2002); and 'financial capacity' (Fiore *et al*, 2011, p 1401).

Examples have been presented in brief of projects that contributed to the development of regional innovation systems: several projects involving CATAPULT Centres have been identified as particularly pertinent. As a result, the contribution to the success of a regional innovation system by intermediaries operating in a Triple Helix model of innovation has been illustrated – for instance, the collaborative development of e-motor technology between the HVM CATAPULT and Drayson Racing. This particular programme showed how intermediaries funded by the government, such as CATAPULT Centres, could help support high-tech industries in their locality, applying expertise from science to industry.

We have shown how links with the concept of open innovation can made. An 'open innovation' landscape is what underpins the emergence of both the Triple Helix model of innovation and the subsequent development of regional innovation systems; we have offered typical examples of the activities of CATAPULT Centres displaying open innovation characteristics and activities. We would argue strongly that innovation policy makers should not only support a Triple Helix model of innovation and the regional innovation system, but also promote and support open innovation activity in organizations. We argue further that by doing so organizations will then be better placed to take advantage of the benefits of open innovation.

That said, it is important to note that the topics discussed here are still being debated in their respective research fields. Authors as far back as Cooke and Morgan (1998) have suggested that, despite arguments to the contrary, there have only been three historically successful regional innovation systems: Silicon Valley (California), Emilia-Romagana (Italy), and Baden-Württemberg (Germany). Consequently there is still reliance on much of the literature from 1995–2003, which focused on the definition and existence of regional innovation systems. According to Doloreux and Parto (2004) the concept requires further development, despite these efforts. Work on regional innovation systems is often said to suffer from bias, by the authors themselves and epistemologically. For example, the analysis of the intellectual structure of the regional innovation systems field has been conducted according to subjective and qualitative approaches, and there is an absence of research that adopts a holistic view of the role of single-focus firms in the development of a regional innovation system (D'Allura *et al*, 2012). Consequently a broad and thorough revisiting of the conceptual foundations of the area might highlight further its relevance in explaining existing phenomenon.

Supplementary empirical studies investigating the role of intermediaries as sponsors, brokers and boundary-spanners would emphasize further the integrative nature of the concepts and provide extra theoretical validation. In addition, the Triple Helix model has recently been expanded to include four, or even *n*, helixes; for example, Rieu (2011) has introduced the public or 'society' as an additional sphere of influence. Further studies might wish to examine the authenticity of these additional helixes and assess how they fit into the activities of intermediaries and the regional system of innovation. The role and impact of science, industry and government in different regions and the subsequent impact on the activities of intermediaries may also provide an interesting avenue for further exploration. For instance, the roles and impacts of universities often vary from one regional helix space to another (Martinelli *et al*, 2008); comparing and contrasting different regions might – or might not – highlight intermediaries performing different roles and activities. How these fit into an overall national system of innovation, together with factors that contribute to the success of projects involving intermediary organizations (such as CATAPULT Centres) would also further our understanding of the innovation process.

In addition, the IP implications of open innovation are a major concern for many people; and how the results of successes or failures of projects involving multiple actors are redistributed is still a largely unresolved issue. Related to this, authors such as Chesbrough (2012) have openly supported the use of a business model that involves the protection of IP to sustain investment and allow for scale effects. Chesbrough suggested that IP protection actually enables companies to collaborate and coordinate confident in the knowledge that they will be able to enjoy some protection from direct imitation by others in the community. A report by the Big Innovation Centre on UK CATAPULTS stated that IP accounted for 0% of revenue in 60% of business cases that go through the Centre (Andersen and Le Blanc, 2013). This highlights the lack of clarity and understanding about the importance of IP in the open innovation arena. While some authors – for example, Kline (2003) – have suggested that governance structures such as licensing agreements can support IP patents, others – such as Kinsella (2001) – have called for a radical rethink in how IP is understood. A systematic analysis of open innovation environments, recording how knowledge, learning and the rewards/costs of business are redistributed and protected, would therefore be beneficial. Until that has been done, however, any analysis serves only to highlight redistribution tendencies of that particular phenomenon.

Despite these limitations, arguments for and against the competing models of innovation have been at the heart of the innovation debate for a number of years, with the supporters of particular models vehemently defending and arguing for or against the theoretical merits of each. We take the view that, rather than discussing, comparing and arguing the theoretical merits of each individual model, progress would be better served by focusing in greater detail on the overlaps, bringing the models together instead of pushing them apart. It is hoped that this paper represents a step in that direction.

Notes

[1]Technology Readiness Levels were developed in the 1960s by NASA and are '. . .are a type of measurement system used to assess the maturity level of a particular technology. Each technology project is evaluated against the parameters for each technology level and is then assigned a TRL rating based on the projects progress. There are nine technology readiness levels. TRL 1 is the lowest and TRL 9 is the highest.' See: https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html and http://esto.nasa.gov/files/trl_definitions.pdf.

References

Abuhamad, A., and Shaltoni, A.M. (2013), 'Open innovations and international collaboration in the context of emerging economies', *International Journal of Business* and *Management*, Vol 8, No 8, p 12, http://search.ebscohost.com/login.aspx?direct=true&db=edb&AN=87080469&site=eds-live.

Ahuja, G. (2000), 'Collaboration networks, structural holes, and innovation: a longitudinal study', *Administrative Science Quarterly*, Vol 45, No 3, pp 425–455.

Andersen, B., and Le Blanc, E. (2013), *Catapult To Success: Be Ambitious, Bold and Enterprising – Learning from European Technology and Innovation Centres*, Big Innovation Centre, London, http://www.biginnovationcentre.com/Assets/Docs/Catapult-to-Success-report-final.pdf.

Anderson, E.S., Dalum, B., and Willumsen, G. (1981), *International Specialisation and the Home Market – An Empirical Analysis*, Aalborg, Aalborg University Press.

Archibugi, D., Howells, J., and Michie, J. (1999), *Innovation Policy in a Global Economy*, Cambridge University Press, Cambridge.

Asheim, B.T., and Isaksen, A. (2002), 'Regional innovation systems: the integration of local "sticky" and global "ubiquitous" knowledge', *Journal of Technology Transfer*, Vol 27, No 1, pp 77–86.

Asheim, B.T., Coenen, L., and Svensson-Henning, M. (2003), *Nordic SMEs and Regional Innovation Systems*, Lund, Sweden, http://www.nordicinnovation.org/Global/Publications/Reports/2003/Nordic SMEs and Regional Innovation Systems.pdf.

Audretsch, D.B., Hülsbeck, M., and Lehmann, E.E. (2012), 'Regional competitiveness, university spillovers and

entrepreneurial activity', *Small Business Economics*, Vol 39, No 3, pp 587–601.
Boardman, C., and Gray, D. (2010), 'The new science and engineering management: cooperative research centers as government policies, industry strategies, and organizations', *Journal of Technology Transfer*, Vol 35, No 5, pp 445–459.
Bowonder, B., Dambal, A., Kumar, S., and Shirodkar, A. (2010), 'Innovation strategies for creating competitive advantage', *Research Technology Management,* Vol 53, No 3, pp 19–32.
Burt, R.S. (2004), 'Structural holes and good ideas', *American Journal of Sociology*, Vol 110, No 2, pp 349–399.
CATAPULT.org.uk (2013a), *Drayson Racing Technologies: e-Motor Testing for a New World Land Speed Record*, https://hvm.catapult.org.uk/case-studies-details/-/asset_publisher/YFXiSex5cXid/content/drayson-racing-technologies-e-motor-testing-for-a-new-world-land-speed-record/2157642 (accessed 22 December 2014).
CATAPULT.org.uk (2013b), *TATA Steel*, https://hvm.catapult.org.uk/case-studies-details/-/asset_publisher/YFXiSex5cXid/content/tata-steel/2157642 (accessed 22 December 2014).
CATAPULT.org.uk (2014a), *CPI and Cohda Use Printed Electronics to Optimise Crypsis Lighting,* https://hvm.catapult.org.uk/case-studies-details/-/assetpublisher/YFXiSex5cXid/content/cpi-and-cohda-use-printed-electronics-to-optimise-crypsis-lighting/2157642 (accessed 22 December 2014).
CATAPULT.org.uk (2014b), *Local Enterprise Partnerships (LEPs)*, https://ore.catapult.org.uk/local-enterprise-partnerships-leps- (accessed 22 December 2014).
CATAPULT.org.uk (2015a), *Additive Manufacturing for Medical Applications*, https://hvm.catapult.org.uk/case-studies-details/-/asset_publisher/YFXiSex5cXid/content/additive-manufacturing-for-medical-applications/2157642 (accessed 17 August 2015).
CATAPULT.org.uk (2015b), *Development of New Thread-Rolling Processes for the Aerospace Industry*, https://hvm.catapult.org.uk/case-studies-details/-/asset_publisher/YFXiSex5cXid/content/development-of-new-thread-rolling-processes-for-the-aerospace-industry/2157642r/YFXiSex5cXid/content/development-of-new-thread-rolling-processes-for-the-aerospace-industry/2157642 (accessed 17 August 2015).
CATAPULT.org.uk (2015c), *Innovation Challenges*, https://ore.catapult.org.uk/innovation-challenges (accessed 17 August 2015).
Chesbrough, H. (2003), *Open Innovation: The New Imperative for Creating and Profiting from Technology*, Harvard Business Press, Watertown, MA, http://search.ebscohost.com/login.aspx?direct=true&db=buh&AN=24090742&site=ehost-live.
Chesbrough, H. (2006), *Open Business Models: How to Thrive in the New Innovation Landscape*, Harvard Business Press, Watertown, MA.
Chesbrough, H. (2012), 'Open innovation', *Research Technology Management*, Vol 55, No 4, pp 20–27, http://search.ebscohost.com/login.aspx?direct=true&db=buh&AN=77491383&site=ehost-live.
Chesbrough, H., and Crowther, A.K. (2006), 'Beyond high tech: early adopters of open innovation in other industries', *R&D Management*, Vol 36, No 3, pp 229–236.
Chesbrough, H., Vanhaverbeke, W., Bakici, T., and Lopez-Vega, H. (2011), *Open Innovation and Public Policy in Europe*, ESADE Business School, Barcelona, http://www.sciencebusiness.net/Assets/27d0282a-3275–4f02–8a3c-b93c2815208c.pdf.
Christiansen, J.K., Gasparin, M., and Varnes, C.J. (2013), 'Improving design with open innovation: a flexible management technology', *Research-Technology Management*, Vol 56, No 2, pp 36–44.
Cooke, P. (2008), 'Regional innovation systems, clean technology and Jacobian cluster-platform policies', *Regional Science Policy and Practice*, Vol 1, No 1, pp 23–45.
Cooke, P., and Morgan, K. (1998), *The Associational Economy: Firms, Regions and Innovation*, Oxford University Press, Oxford.
Dahmen, E. (1970), *Entrepreneurial Activity and the Development of Swedish Industry, 1919–1939* (American Economic Association, Translation Series), Richard E. Irwin, Homewood, IL.
D'Allura, G.M., Galvagno, M., and Mocciaro Li Destri, A. (2012), 'Regional innovation systems: a literature review', *Business Systems Review*, Vol 1, No 1, pp 139–156.
Doloreux, D. (2002), 'What we should know about regional systems of innovation', *Technology in Society*, Vol 24, No 3, pp 243–263.
Doloreux, D., and Parto, S. (2004), *Regional Innovation Systems: A Critical Synthesis*, Institute for New Technologies, United Nations University, Maastricht.
Doloreux, D., and Parto, S. (2005), 'Regional innovation systems: current discourse and unresolved issues', *Technology in Society*, Vol 27, No 2, pp 133–153.
Etzkowitz, H. (2003), 'Innovation in innovation: the Triple Helix of university–industry–government relations', *Social Science Information*, Vol 42, No 3, pp 293–337.
Etzkowitz, H. (2010), *The Triple Helix: University–Industry–Government Innovation in Action*, Abingdon, Routledge.
Etzkowitz, H., and Leydesdorff, L. (1995), 'The Triple Helix – university–industry–government relations: a laboratory for knowledge-based economic development', *EASST Review*, Vol 14, No 1, pp 14–19.
Euchner, J.A. (2010), 'Two flavours of open innovation', *Research-Technology Management*, Vol 53, No 4, pp 7–8.
Fernandes, C.I., and Ferreira, J.J.M. (2013), 'Knowledge spillovers: cooperation between universities and KIBS', *R&D Management*, Vol 43, No 5, pp 461–472.
Fernandez, R.M., and Gould, R.V. (1994), 'A dilemma of state power: brokerage and influence in the national health policy domain', *American Journal of Sociology*, Vol 99, pp 1455–1491.
Fiore, A., Grisorio, M.J., and Prota, F. (2011), 'Regional innovation systems: which role for public policies and innovation agencies? Some insights from the experience of an Italian region', *European Planning Studies*, Vol 19, No 8, pp 1399–1422.
Freeman, C. (1995), 'The "National System of Innovation" in historical perspective', *Cambridge Journal of Economics*, Vol 19, No 1, pp 5–24.
Gassmann, O., and Enkel, E. (2004), 'Towards a theory of open innovation: three core process archetypes', *Proceedings of the R&D Management Conference, 6–9 July, Lisbon*, pp 1–18.
Hargadon, A., and Sutton, R.I. (1997), 'Technology brokering and innovation in a product development firm', *Administrative Science Quarterly*, Vol 42, No 4, pp 716–749.
Hauser, H. (2010) *The Current and Future Role of Technology and Innovation Centres in the UK*, Department for Business, Innovation and Skills, London, https://www.catapult.org.uk/documents/2155693/2268412/The+Current+and+Future+Role+of+Technology+and+Innovation+Centres+in+the+UK.pdf/acf22ce0–877d-499e-a03e-289bd24717c0?version=1.2.
Herzog, P., and Leker, J. (2011), *Open and Closed Innovation: Different Cultures for Different Strategies,* 2nd edition, Gabler/Springer, Wiesbaden.
Hewitt-Dundas, N., and Roper, S. (2011), 'Creating advantage in peripheral regions: the role of publicly funded R&D centres', *Research Policy*, Vol 40, No 6, pp 832–841.
Hirschman, A. (1958), *The Strategy of Economic Development*, Yale University Press, Newhaven, CT.

Howells, J. (2006), 'Intermediation and the role of intermediaries in innovation', *Research Policy*, Vol 35, No 5, pp 715–728.
Huizingh, E.K.R.E. (2011), 'Open innovation: state of the art and future perspectives', *Technovation*, Vol 31, No 1, pp 2–9.
Igartua, J.I., Garrigos, J.A., and Hervas-Oliver, J.L. (2010), 'How innovation management techniques support an open innovation strategy', *Research-Technology Management*, Vol 53, No 3, pp 41–45.
Ivanova, I. (2014) 'Quadruple helix systems and symmetry: a step towards helix innovation system classification', *Journal of the Knowledge Economy*, Vol 5, No 2, p 357, http://search.ebscohost.com/login.aspx?direct=true&db=edb&AN=96064671&site=eds-live.
Kinsella, N.S. (2001), 'Against intellectual property', *Journal of Libertarian Studies*, Vol 15, No 2, (SEAS SPR), pp 1–54.
Kirkels, Y., and Duysters, G. (2010), 'Brokerage in SME networks', *Research Policy*, Vol 39, No 3, pp 375–385.
Kline, D. (2003), 'Sharing the corporate crown jewels', *MIT Sloan Management Review*, Vol 44, No 3, pp 89–93.
Landry, R., Amara, N., and Lamari, M. (2002), 'Does social capital determine innovation? To what extent?', *Technological Forecasting and Social Change*, Vol 69, No 7, pp 681–701.
Lawton Smith, H., and Bagchi-Sen, S. (2010), 'Triple Helix and regional development: a perspective from Oxfordshire in the UK', *Technology Analysis* and *Strategic Management*, Vol 22, No 7, pp 805–818.
Levy, C., and Reid, B. (2011), *Missing an Open Goal? UK Public Policy and Open Innovation*, Big Innovation Centre, London, http://biginnovationcentre.com/Assets/Docs/Reports/Missing-an-open-goal.pdf.
Lichtenthaler, U. (2011), 'Open innovation: past research, current debates and future directions', *Academy of Management Perspectives*, Vol 25, No 1, pp 75–93, http://search.ebscohost.com/login.aspx?direct=true&db=buh&AN=59198451&site=eds-live.
Lorenzen, M. (1998), *Specialisation and Localized Learning: Six Studies on the European Furniture Industry*, CBS Press, Copenhagen.
Lundvall, B.-Å. (1985) *Product Innovation and User–Producer Interaction*, Aalborg Universitetsforlag Press, Aalborg.
Martinelli, A., Meyer, M., and von Tunzelmann, N. (2008), 'Becoming an entrepreneurial university? A case study of knowledge exchange relationships and faculty attitudes in a medium-sized, research-oriented university', *Journal of Technology Transfer*, Vol 33, No 3, pp 259–283.
McEvily, B., and Zaheer, A. (1999), 'Bridging ties: a source of firm heterogeneity in competitive capabilities', *Strategic Management Journal*, Vol 20, No 12, pp 1133–1156.
Miles, I. (2000), 'Services innovation: coming of age in the knowledge-based economy', *International Journal of Innovation Management*, Vol 4, No 4, pp 371–389.
Nakwa, K., and Zawdie, G. (2012), 'The role of innovation intermediaries in promoting the triple helix system in MNC-dominated industries in Thailand: the case of hard disk drive and automotive sectors', *International Journal of Technology Management and Sustainable Development*, Vol 11, No 3, pp 265–283, http://search.ebscohost.com/login.aspx?direct=true&db=buh&AN=85862504&site=ehost-live.
Perroux, F. (1969), *Indépendance de l'Économie Nationale et Interdépendance des Nations*, Union Générale d'Éditions, Collection Monde en Développement (reprinted in 1971), Paris.
Porter, M.E. (1990), 'The competitive advantage of nations', *Harvard Business Review*, Vol 68, No 2, pp 73–93.
Ranga, M., and Etzkowitz, H. (2013), 'Triple Helix systems: an analytical framework for innovation policy and practice in the knowledge society', *Industry and Higher Education*, Vol 27, No 4, pp 237–262.
Rieu, A.-M. (2011), 'Fourth Helix: sustaining research diversity – the social turn of science and technology policy (the case of Japan)', paper presented at the Triple Helix IX International Conference, 11–14 July 2011, Stanford, http://www.leydesdorff.net/th9/O-127_Rieu%204th%20helix%20Stanford%206–11.pdf
Saad, M., and Zawdie, G. (2011), 'The emerging role of universities in socio-economic development through knowledge networking' [Introduction to Special Issue], *Science and Public Policy*, Vol 38, No 1, pp 3–6.
Shohet, S., and Prevezer, M. (1996), 'UK biotechnology: institutional linkages, technology transfer and the role of intermediaries', *R&D Management*, Vol 26, No 3, pp 283–298.
Technology Strategy Board (2012), *Catapult Update: Shaping the Network of Centres*, https://www.catapult.org.uk/documents/10582/221199/pdf/969a8985–6f77–4fb8–85a8-e4a63a1675d0 (accessed 16 December 2015).
Tödtling, F., Prud'homme van Reine, P., and Dörhöfer, S. (2011), 'Open innovation and regional culture: findings from different industrial and regional settings', *European Planning Studies*, Vol 19, No 11, pp 1885–1907.
Trott, P. (2008), *Innovation Management and New Product Development,* 4th edition, Pearson Education, Harlow.
Wang, Y., Vanhaverbeke, W., and Roijakkers, N. (2012), 'Exploring the impact of open innovation on national systems of innovation: a theoretical analysis', *Technological Forecasting and Social Change*, Vol 79, No 3, pp 419–428.
Watkins, D., and Horley, G. (1986) 'Transferring technology from large to small firms: the role of intermediaries', in Webb, T., Quince, T., and Watkins, D., eds, *Small Business Research*, Gower, Aldershot, pp 215–251.
Westergren, U.H., and Holmström, J. (2008), 'Outsourcing as open innovation: exploring preconditions for the open innovation model in the process industry', in Boland, R., Limayem, M., and Pentland, B., eds, *Proceedings of the 29th ICIS (International Conference on Information Systems),* 14–17 December, Paris.
Wood, P., ed (2003), *Consultancy and Innovation: The Business Service Revolution in Europe*, Routledge, London.