Systems of innovation as evolving complex economic systems

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This paper brings together several currents of thought that, though close and related, are not necessarily linked, and remain somewhat independent. It uses the resulting concepts and methods to the analysis of innovation systems. The paper starts with a discussion of evolutionary economics, as well as the complexity and systems dynamics approach, (section 1) and continues with the systems of innovation perspective (Section 2) and goes on with an illustration of RSIs as complex evolutionary systems (Section 3). It concludes that the system of innovation approaches would gain generality and precision if blended with evolutionary economics and system dynamics.

1. The evolutionary economics and complexity and systems dynamics approaches and its role within evolutionary economics and management and its relationship with systems dynamics.

1.1 The evolutionary approach in economics uses many similar assumptions as the complexity perspective and its problems are the same (Table 1) (Loasby, 1999; Magnusson and Ottosson, 1997; Nelson and Winter, 1982). However, evolutionary economics and management has put somewhat more emphasis on concepts than on methods and modelling. Key themes in evolutionary economics are bounded rationality thus learning, as well as institutions and routines depicted as knowledge and order repositories to reduce uncertainty (Metcalfe, North 1997), capabilities (Loasby, 1999), multiple levels of evolution and selection, and path dependency (Magnusson and Ottosson, 1997; North, 1997)

TABLE 1: THE THEMES OF EVOLUTIONARY ECONOMICS, SYSTEMS OF INNOVATION AND COMPLEXITY APPROACHES

Themes	Evolutionary economics	Complexity/ system dynamics	Systems of innovation
Micro-behavioural basis	Bounded rationality (Nelson & Winter, 1982)	Natural rationality (Darley & Kaufman, 1997)	Bounded rationality?
Types of knowledge considered	Local and general Codified and tacit	Local and general Codified and tacit	Local and general Codified and tacit
Learning	Sometimes evocated	Central	Central
Path dependency	Central	Central	Sometimes evocated
Multiple equilibria (Multistability)	Central	Central	Sometimes evocated
Change	Central	Central	Important

1.2 System dynamics approaches are similar but go a step further in modelling. (Forrester, 1971). Different authors have linked explicitly evolutionary economics and systems dynamics several times, such as Radzicki and Sterman (1994). There is an economics brand of complexity that emphasizes systems thinking and modelling around the Santa Fe Institute (Arthur, 2002; Arthur et al, 1997, Quadrio Curzio and Fortis, 2002; Rosser, 2003). This complexity approach also exists in political science (Axelrod, 1997), and a business theory (Sterman, 2000).

Let us recall the features of complexity according to Arthur et al (1997). These are:

- **Dispersed interaction**: many agents act in parallel
- **No global controller** or universal competitor
- **Cross-cutting hierarchical organisation**: different levels of interaction and organisation
- **Continual adaptation** occurs, as agents accumulate experience.
- **Perpetual novelty** through the creation of new markets, technologies, behaviours and institutions.
- **Out-of-equilibrium dynamics**. The economy operates far from any optimum or equilibrium.

The cognition and micro-behavioural assumptions of the complexity approach are also similar to evolutionary economics (Table 2). Complexity and modelling (Arthur et al., 1997).

2 The innovation systems (IS) perspective is an assorted current of mid-level theories of the economy and society trying to respond to the central question of "why do some countries, and some regions within them, innovate" as well as "how do nations, regions and industries innovate". The innovation system approach points to several issues, which are central to economic growth, particularly the institutional framework of innovation. The systems of innovation perspective has put emphasis on learning, institutions and interaction. This current of thought has already delivered quite a good number of questions and answers to the major problems as well as many empirical papers (Edquist, 1997a; Freeman, 1987, 1995; Lundvall, 1992; Breschi and Malerba, 1997; Metcalfe, 1995; Nelson, 1993; Niosi et al., 1993). However, this literature has remained somewhat descriptive (lacking both modelling and theorizing). Edquist has even suggested that its conceptual ambiguity is a strength (Edquist, 1997: 27) due to its emergent character. The IS perspective has neglected the formal analysis of the managerial and public policy dimensions, those that may help it to become a guide to institution building.

This paper suggests treating innovation systems as adaptive, complex and evolutionary systems thus linking it systematically to large currents of thought, and adding modelling, in order to improve its chances to provide public policy advise. Not all authors in the approach are evolutionary (Nelson, vs. Lundvall) but their perspectives are compatible due to their system dynamics problems, and bounded-rationality behavioural assumptions. The modularity of policies (Mohnen et al., 2002) explains that only a few NSIs and RSIs (countries and regions) actually develop as governments at all levels are unable to understand the complexity of policy making and the evolving nature of these innovation systems.

3 An illustration**.** Regional innovation systems as evolutionary complex systems. **(Cooke and Morgan, 1998; de la Mothe & Paquet, 1998, Howells, 1999; Saviotti, 1996)**

Definitions about clusters, learning regions and regional innovation systems abound. Without entering into a long theoretical debate, the distinction between learning regions and regional innovation systems is worth recalling. Learning regions are those with research capabilities while regional innovation systems include a full panoply of organisations and institutions, including those that allow the technologies to be tested in the market. For the sake of simplicity, this paper adopts a definition based on Cooke and Morgan (Cooke and Morgan, 1998: 70-1).

TABLE 2: DEFINING REGIONAL INNOVATION SYSTEMS

> “Regions which possess the full panoply of innovation organisations set in an institutional milieu /…/ where systemic linkage and interactive communication among the innovation actors is normal, approach the designation of regional innovation systems. The organisations can be expected to consist of universities, basic research laboratories, applied research laboratories, technology transfer agencies, regional public and private /…/ governance organisations, vocational training organisations, banks, venture capitalists, and interacting large and small firms. Moreover they should demonstrate systemic linkages through concertation programmes, research partnerships, value added information flows, and policy action lines from the governance organisations. These are systems that combine learning with upstream and downstream innovation capability and thus warrant the designation *regional innovation system*” (Cooke and Morgan, 1998: 71)

In RSIs the local character of knowledge is key (Cooke and Morgan, 1998: ch.3). Networks and institutions are repositories and channels of knowledge (Loasby). Incubation is a central reproductive mechanism. Inertia is due to large labour pools (and sometimes also to other elements, such as large manufacturing plants).

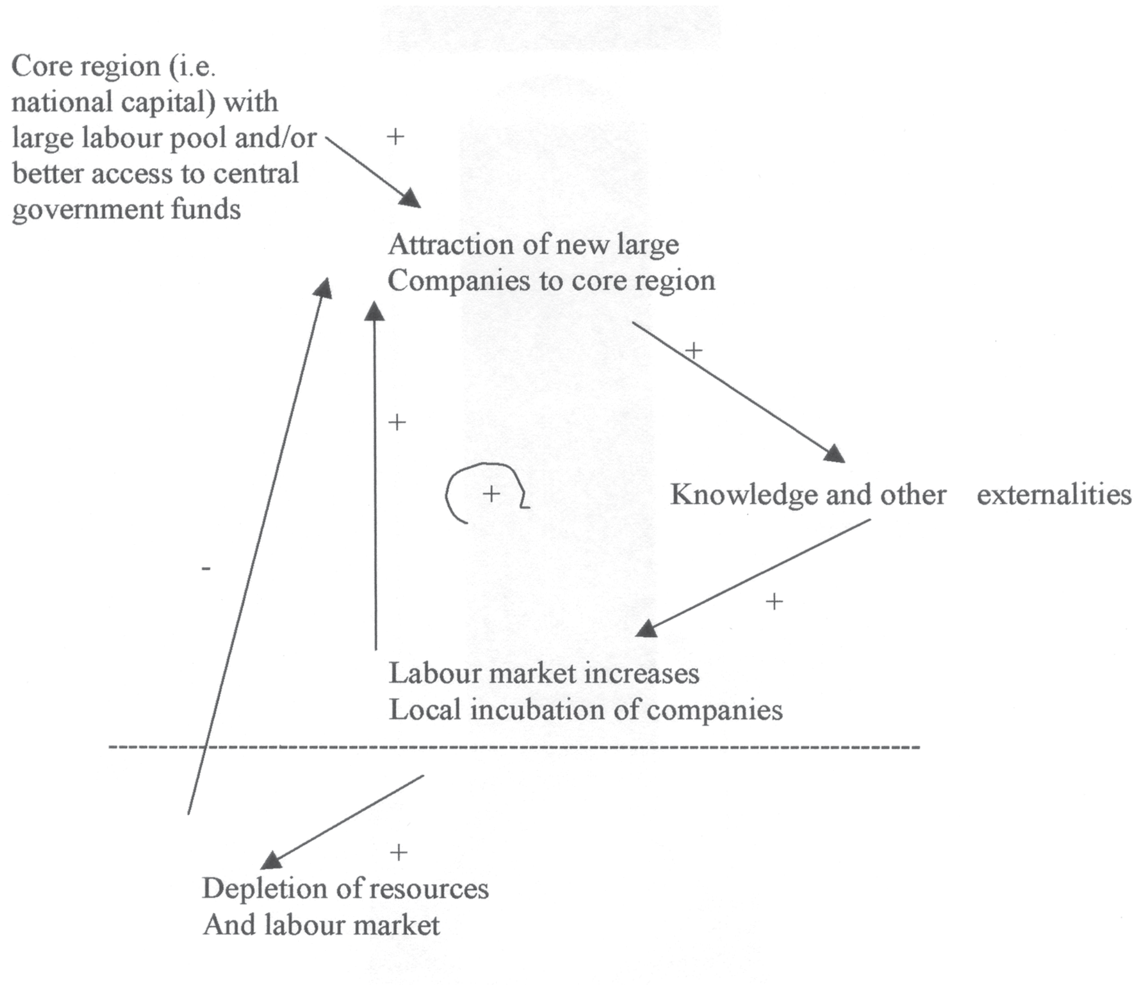
Three dimensions in which regional innovation systems differ are regional governance structure, long-term evolution and specialisation, and core/periphery differences (Howells, 1999).

Governance means, in Howells terms, the impact of government and the division of responsibilities between different levels of authority in nations. Thus in Canada, education (including higher education) is the responsibility of the provinces, while in Germany universities are under the aegis of the Länder. In both cases, large regional differences in the quality and quality of the local human capital as well as the role of such organisations as incubators of new technology based firms, may be explained by the way the regional (respectively provincial or Länder) authorities fulfil this responsibility. The national government may also either pick winning regions, thus deciding what region will host a specific industry (i.e. France picking Toulouse in aerospace) or level the field for the open competition of all regions in the development of a new technology.

The issue of specialisation is central. Some authors have maintained that regions tend to become more specialised over time (i.e. Cooke and Morgan, 1998: 72) and that specialisation is the logical outcome of market forces such as major labour markets, intra-industry spillovers and access to specialised input suppliers (Krugman, 1991). Labour market, local knowledge and specialised suppliers bring entry advantages to new firms in specialised regions. Other authors believe that inter-industry spillovers are far more important and that growing innovative regions will consist basically of diversified large metropolitan areas (Jacobs, 1969). Howells (1999) pinpointed the dangers of overspecialised regions where strong fluctuations and decline threatens existing firms. In Western Europe, the United States and Canada the weight of large metropolitan areas has been disproportionately high and is still growing (see for the European Union European Commission, 2001; for the USA Audretsch and Feldman 1999; and for Canada Beckstead, et al 2003).

The core/periphery issue tends to emphasize the fact that in most industrial countries (including France and the United Kingdom) one large metropolitan area, usually the national capital, centralises a high percentage of the total research and innovation activities of the country. Often its share of the country's R&D and innovation effort increases up to a certain point then recedes as agglomeration diseconomies appear. This argument is modelled in Figure 2.

Figure 2: Feedback loops favouring large metropolitan areas



Feedback loops exit that tend to reinforce the research and innovation weight of the large metropolis up to a certain point, when countervailing forces (such as the increasing price of housing, the depletion of natural resources or the shortages in the labour force) start to manifest themselves. The process seems installed in several nations. The Île de France region in France (with Paris as centre) seems to be losing ground compared to other French regions (OST, various years).

The evolutionary economics approach sheds a different, complementary light to the systems approach. How does the system reproduce itself? How do new organisational entities come to appear?

In managerial literature this is the issue of incubation and spin-offs. Another evolutionary issue is: what are the sources of inertia in the system? What forces do the changing elements need to fight in order to allow the system to mutate through time?

The three cases of aerospace, biotechnology, and ICTs can illustrate the previous points. They will be developed summarily due to time and space constraints.

3.1 Aircraft regional innovation systems. They were at their beginnings (1900-1945) Perroux poles. They were composed of a tier 1 prime contractor (such as Airbus, Boeing, Bombardier) surrounded by local tier 2 suppliers of major subsystems (structures, engines, avionics), and tier 3 suppliers of parts and components (metal parts, chips, cables, etc.). At that time, the regional input-output matrix was densely filled out with local flows of equipment, and regional knowledge spillovers abounded. Some of these tier 2 and 3 suppliers were spin-offs from large tier 1 corporations. From this original configuration, these RSIs have evolved towards an international sectoral system, with tier 1 OEMs located in one region, and tier 2 suppliers of major subsystems located in other regions. Montreal moved from the first type of RSI to the second type in the post-war period. Seattle is now moving from the first to the second type, as Boeing has recently decided to outsource the supply of major subsystems across the world. International knowledge spillovers across the supply chain are now more important than local ones.

Aircraft regional innovation systems, in both the original and present-day forms, display strong geographic inertia, due to the weight of large labour pools and huge manufacturing plants.

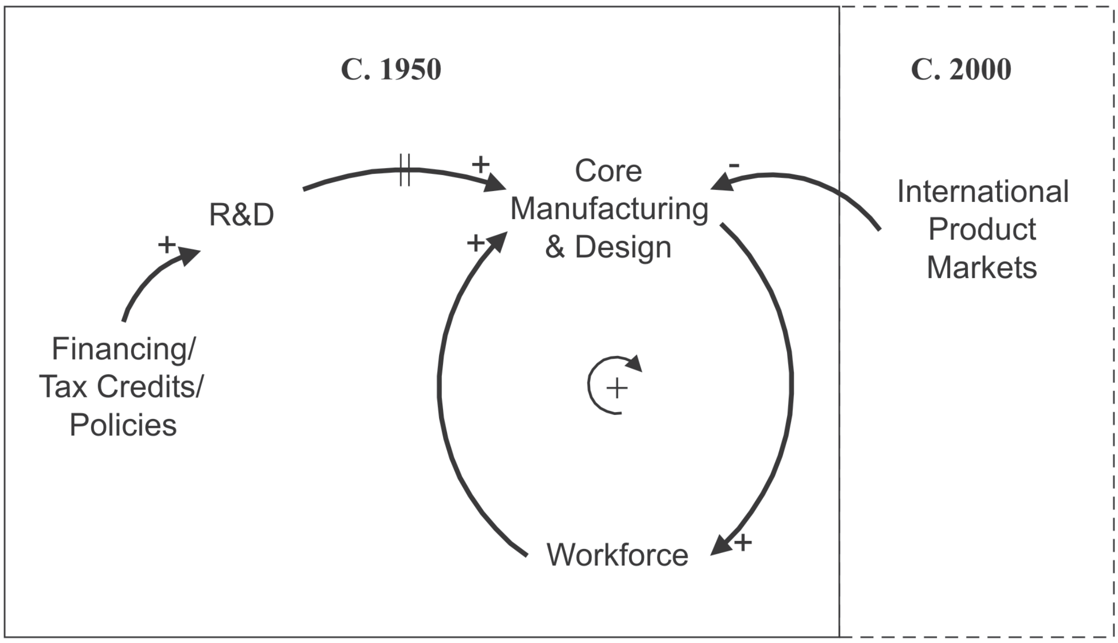


Figure 3: Aerospace RSIs

3.2 Biotechnology regional innovation systems. They were at their origins formed by research universities surrounded by a few specialised biotechnology firms (SBFs) incubated at the universities. Over time, venture capitalists, originally interested in ICT new firms, started changing their behaviour and investing in local SBFs. Also, during the 1980s and 1990s, at least in the United States and

Canada, universities changed their behaviour and created offices of technology transfer and intellectual property management in order to get a share of the value created by the SBFs working with technology developed in academic institutions. Local technology markets (universities selling and licensing technology to private firms) superseded local knowledge spillovers. Over the course of time, venture capitalists learned more about biotechnology financing and became more interested in doing cross-regional investment, mostly within nations, but also sometimes across national boundaries. Universities and their academic research still are the main incubators of new SBFs, but their behaviour has changed to accommodate the changing expectations and conduct of venture capitalists and growing SBFs.

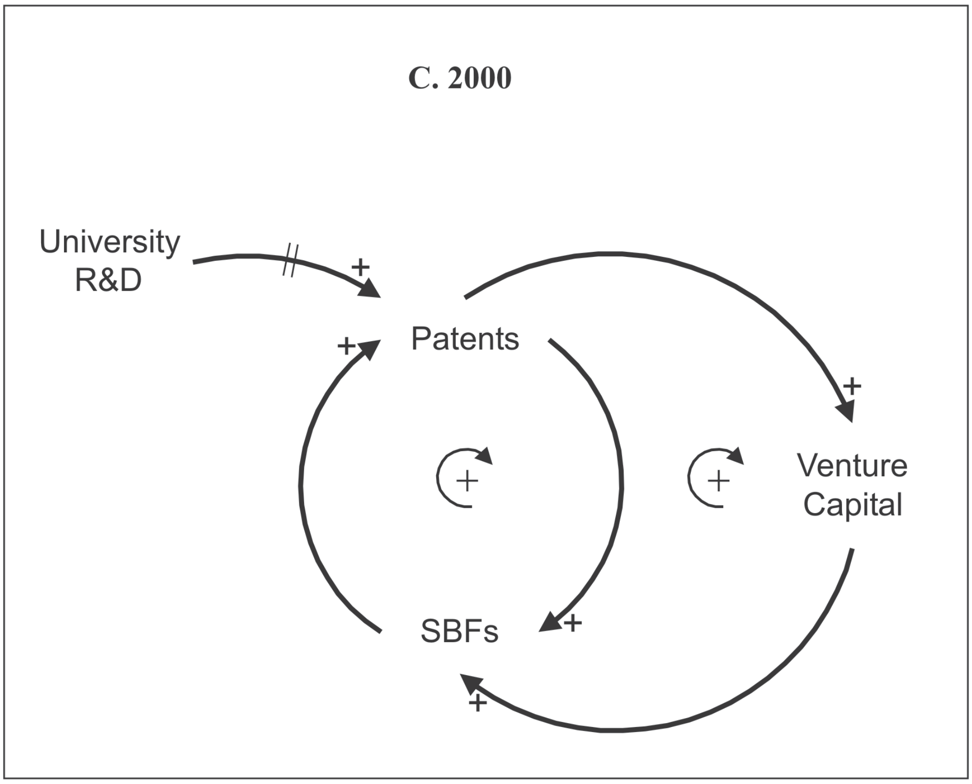
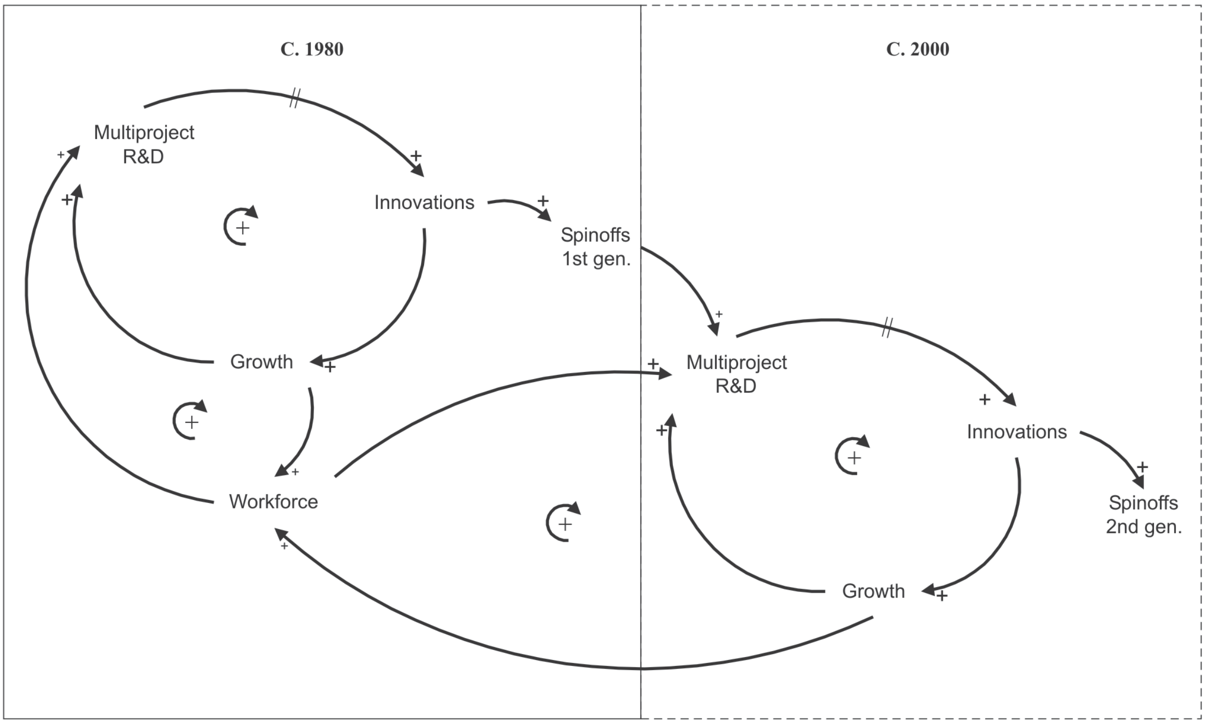


Figure 4: Biotechnology RSIs

Biotechnology RSIs display enormous inertia due to the large labour pool they mobilise, but conversely to aerospace, there is a high turnover of firms within the region, due to mergers, acquisitions and new firm foundation.

3.3 Information technology regional innovation systems. They most often started with one or a few large R&D laboratories of major corporations and eventually large research universities. Major private laboratories became the incubators of other ICT start-ups as they had the size and resources to outperform even the largest research universities in terms of new firm formation. Venture capital emerged in the 1950s and 1960s in the United States main agglomerations (such as Boston and San Francisco) to respond to the new demand of risk financing. Networks of private innovators, research universities and venture capital emerged first within the region, then across regions, in order to exploit the new technological opportunities created by the ICTs. Silicon Valley, launched by the joint thrust of companies such as Shockley Semiconductors (an AT&T spin-off) and Stanford University, is a case in point. But most other ICT regional systems that have been studied respond to this evolutionary pattern.

Figure 5: ICTs RSIs

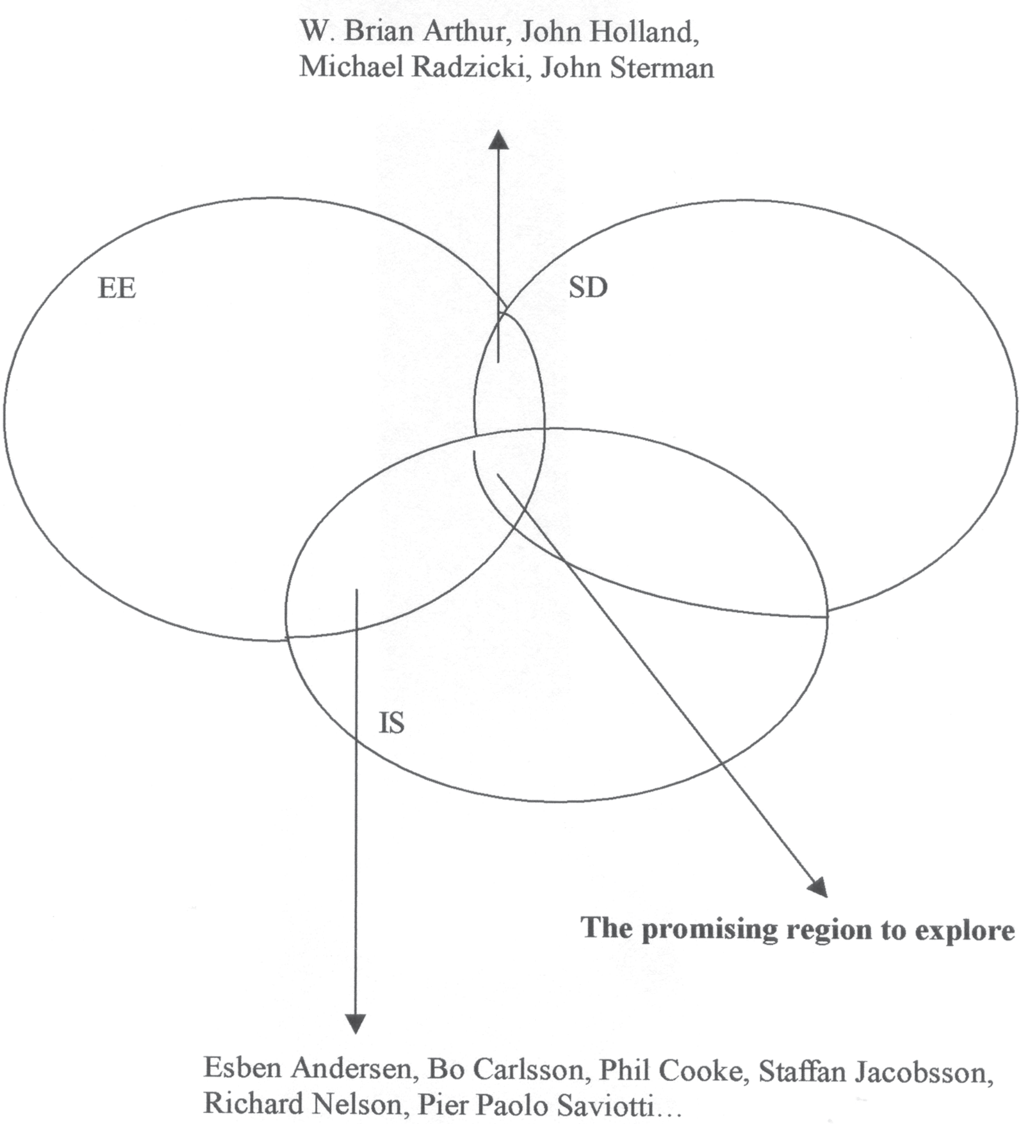


ICT clusters and RSIs are strongly rooted in large agglomerations and they seldom disappear or move to other locations. In that sense they display geographical inertia. Conversely, like their biotechnology counterparts, there is strong turnover of firms, as high barriers do not restrict entry, and mergers, acquisitions and exit are frequent.

CONCLUSION

Innovation systems theory has now developed into a major current of thought. Hundreds of researchers are now developing it in different directions, and a few policy makers are trying to use it as a guide for action. As such, it needs to reinforce its theoretical basis as well as its modelling in order to provide clear-cut concepts and testable hypothesis about the probable evolution of innovation systems and the role of policies that aim at strengthening or creating such systems. A more decided anchoring in evolutionary economics, and the use of systems dynamics modelling, may be useful in moving from conceptual ambiguity, and descriptive theorising into more formal theory and the testing of clear-cut hypothesis.

Figure 1: Evolutionary economics (EE), systems dynamics (SD) and innovation systems (IS)



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