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# **A systems approach to mapping UK regional innovation ecosystems for policy insight**

**Authors:**

**Dan Arthur**

IPD Ltd, London, UK

**Jonathan Moizer**

University of Plymouth, UK

**Jonathan Lean**

University of Plymouth, UK

**Corresponding author:**

Jonathan Moizer, Plymouth Business School, University of Plymouth, Plymouth PL4 8AA, UK. Email: [jonathan.moizer@plymouth.ac.uk](mailto:jonathan.moizer@plymouth.ac.uk)

**Abstract:**

The literature on innovation and regional economic development shows widespread references to ‘systems’ but relatively little application of systems thinking and problem structuring methods. Innovation models are thus under-theorised with operationally-based maps that link the structure of innovation systems to behaviour and possible policy levers. This conceptual paper addresses this shortfall by applying a systems mapping approach to regional innovation ecosystems which sets out the structural drivers and actor inter-relationships in regional economies with universities acting as focal points for knowledge application. A causal feedback map is hypothesised from participative research and the innovation literature, providing an integrative framework and enabling initial policy

discussions about the drivers of regional innovation. Hence this model identifies the virtuous reinforcing behaviours that act endogenously within an innovation ecosystem to drive economic growth. Several policy questions concerning regional innovation and university–industry–government collaboration are surfaced by the model. Finally, possible policy interventions are proposed.

**Keywords:**

Regional innovation ecosystems, Triple Helix, Quadruple Helix, innovation districts, systems mapping, HEIs

Innovation plays a key role in achieving regional development in knowledge-based economies. Governments can play a strategic role in supporting innovation by shaping new markets and building competitive advantage by developing collaborative linkages between the public and private sectors and universities and by breaking down conventional barriers between business sectors and academic disciplines.

While systems approaches are implied in the regional economic development literature to be relevant to understanding both the conditions and policies that support innovation, it appears to be challenging for policy makers to manage the complex inter-relationships involved. The UK Government’s Innovation Strategy (BEIS, 2021: 17) recognises that ‘the innovation process occurs in an ecosystem in which companies, public research institutions, further education providers, financial institutions, charities, government bodies and many other players interact through the exchange of skills, knowledge and ideas, both domestically and internationally’. This strategy depicts the main actors in the innovation system as shown in Figure 1, also showing talent, finance and knowledge flows, and goes on to make 43 references to the keyword ‘ecosystem’.

INSERT FIGURE 1 ABOUT HERE

The Dowling (2015) Review of strategic business–university collaborations in the UK acknowledged, though, that governments had difficulty in managing policy support mechanisms for research and innovation due to the complexity of the ecosystems. It recognised a need to tackle systemic issues in cross-cutting themes such as developing technologies, promoting workforce skills, access to finance and using procurement to strengthen supply chains (Giones, 2019). This implies a requirement for co-ordination by urban planners and policy makers to provide a coherent, systemic overview and a common identity (NCUB, 2021: 22). The formation and rise of university science parks is an example of a co-ordination policy measure in which an investment in innovation through infrastructure and tax advantages is required to initiate knowledge spillovers.

Achieving regional economic development through developing these ecosystems depends on the agglomeration processes that were identified by Porter (1998). These processes need to reach a critical mass for successful business clusters, which generate sufficient spillover effects or positive network externalities (Auerswald and Dani, 2017; Donahue et al., 2018). Where complex adaptive systems contain such positive feedback (Arthur, 1999), the mutual dependency of reinforcing growth drivers can mean that the ecosystem fails to reach a threshold of adequate connectedness to become robust and self-regenerating (Martin and Sunley, 2011). Additionally, the complexity in both the business environment and the policy-making process can lead to ineffective policies (Ghaffarzadegan et al., 2011) and business engagement.

A systems approach aims to represent this complexity but also to provide an overview that will facilitate broader and more targeted measures. This will provide policy makers, HEIs and regional development planners with a common identity and co-ordination ability that will enhance the prospects of planning success (NCUB, 2021). Such a systemic approach to research and innovation is evident in UK Innovation Strategy (BEIS, 2021) and

in developing place-based initiatives such as ‘Innovation Districts’, typically linked to regional universities. For example, a report by the National Centre for Universities and Business (NCUB, 2021: 76) concludes that:

‘[...] the UK should not simply grow each individual part of the innovation system. The UK must also strengthen the interconnectedness of the system, such that the sum becomes much stronger than the parts.’

The UK Government’s Levelling Up White Paper draws on this systemic overview by recognising a rich set of ‘capitals’ (assets or resources<sup>1</sup>) that combine as interconnected factors leading to self-reinforcing virtuous or vicious spirals (DLUHC, 2022: 87-89):

‘The six capitals are inextricably linked as part of a complex, adaptive economic ecosystem. Indeed, it is interdependence among the capitals that generates the forces of agglomeration, as the strength in one capital cascades to the others in a cumulative, amplifying fashion.’

Generating virtuous cycles of economic development and investment (Krueger, 1993) is seen as vital to regional regeneration (e.g., the UK’s Northern Powerhouse and Local Enterprise Partnerships policies – see DfT, 2015).

However, a problem with current analytical approaches in the literature is that, whilst they recognise the presence of systems in regional innovation partnerships and structural interconnections and frequently refer to ensuing dynamics, they rarely explicitly apply systems thinking and problem structuring methods to policy development, planning and dialogue. Asheim et al. (2011) outlined a need to provide a theoretical basis to understand issues of system coherence, boundaries, dysfunction and failure. Chaminade and Edquist

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<sup>1</sup> The six capitals are: physical, human, intangible, financial, institutional and social.

(2010) and Song et al. (2020) have both called for further work to examine the dynamics of the system of innovation to better understand the impacts of policy support mechanisms for university–industry partnerships, with Asheim (2019) also recommending additional process-based understanding of these systems.

The aim of this paper is to address these current issues by proposing the use of systems thinking as a problem structuring approach in the arena of regional innovation economics, using it to develop a causal feedback model that captures the drivers of economic growth situated at the nexus between higher education, industry and government. Its contribution is to provide a comprehensive integrative approach to analyse endogenous growth drivers and to identify policy levers and intervention points.

The paper is organised as follows. First, we survey the literature on regional innovation systems and the Triple Helix metaphor, and the contribution of systems thinking approaches in the management science and operational research fields. Second, we apply a causal mapping approach to portray economic growth drivers, reciprocity and feedback in regional innovation systems. We then describe the causal feedback structure, consider related policy questions and identify possible intervention levers. Finally, we propose avenues for further development and application of the model.

### **Regional innovation systems and the Triple Helix**

The literature on regional innovation systems recognises the non-linear and systemic nature of the interplay of government, industry and universities in regional economic development. The term ‘regional innovation system’ (RIS) is widely attributed to Cooke (1992) and arose out of the earlier concept of the ‘national innovation system’ advanced by several authors (Freeman, 1995; Lundvall, 1992; Nelson, 1993; Patel and Pavitt, 1994). RISs consist of ‘interacting knowledge generation and exploitation subsystems linked to global, national and other regional systems’ (Cooke, 2004:3) that may stretch across several sectors (Asheim and

Gertler, 2005; Coenen et al., 2017). Different actors in an RIS may have different needs within the system based on their respective agency (Swenberg, 2020).

The theoretical precursors of the NIS stemmed from Alfred Marshall's (1890) notion of agglomeration and industrial districts in his *Principles of Economics* and went on to include economic geography, innovative milieux and clusters (Porter, 1998). Cooke et al. (2011) traced three related strands of research that predated the RIS concept which arose from economic geography and regional science: (i) the systems view of planning, (ii) empirical work showing that collaborative networks of smaller companies could be economically competitive and (iii) the derivation from the NIS. The systems approach and Schumpeter's (1911) stance on innovation in his *Theory of Economic Development* held an evolutionary rather than a prevailing linear understanding of innovation. However, Edquist (2005) claimed that the NIS literature was under-theorised. Arguably, this also applies to the RIS (Asheim et al., 2011), who also point out that system evolution and development is often not addressed. According to Weber and Truffer (2017:104), a criticism of the RIS concept is that it is largely a descriptive and static approach:

'[...] in spite of this widespread recognition of non-linearities and systemic effects, it is fair to say that the [innovation systems] approach, until rather recently, was mainly restricted to providing analytical categories, but did not use the enhanced understanding of system dynamics, not least for predictive purposes. The criticism of being largely descriptive rather than explanatory in nature has its roots in this apparent lack of explicitly addressing how the interplay between the different elements of innovation systems at meso- and micro-levels gives rise to non-linear dynamics of change.

Hence they go on to propose the need to advance understanding using process-based approaches for the future of the RIS concept.

### *The ecosystem concept*

At the academic and policy levels there has been a shift in terminology, with many writers using the ecologically-derived innovation 'ecosystems' variant (Papaioannou et al., 2009;

Schroth and Häußermann, 2018). The ecological concept was applied from the field of biology to social systems to represent better the evolutionary nature of interrelations between different actors, their innovative activity and the environment. Miller (1975: 77) had suggested that within an ecosystem ‘everything is connected to everything; everything feeds back through the ecosystem on itself. The interconnectedness preserves the overall system. Moore (1993) first coined the term ‘business ecosystem’, in which he likened networks of businesses to a biological system, evolving from a random grouping of elements towards a more organised community where the ecosystem emerges from a mix of capital, customer interest and talent generated by new innovations.

Innovation ecosystems have become a global phenomenon in which entrepreneurial activity forms around geographical clusters (Ferras-Hernandez and Nylund, 2019), the best-known being the USA’s Silicon Valley. As such, the name reflects the same concepts as those described in the RIS concept but with the added dimension of Internet and mobile communications, relaxing the physical presence requirement of businesses in a given geographical location, as well as market forces. The complex set of actors is diverse and includes entrepreneurs, investors, researchers, university faculty, venture capitalists, funding agencies and policy makers (Belitski and Heron, 2017), who interact to generate knowledge and new technologies at national or regional level (Mercan and Göktaş, 2011). Innovation ecosystems are dynamic, as their structure is ever-changing according to emerging wants and needs.

Nevertheless, Oh et al. (2016) argue that the ‘eco’ prefix indicates a flawed analogy to a natural ecosystem, is probably only a loose metaphor – designed, not evolved – and adds very little to NIS/RIS concepts with additional interpretative risks. Hence, in this article, we use the term RIS.



### *The Triple Helix metaphor*

The Triple Helix model (Etzkowitz and Leydesdorff, 1995; 2000) is another biologically-inspired metaphor for innovation systems derived from the NIS concept. The Triple Helix thesis proposes that universities can play an enhanced role in innovation systems in increasingly knowledge-based societies through knowledge creation and transfer (Ranga and Etzkowitz, 2013). The underlying model is analytically different from the NIS approach, which considers the firm as having the leading role in innovation. Central to the Triple Helix model is the increased interaction between universities, industry and government as relatively equal partners and the new forms of innovation and socioeconomic development that have arisen from such cooperation (Etzkowitz, 2003a). Although this is a departure from linear university–industry linkages to a more interactive innovation model (Etzkowitz, 2002), the Triple Helix literature makes extensive reference to systemic relations through an evolutionary economics lens.

Asheim et al. (2019) view the Triple Helix concept as ‘an operationalisation of a RIS as an explicit regional innovation policy’ and define the Triple Helix with an explicit positioning of the public sector and as taking a normative and top-down perspective, as distinct from RIS, indicating that this perspective has been applied in a rather static way. Pique et al (2018: 6) also concede that the Triple Helix model is ‘sometimes interpreted to depict a rather static scheme’. Nonetheless, the claim is that the ‘Triple Helix as an analytical model adds to the description of the variety of institutional arrangements and policy models *an explanation of their dynamics*’ (Etzkowitz and Leydesdorff, 2000: page ref?, emphasis added).

Ranga and Etzkowitz (2013:237, emphasis added) present ‘the concept of Triple Helix *systems* as an analytical construct that synthesizes the key features of university–industry–government (Triple Helix) interactions into an “innovation system” format, defined

according to *systems theory* as a set of components, relationships and functions’. Therefore, they claim that the Triple Helix concept does provide an explicit framework for systemic and non-linear interaction between the Triple Helix actors and circulation of knowledge flows and resources. On this basis, the authors are advancing the Triple Helix as explicitly a systems approach. Nonetheless, Triple Helix relationships are not expressed through a set of stock-flow structures connected by a web of information feedbacks as a structural theory of dynamic behaviour that is characteristic of the system dynamics approach, as described by Morecroft (2015).

### *Knowledge Triangles, Innovation Districts and Quadruple Helix*

‘Knowledge Triangles’ are innovation policy frameworks that are widely used in OECD countries and Europe according to Unger and Polt (2017:10), who explain that the concept has gained popularity because it emphasises ‘an integrated (systemic) approach to the interlinkages between research, education and innovation’. The focus is on *activities* in these spheres, whereas the Triple Helix model starts with *actors*. These authors depict Triple and Quadruple Helix models within a Knowledge Triangle but, whilst claimed as a practical policy framework, it gives only a rather cursory recognition of second-round effects (of funding allocations).

Extensions to the Triple Helix model emphasise the role of societal innovation in the Quadruple Helix (McAdam and Debackere, 2018) and the natural environment as a fifth aspect in the Quintuple Helix (Carayannis et al., 2012). It can be argued that the societal element is a key aspect of the rise of Innovation Districts (NCUB, 2021).

Having considered various approaches to the conceptualisation of innovation systems, we now consider methodological approaches to mapping and modelling them.

## **Systems thinking and information feedback**

Systems thinking covers a wide range of subjects that restores holism and interdisciplinarity in place of reductionism (Fuenmayor, 1991). Systems thinking writers have often classified single-theme propositions like General System Theory, Cybernetics, Operational Research, System Dynamics, Soft Systems Methodology in the fields of management, social science and philosophy. Systems are characterised by multiple agents/actors, interdependencies, endogenous change and emergent behaviour. The limitations of systems thinking are that, by focusing on the interrelationships of the parts, less attention is paid to the details of individual components. Interrelationships fit less well into traditional subject matter areas, so empirical data and theory can be much less established and therefore contested. An individual systems model might be very context-specific and so not subject to general procedures for corroboration or peer review in traditional subjects.

Whilst the RIS has been derived with evolutionary economics in mind, there has been relatively little contact with the literature on management science, operational research and problem structuring methods, which strongly emphasises the roles of models and modelling given its scientific roots. This is probably because these disciplines are usually seen to be more closely related to business and management than regional economics. Radzicki (1990) noted the ideas of circular and cumulative causation in institutional economics, although the NIS concept had been positioned more within evolutionary economics (Lundvall, 1992; Freeman, 1995).

System models are widely used to support decisions and policy making in both public policy and industry sectors (Greenberger et al, 1976; Morecroft and Sterman, 1994). The key benefits of the modelling process, as distinct from outcomes, results or answers from the model itself, are insight generation, understanding and communication (Scott et al., 2016). Consensus building can develop from small, aggregate models where the emphasis is on

high-level concepts and causal feedback relationships between the main institutions or actors which are thought to drive or constrain development and capability-building (Ghaffarzadegan et al., 2011). Small models are preferable for the initial conceptualisation and final communication stages of higher-level policy-based models (Pruyt, 2013). Large or detailed decision support models which capture agent detail, heterogeneity or spatial effects may not be important considerations.

Causal loop diagramming is a systems-oriented problem structuring method (PSM) (Mingers and Rosenhead, 2004). It is a soft or qualitative mapping approach that embraces systemicity in the thinking world of policy makers as distinct from the recognition of systems in the real world (Checkland and Scholes, 2001). PSMs are widely used in participatory modelling activities such as group model building.

Causal loop diagrams have been used to study innovation strategy in firms (Galanakis, 2006), innovation and risk management (Wu et al, 2010) and to understand the implementation of innovation in firms (Repenning, 2002). Lee and Tunzelmann (2005) used causal loops to explain the structure behind a system dynamics model of IT firms in the Taiwanese NIS; Samara et al. (2012) applied them to identify product and process innovation in the Greek NIS; and Yun et al (2017) investigated platform business models' impact on South Korean RISs.

Whilst these studies help us to understand the nexus between causal feedback processes and policy intervention applicable in specific innovation systems, they do not frame the wider regional interdependencies between universities, industry and government. As regards the Triple Helix metaphor, a few studies have used causal loop diagramming to characterise aspects of the feedback relationships that exist within them – for example, Perdana and Kusnanda (2012), Urze and Abreu (2015) and Maruccia et al. (2020).

The main concepts of a system can be captured within causal loop diagrams, where structural effects or interdependencies and information feedback between the main sectors or actors are the drivers of system behaviour. Causal loop diagrams containing causal-effect linkages can be built up sequentially in policy discussions. When they are presented in this way, they can be effective story-telling devices (Lane et al, 2016) and can be succinct, one-page diagrams (Coyle, 2001). The polarity of feedbacks can lead to some indications of growth or collapse in the case of positive feedbacks<sup>2</sup> or constraints on such change with negative feedback,<sup>3</sup> which is often a source of policy resistance in complex systems (Sterman, 2002). Positive feedback loops can lead to virtuous or vicious cycles of behaviour.

## **A systems model of regional innovation systems**

Systems modelling implies diagrammatic mapping and, optionally, subsequent quantitative modelling of the causal linkages of reciprocity and feedback in economic development and to address modern policy challenges (Stroh, 2015; OECD, 2020). For example, achieving sustainable economic growth involves identifying the self-reinforcing and counteracting forces (Sternfels, 2021).

Applied to regional innovation, systems modelling allows the systemic interactions of actors in the Triple and Quadruple Helix metaphors to be made explicit as an RIS. The modelling approach taken here is the system description or problem structuring phase of the system dynamics methodology as used in urban growth and decay simulation modelling by Forrester (1969) and Hamilton et al. (1969) and was applied to regional innovation policy by Fratesi (2015). System dynamics has been associated with the institutional, evolutionary and

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<sup>2</sup> A feedback loop has a positive polarity if it contains an even number of negative causal links which exhibits reinforcing behaviour and can be marked by an 'R' or '+' to denote this.

<sup>3</sup> A feedback loop has a negative polarity if it contains an uneven number of negative causal links which exhibits balancing behaviour and can be marked by an 'B' or '-' to denote this.

behavioural schools of heterodox economics (Radzicki, 1990). This entails representing the system resources and flows that alter resource levels and the interconnecting information feedback structure that describes the causal network of linkages which together control the dynamic performance of innovation systems.

To provide a structure of endogenous growth drivers, we take an aggregate or top-down modelling approach as opposed to a disaggregate bottom-up approach as used in agent-based modelling. This is done to structure the problem and to aid communication of the causal interdependencies. By this structural mapping, the possible loci of high-leverage policy interventions to encourage enterprise and innovation can be identified and communicated.

This model was hypothesised and derived inductively from the authors' participation in UK regional innovation projects based on knowledge transfer initiatives and the literature. This was supplemented by presentations of government policy objectives about government-sponsored industry-academic partnerships and was subsequently tested in policy discussions with government officials interested in systems approaches. However, the key concepts and methodology are proposed to be generic and applicable internationally.

We present this as an initial, tentative map to demonstrate a methodology that can facilitate discussion but is not intended as a final 'validated' or unalterable model. Each of the links may have uncertain strength, and indeed the polarity might be subject to debate. Extensions could be made to address current interest in Quadruple Helix ideas and application to the current rise in Innovation Districts.

### *Description of model structure*

In Figure 2, a multi-loop causal loop model<sup>4</sup> illustrates the positive feedbacks<sup>5</sup> that can be hypothesised as drivers of development and sustainability within university–business–government RISs. Figure 1 depicted the main system actors, whereas here we illustrate the main system resources in a similar way to the Capitals Framework illustrating potential vicious cycles in the previously mentioned Levelling Up White Paper (DLUHC, 2022: 88).

For each link, we provide supporting evidence of causal effects from relevant literature. The starting point was to consider what the key capabilities (i.e. stock variables) were that seemed important to each actor and what driving forces (Lewin, 1951) strengthened the interactions and partnerships with the other actors, and then to arrange them into the seven main themes. Each of these themes describes reinforcing feedback loops (R) and the themes now described in turn (we deliberately omit constraining forces for the sake of clarity). We do not at this stage indicate any strength of effect of these relationships or claim which are the dominant stock variables: therefore, there is not here any hierarchy of the seven main loops.

INSERT FIGURE 2 ABOUT HERE

*Student recruitment (R1)*. Tracing through the Student Recruitment Loop we see the first of the series of reinforcing variables at work. The perceived strength of the academic institutions influences their ability to attract high-calibre academics (O'Loughlin et al., 2015), with quality of teaching and applied research determined by the academic calibre. Student

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<sup>4</sup> Model elements are linked by cause-effect arrows and change in either the same direction indicated by a +ve polarity or in the opposite direction as indicated by a -ve polarity. Hash marks on a causal link denote a time delay between cause and effect.

<sup>5</sup> A positive or reinforcing loop (R) is evident when actions or events within a feedback loop reinforce each other, leading to growth or decline.

recruitment is influenced by the reputation of the institution for teaching and research activity (Drennan and Beck, 2001; Greatbatch and Holland, 2016). In turn, teaching and research equip graduates with a level of relevant knowledge and skills which impacts on graduate employability (Gulbrandsen and Solesvik, 2015). The level of graduate employability influences the attractiveness of the academic institution to student applicants (Maringe, 2006) which shapes the perceived strength of the institution (Finch et al., 2015).

*Academic recruitment (R2).* The academic recruitment and student recruitment loops share three common variables. The perceived strength of academic institution influences its attractiveness to high-calibre academics (Metcalf et al, 2005) which in turn impacts on the quality of teaching and research (Neri and Wilkins, 2019). The quality of teaching and research can lead to the creation of academic expertise in research centres or centres of expertise which serve as a magnet for funding and applied research success stories (Perkmann et al., 2013; Sedlacek, 2013). These together boost the perceived strength of the academic institution.

*Academic expertise (R3).* The academic expertise held in centres of excellence encourages university collaborations with business, which allows the creation of industrial awareness and the development of industry case studies by academics (Barnes et al., 2002; Galán-Muros and Plewa, 2016). These in turn are disseminated in the classroom as well as feeding into applied research outputs such as reports and peer-reviewed articles, with the result of further developing academic expertise (Amaratunga and Senaratne, 2009).



*Perception of region for innovation (R4a and R4b).* This is a long and slow feedback containing many elements and multiple delays between actions and consequences. The attractiveness of a UK region to entrepreneurs results in both the migration of businesses and new start-ups in the region. There may be a significant delay at this point between the change in a region's attractiveness, the realisation of this change by entrepreneurs and their plans and actions to actually start up a businesses or relocate them due to the human capital created in universities (Tavassoli and Carbonara 2014; Lehmann and Menter, 2016). This provides opportunities for academic staff to collaborate with businesses, generating levels of industrial awareness and case study material which in turn influence the quality of teaching and applied university research (Gertner et al., 2011; Ankrah and Omar, 2015).

The loop bifurcates at this point. One route leads to the development of academic expertise in centres of excellence which governs the perceived strength of the academic institution. The second route arrives at the perceived strength of an academic institution through the quality of teaching and skills development influencing graduate employability (Osmani, 2015; Harvey, 2017; Clarke, 2018), determining the attractiveness of a university to student applicants (Andrews and Russell, 2012; Shah, et al., 2013). The level of student capability then in turn enhances the perceived strength of the academic institution. This perceived strength impacts on the attractiveness of the region to entrepreneurs, particularly in high-technology fields (Feldman and Francis, 2004; Etzkowitz, 2017). Again, there is a time lag between any changes to the perceived strength and attractiveness of the region as institutional reputations consistently take time to build or decline.

*Graduate recruitment (R5).* The creation of jobs by innovative businesses working in partnerships with HEIs can provide a magnet for retaining graduate labour which otherwise could have relocated (Pollard et al., 2015; Galán-Muros and Davey, 2019; Evers, 2019).

Recently formed relationships with new graduates can maintain close relationships for staff and students remaining in university networks and can thus foster continuing collaboration.

*Business innovation (R6).* Academic collaboration with businesses can stimulate innovation within businesses (Etzkowitz, 2003b), which in turn translates into business performance (Guerrero and Urbano, 2017). Business performance can be linked to the need to create graduate positions in businesses, which allows a competitive region to attract graduates for employment (Dabrowska, 2011). Graduates can encourage links between their businesses and academic institutions (David and Coenen, 2014), thus ensuring feedbacks working in the virtuous direction.

*Regional partnerships (R7).* The final feedback loop concerns partnerships between academia and business at the regional level. As described in R4 and R5, the attractiveness of the region to entrepreneurs leads to the migration of businesses and new start-ups in the region, which in turn provides opportunities for more university–business collaboration. These effects impact upon the intensity of innovation of businesses and the ensuing business performance (Schofield, 2013; Ho et al., 2016). The level of business performance will determine whether enhanced competitiveness is achieved (Rantala and Ukko, 2019; Tseng et al., 2020). After a delay for business leaders to recognise the enhanced regional competitiveness of businesses, this influences the attractiveness of the region to entrepreneurs (Ranga and Etzkowitz, 2013).

#### *Policy questions arising from model*

The causal loop model of the innovation system presented in Figure 2 has been used as a communication and issue framing device to guide discussions with public sector policy

experts concerning investment decisions and supporting policy measures to aid understanding of the drivers of regional innovation. It can also serve as one possible model to locate important metrics about interconnections for the Knowledge Exchange Framework (UKRI, 2020).

Current UK Innovation Strategy (BEIS, 2021) recognises the complexity in the public funding landscape to support the development of innovation collaborations and make the whole system work better. Understanding the interdependencies, non-linearities and delays mentioned in this Strategy is of great interest, as is addressing the challenges in identifying the most effective policy measures or schemes when financial resources are constrained. Some of the practical policy-related questions that the casual loop model helps to elicit are covered below under seven headings. All of them imply gaining a meso-level, or operational understanding of mechanisms and economic drivers that lie between an overall macro- and a micro-perspective

*Explaining system dysfunction or underperformance.* The regional innovation system and spillover effects are considered to work well in the UK's 'Golden Triangle' of London–Oxford–Cambridge and, more broadly, the South-East of the UK. However the system does not seem to work so effectively in other regions. The Productivity Plan (BIS, 2015) referred to the aim of achieving growth in the Northern Powerhouse<sup>6</sup>. In Figure 2, reinforcing loops R1, R2, R3 on the Higher Education Institutions<sup>7</sup> side of the model do not seem to activate the R5, R6, R7 loops on the business side. Is this because the linkages between the

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<sup>6</sup> The Northern Powerhouse is the UK government's vision for a super-connected, globally-competitive regional economy of 11 north England and Wales Local Enterprise Partnerships with a flourishing private sector, a highly-skilled population, and world-renowned civic and business leadership (Northern Powerhouse (2022)).

<sup>7</sup> Higher education institutions in the UK comprise of universities and colleges that provide a tertiary education.

universities and businesses, for instance, via loop R4 are weakly developed? In lower-performing regions, businesses may not be so readily inclined to address innovation challenges via university collaborations. Is this a matter of inadequate infrastructure, relationship brokering or other reasons?

*Locating weakness in interrelationships.* For the many causal linkages in the loop model, where in the diagram are the linkages too weak for the growth loops to be self-sustaining? For instance, in the key innovation loop R6, the implication is that businesses that collaborate with universities will inevitably lead to innovation in the firm. This depends on the nature of the collaboration. If businesses recruit graduates via a scheme that is government-backed, for instance, and yet uses the graduate labour for business-as-usual activities, then this linkage is not likely to produce innovative output. Again, even if the relationship is technically challenging and research-intensive, the likelihood of innovation being produced that generates commercial return and creates new jobs is not guaranteed. Similar arguments could be raised through every linkage in the diagram regarding the qualitative nature of the causal influence – that is, the actual relative strengths of the reinforcing loops described can't be determined without additional, detailed, quantitative empirical evidence on the causal links and whether this means the growth processes are stalled by balancing or confounding factors.

*Early indicators of good practice or collaborative developments.* Where delays or lags are present in growth processes, for example in building long-term relationships and regional comparative advantages, are there interim measures or early indicators that can reveal good practice or beneficial improvements in collaborations? Early indicators would signal to actors or to those involved in regional policy that mutually reinforcing results will follow in due course. This poses the need to identify metrics and quantities by which the system state

and change can be assessed. The regional comparative advantages published by BIS (2015) give some basis for identifying important stock variables but some variables shown in the diagram are qualitative or semi-qualitative, for some of which there may be proxies. Some variables may have indicators showing cross-sectional performance relative to other regions (e.g., university league tables) without consistently being able to track changes through time.

*Improve dynamic understanding of delay effects.* Almost all of the relationships in Figure 2 have a delay implied in the link between cause and effect. Some of the more extensive delays are marked with a double-bar across the causal link. Some implied delays lie within the changes required in a stock variable before there is a corresponding change in an interlinking flow variable. A tenet of system dynamics is that stock variables can be changed only by the related in-flows and out-flows. A string of stock–flow relationships connotes an implied delay in the system state variables changing. Overall, there is a lack of a dynamic understanding in delay effects and the mechanisms of change.

*Identify tipping points/pressure points or when further investment ineffective.* Implicit with positive feedback relationships is not only the idea of exponential growth (or decay) but also threshold effects; that is, tipping points or saturation effects. The model can help to identify what these are or where they might lie.

*Location of intervention points – switches or sliders.* The diagram gives some hint of where policy makers could intervene and implies switching on certain policy instruments or increasing their intensity. The diagram serves to highlight debate for where these input options lie and what their effect might be and serves as an agenda for further modelling work.

*Compare policy options.* What and where do different policy mechanisms or government-aided schemes have effect? Which are worth keeping or have the greatest effectiveness, given limited funding and the need for simplification?

Which policy options have the greatest return on investment in a context in which investment funding is limited? The diagram cannot begin to answer such a question, which implies a much more disaggregated and quantified model. This would provide a means of undertaking cost–benefit analyses where the effects of different schemes can be compared.

*Possible intervention policies and leverage points.*

In Figure 2, two key pressure points lie at the centrally-positioned variable *collaboration with business*:

- *Relationship management and infrastructure.* Universities can take a leading role in this ‘third mission’ (Compagnucci and Spigarelli, 2020) of reach-out to business, beyond the primary missions of teaching and research, to invest to create infrastructure, facilities, resources and staffing for reach-out activities towards business. These often take the form of technology transfer offices, which can deliver commercialisation and intellectual property advice and services.
- *Government investment/policy measures.* There is a clear role for government or the regional innovation authority here in supporting investment in infrastructure for regional assets that aid academic–business collaboration. This includes, for example, joint financial stakeholding in science parks, innovation centres and research facilities between public authorities and universities.

The interconnected reinforcing loops presented in the causal loop model imply other possible intervention or leverage points. These are summarised in Table 1.

INSERT TABLE 1 ABOUT HERE

In R1 (student recruitment loop), possible leverage points include the marketing of courses, funding or scholarship possibilities and the adjustment of entrance qualifications. A longer-term pressure point is to invest in staff and resources to boost teaching and research quality ratings and thus the ‘quality of applied teaching and research’.

In R2 (academic recruitment and retention loop), the focus is more on the contract R&D and business liaison activities in centres of expertise or commercially-oriented research laboratories. Potential staff with adequate qualifications who might be attracted from industry are more likely to be engaged with university operations that are outward- (business-) facing. Thus, a leverage point might be to offer appointment and career development pathways for staff from industry whose commercial applied experience can be treated as equivalent to that of career academic staff and with incentives for industrial reach-out. The latest UK Research Excellence Framework’s<sup>8</sup> – REF 2021 – weights research impact<sup>9</sup> at 25% of the total assessment, which goes part of the way to encourage applied work and industrial relevance. It has been increased from 20% in the previous REF of 2014 based on the recommendations of Witty’s (2013) review of universities and growth to stimulate industrial engagement further to benefit local businesses, but this does not address recruitment and progression issues for staff whose strength is in industrial liaison.

In R3 (academic expertise loop), investment in assembling academic expertise and promoting it to industry is largely an administrative task and a possible leverage point. Centres of expertise are likely to originate organically over time rather than by sudden creation, with existing staff having built up contacts with industry or had them from a previous career or retained them through alumni networks. Investing in promotional materials such as case studies and teaching materials is useful, but the reputation of a centre

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<sup>8</sup> The Research Excellence Framework (referred to as the REF) is a system used for the periodic assessment of the depth and quality of research across UK HEIs. See <https://www.ref.ac.uk/> for the latest 2021 REF detail.

<sup>9</sup> Research impact relates to the effect that research in HEIs has on the economy and society.

is built progressively over a long period. The expertise lies within an individual's deep tacit knowledge but also in the complementarity and team-based technical acumen that come through being a centre. An important lever, then, is the use of incoming funds to buy out academic staff time to release them to reach out, contract research and spend time in industry. This might come in the form of reduced administration and teaching schedules, but also of industry placements or sabbaticals.

The R4 loop (higher education perception) is important for linking together the academic and industrial wings of the overall causal loop model. Higher education institutions can leverage marketing for reach-out to businesses to draw businesses into the region, or perhaps more likely to serve as a hub to alert firms about possible resources on offer – whether skilled graduates or applied knowledge. Academic expertise that may be expressed as a hub of several research centres of excellence, and one or several clusters associated with not just one university or region, can serve as a draw to entrepreneurs who wish to locate in a region. The UK's Northern Health Science Alliance is an example (although due to its size this spans several regions). Another example is the UK Catapult Centres, inspired by the Hauser (2010) report, which offer 'translational infrastructures' – physical centres in a specific location that connect business and research but with the facilities to offer collaboration and deliver business development and create jobs and to provide a bridge from research outputs to commercialisation.

For R5 (graduate recruitment loop), the attractiveness of the region might be influenced collectively by knowledge transfer based recruitment policies. That is, collaborating firms create jobs that attract and retain graduate talent who find that jobs with an innovation or knowledge transfer element provide career development potential. Graduate recruitment activity can go beyond individual firms advertising jobs and might involve local



government or regional development agency staff marketing a region for its employment prospects.

In R6 (business innovation loop), policies to encourage innovation and tax incentives for research and development are obvious ways of encouraging innovation within firms themselves. Other policies to encourage competitiveness include the facilitation of exports through trade and investment advisory services and credit guarantees.

For R7 (regional partnership loop), a pressure point implied here is infrastructure investment to encourage in-region entrepreneurship, or migration into a region. This is different from the infrastructure such as shared collaboration facilities discussed earlier; it implies something more generally available to the region, such as transport and communication infrastructure, which fosters knowledge and experience interchange.

## **Summary, limitations and implications**

We have aimed to identify the extant literature on innovation systems that widely discusses its systemic character, structural relationships and dynamics, but there is a missing element that maps the information feedback structure which gives rise to this system behaviour. We have proposed a start to acknowledging this theoretical gap by suggesting qualitative mapping techniques from the system dynamics field. This concentrates on the initial mapping task that can help to facilitate drivers of growth by first focusing on the endogenous drivers.

One policy debate is why some regional economies fare less well than others. For example, in the UK London and the South-East is an innovative regional system, but why do other regions not fare as well? What are the relevant mechanisms or growth dynamics in collaborative business–university engagements that can help achieve the UK Government’s

‘Levelling Up’ proposals? Innovation Districts (NCUB, 2021) and Innovation Accelerators (DLUHC, 2022) are proposed as place-based drivers of regional innovation.

The causal feedback model developed in this paper illustrates an indicative mental map of the innovation system of growth drivers. The model provides a tool for locating policy intervention points and can tentatively indicate possible consequences. This information can then help to initiate policy discussions about regional growth mechanisms and can be a starting place from which to formulate or summarise policy questions. A causal model is a structural theory of how a system behaves. Yet, in this systems map, we do not emphasise the content of the model’s elements as much as suggest that the mapping process can be useful in itself, and hence there is a ‘process’ validity that may be equally important to the ‘content’ validity.

The limitations of the systems mapping approach we have adopted in this work are that it does not focus on important questions of detail and that interactions between subcomponents are at a highly aggregated level and thus are not easily measurable. We have not at this stage identified the relative strength of the causal relationships. Extension to a quantitative model may be possible but could be difficult, although the argument here is that qualitative approaches still have significant benefits. Additionally, positive feedbacks work to support change in the upward or downward direction depending on the effectiveness of interventions. Our causal model reflects these at the RIS level but does not recognise that success in one region may impinge on the success of another within a wider positive feedback system.

Further work on this model could entail developing or critiquing it in an interactive policy process and applying it and the Quadruple Helix perspective to the rise of Innovation Districts. The relative strength of the feedback relationships could be investigated. Questions could be explored: what makes a successful Innovation District and what are the key system

resources (stock variables) that must be built and how? A policy-level or insight quantitative model could be developed to explore these and other delay effects and operational mechanisms identified in the policy questions section of this paper. An alternative way of comparing the competitiveness of regions could investigate Multi Sector Qualitative Analysis (Roberts and Stimson, 1998).

However, a full description of how the system responds to policy interventions involving government, industry and higher education institutions at the regional level could be made more explicit through the development of an empirically testable quantitative simulation model which would allow policy interventions to be more fully explained. In the present study, an initial exploratory qualitative model was presented, with the consequences of the interplay of positive (and negative) feedbacks being more hypothetical. As Sterman (2002) argues, mental simulation alone without explicit computer modelling is known to be unreliable. Nevertheless, the current study provides a foundation for further empirical work and analytics development.

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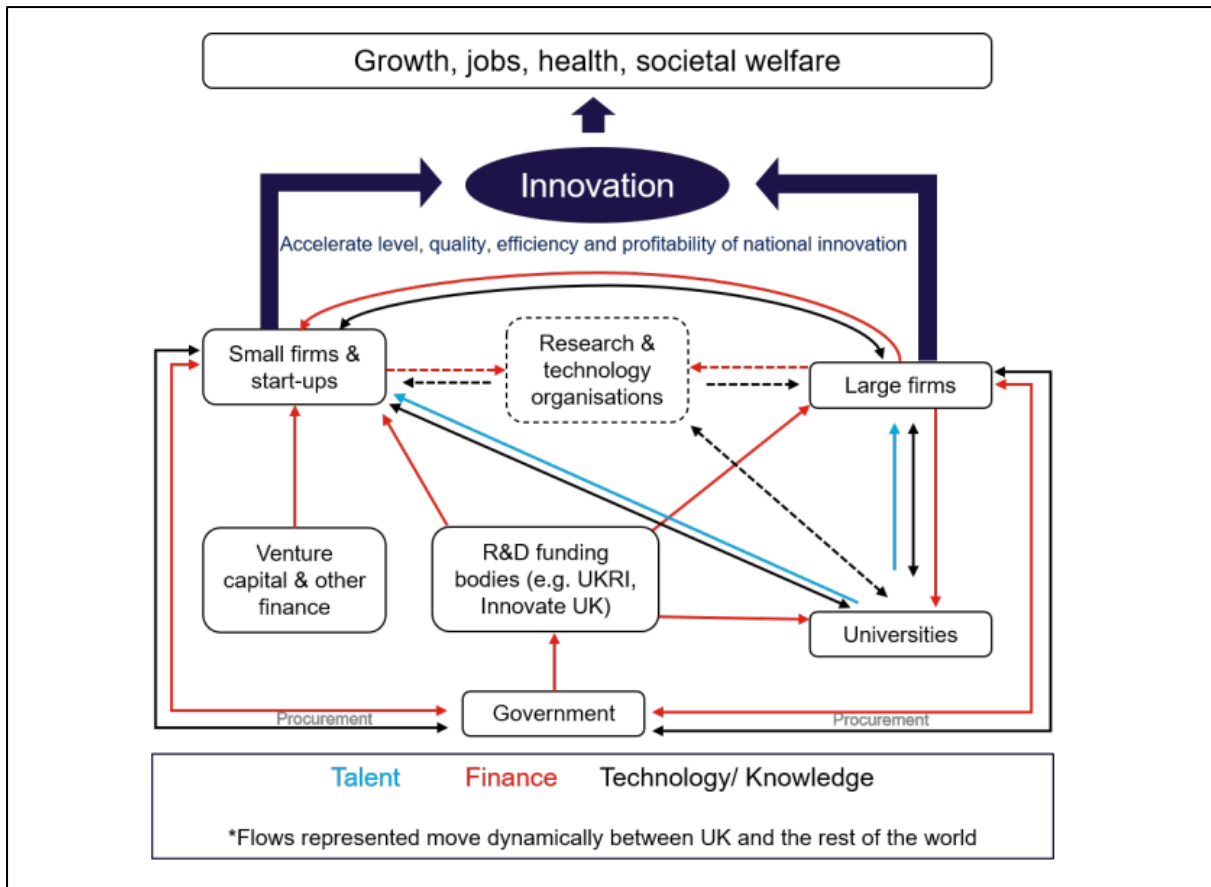


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**Figure 1.** Innovation ecosystem.

Source: (BEIS, 2021: 16).

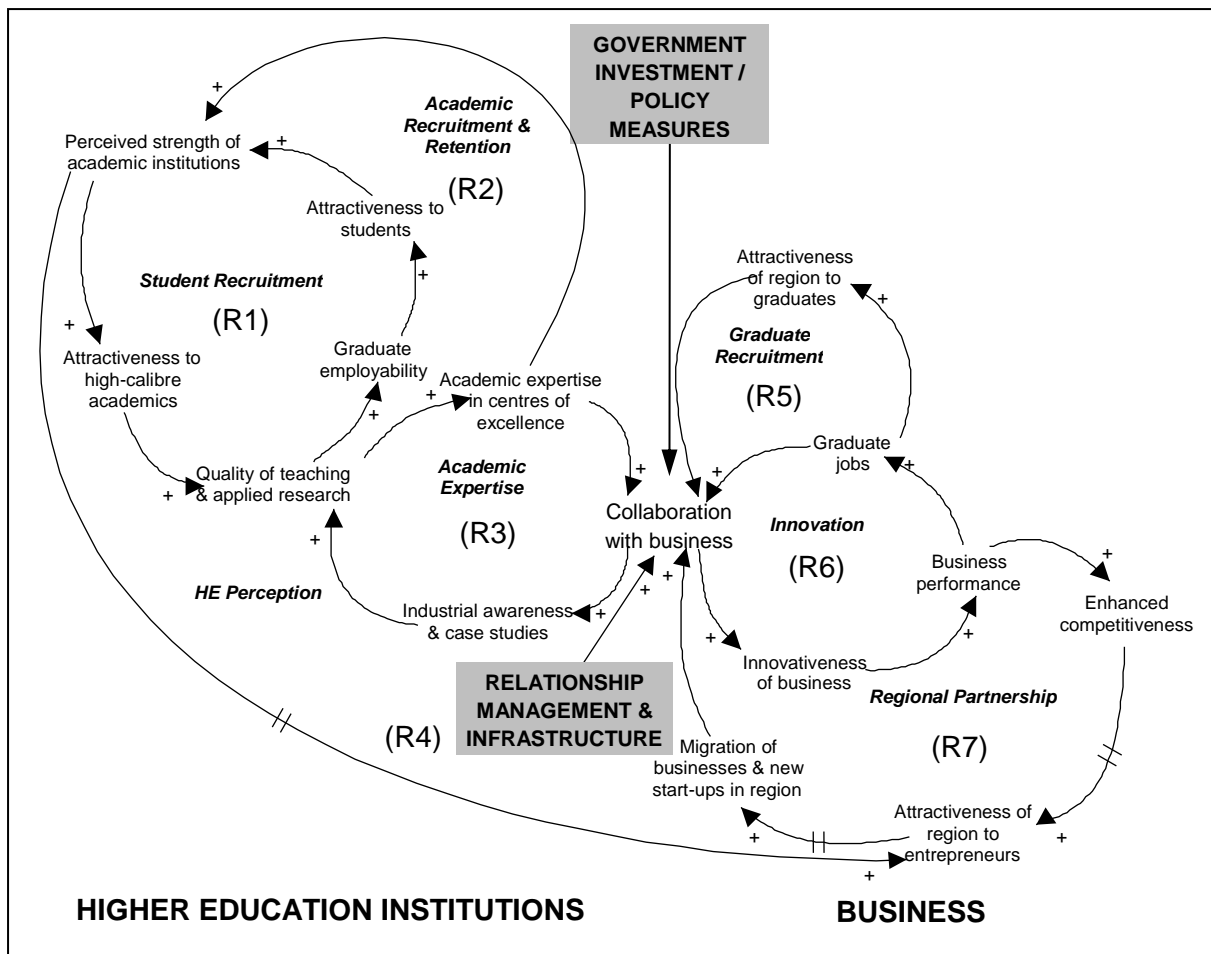


Figure 2. Causal loop diagram of regional innovation in government–university–business collaborations.

**Table 1:. Reinforcing loops and possible intervention policies.**

<b>Reinforcing loop structure</b>	<b>Possible intervention policy lever</b>
R1 – Student recruitment	Marketing, funding, entrance qualifications
R2 – Academic recruitment	Promotion of quality of life and applied research and contract opportunities
R3 – Academic expertise	Investment in centres of expertise, investment in applied research
R4 – Perception of region for innovation	HEI marketing for ‘business reach-out’
R5 – Graduate recruitment	Knowledge transfer based recruitment.
R6 – Business innovation	Investment in research/innovation projects; R&D tax relief
R7 – Regional partnerships	Infrastructure funding to encourage entrepreneurship