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Wixted, Brian
Simon Fraser University - Centre for Policy Research on Science and Technology

October 2006

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CPROST Report 06-04 (DRAFT)

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Brian Wixted brian_wixted@sfu.ca

CENTRE FOR POLICY RESEARCH ON SCIENCE AND TECHNOLOGY
SIMON FRASER UNIVERSITY
Vancouver BC

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Abstract

The literature on clustering that has developed over the last two decades or so has given us a wealth of information on the formation and competitiveness of places in the global economy. Similarly, the systems literature on innovation has been valuable in moving the debate around technology from a focus on the entrepreneur to one than encompasses institutions, government, suppliers, customers and universities. However, there remains an important limit to this research; the borders of political jurisdictions, usually nation states, typically delineate the studies. It is argued in this paper that during an era when the international architecture of production relationships is changing, this view of systems is hindering its further development. This paper briefly examines what we have learnt of innovation systems, including clustering and also explores the limitations of this work. From this foundation it is proposed in this paper that a framework which understands clusters as nodes within extra-territorial networks is a promising approach for internationalising the systems of innovation perspective. The advantage of the approach presented here is that it can simultaneously capture regional specialisations and be disaggregated enough to apply on a technology / sectoral basis. Another principle advantage is that such a framework goes someway towards an understanding of inter-regional and international trade that is consistent with what other studies have shown of the development of innovation *within* particular geographic locations. The paper draws from extensive data analysis of industrial interdependencies that cross national borders to support the case for cluster complexes that transcend regional and national borders.

1. Introduction

At present, analysis of the evolving patterns of international production appears to be split within a tri-polar division of studies. National and regional (cluster) innovation systems on one axis, production fragmentation on another and the (corporate) global production networks (GPNs) that organise trade on the third.

It is argued in this paper that this dichotomy is missing an important space in between. To date there is little research on the internationalisation of *systems of innovation*, a sentiment that is supported by Carlsson (2006). While there is research on innovation at the corporate level and on the economics of internationalisation, there is not yet much work on a systems level approach to understanding innovation within the changing economic structures. In this context the current paper argues that developing an understanding of the internationalisation of innovation systems should be a prime target for researchers in the field of the economics of innovation and technological change (EITC).

The paper proposes that the problem is best researched through the combination of production systems and regional clusters. The resulting framework and supporting empirical evidence highlights the existence of *cluster complexes* as a series of clusters which are networked through extra-territorial linkages of production and knowledge flows in a number of industrial categories.

The current paper starts with an examination of the three approaches to understanding internationalisation and then moves on to discuss the needs of a framework to analyse innovation in an international context. Some evidence on the internationalisation of innovation systems is then presented, followed by a discussion of the underlying dimensions to the formation of linkages between clusters. The paper concludes with a brief outline of some of the implications of the proposed cluster complexes framework and avenues for future research.

2. Internationalisation of the World Economy and Innovation Systems

The three frameworks of business networks, production fragmentation and regional clusters mentioned above, all offer different strengths and weaknesses with regards to their evidence and interpretation of the process of internationalisation.

Global business networks and production

In the 1970s and 1980s there was considerable interest in the role of multinational corporations (see Barnet and Muller 1974) in the world economy, but during the 1990s the interest moved towards the role of global networks[1] of businesses for production and technology development. Each variant of analysis has a slightly different focus, some utilising production and trade data (GVCs) while others adopt sociological techniques (specifically global production networks). They are grouped together here under the label of *global business networks*. These networks of independent businesses and alliance partners operate often within coordination structures provided by a MNC and within specified product design architectures.

There is a large literature of case studies that describes the changes in production processes that began to noticeably evolve over the 1990s. Hess and Yeung claim

> 'Over the last five years, considerable progress has been achieved in economic geography in developing a sophisticated theoretical framework for analyzing territorial formation and economic development in the global economy. This genre of theoretical development has shown the continuing unevenness of the spatiality of production and consumption, the differentiating role of structural and institutional conditions at various scales, and the responses and strategies of firms, non-firm organizations, and government bodies shaping the global economy across space and time' (2006:1193).

Some short examples, from the computing and apparel industries highlight the difficulty of summarising the shifting geographic centres of production and technology and the 'tangled webs'[2] of business networks. Dean and Tam in their article on the production networks of Dell and Hewlett-Packard comment:

> 'U.S. computer brands now farm out much of their manufacturing to Taiwanese concerns, which also are starting to design more of these products as well. The Taiwanese companies pull together parts to build the computers in China and then ship them to the purchaser, all in a matter of days' (2005: B1).

In the case of electronics, as some production shifts to a new country for cost reasons, it would also seem that, frequently, the more complex components remain behind, in seemingly a step structure of value added. Over time, technological upgrading shifts the locus of activity. But it is still the major multinationals that determine the product and production system architecture. As Dean and Tam comment:

> Mr. Bahalla of H-P also takes pains to emphasize that his company isn't just handing off its laptops to contract manufacturers. The Palo Alto, Calif., tech giant retains much control over the process, he says. It orders many of the key

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[1] Global Commodity Chains – GCCs (Gereffi and Korzeniewicz, 1994), Global Production Networks – GPNs (see e.g Ernst and Linsu 2002 and Henderson, Dicken, Hess, Coe and Yeung 2002), International Production networks – IPNs (see e.g. Borrus, Ernst, and Haggard 2000) and Global Value Chains (see e.g. Gereffi, Humphrey and Sturgeon 2005).

[2] See Dicken 2005.

> components itself, such as hard drives and display panels. And H-P provides the base design of the laptop and has established design centers in Shanghai and Taipei to collaborate with its manufacturers (2005: B1).

In contrast to electronics, apparel production fragmentation has been more of a case of re-location and re-localisation, although inter-firm networks are important in this case as well:

> 'The apparel industry has been characterized by global production and trade networks since at least the middle of the twentieth century, and the expansion and growing capabilities of its global supply-base have permitted it to move rapidly from captive to more complex relational value chains over the span of just a few decades. The epicenter of export-oriented apparel production has been East Asia, as Japan in the 1950s and 1960s, Hong Kong, South Korea, and Taiwan during the 1970s and 1980s, and China in the 1990s emerged sequentially as world-class textile and apparel exporters' (Gereffi *et al.* 2005: 91).

While global business network analyses offer rich descriptions of the emerging world economy, the shortcoming of this literature lies with an inability to develop an aggregate perspective from the case studies (see Hess and Yeung 2006). Dicken comments

> 'certain scales have particular significance, most notably the national state scale. The state still matters – a lot. It is for this reason that I have used the term *transnational* – rather than global – production network. One of the most significant relationships in the global economy, therefore, is that of power and bargaining between TNCs and states, a process in which the outcomes are far less predictable and far more contingent than most of the literature allows. … Both TNCs and states demonstrate a strong propensity to organize themselves regionally. Again, however, the relationships between transnational production networks on the one hand and regional political institutions and structures on the other are extremely variable and, essentially, indeterminate' (2005: 22-23).

System perspectives, it would appear, are therefore even required by those studying business networks, as they offer specific insights unavailable from detailed studies of a single production system.

Production fragmentation

The fragmentation approach pioneered by Arndt (1998) along with Jones and Kierzkowski (see e.g. 2001); in contrast, to the business network approach is interested in the processes driving the geographic disintegration of factory. Gone, seemingly, are the days when the vision of production was the massive integrated factory. The two key drivers of this fragmentation process, as many authors perceive it, is driven by reductions in transportation and communications costs that have opened up access to new (cheaper) locations for production. As Kierzkowski states:

> 'What is new, is the increasing importance of the off-shore element in outsourcing and the growing role of low-wage countries in that development. **What has made this growth possible has been the recent revolution in communications and related technologies and a sharp reduction in coordination costs** that came with it. With the death of distance, to borrow the title of a recent book in this area, the scope for modularizing and reorganizing production processes has increased considerably. No wonder that the countries of East Asia have been exploiting, in a good sense of the word, new opportunities' (emphasis added 2001a: 7).

To date a large number of the articles in this research topic have adopted a highly theoretical[3] or modeling[4] based approach and exhibit a particular interest in the welfare effects[5] of changes both in developed and developing economics.

> 'Economists have investigated this phenomenon with a focus on welfare and factor-price effects, mainly using Heckscher-Ohlin-type trade models. Existing studies emphasize a positive welfare effect of international fragmentation, but reveal ambiguous effects on factor prices' (Kohler 2001: 31).

Another strand of this research is based on very specific case studies of individual situations where the production process has geographically fragmented. So for example; there is analysis of bicycles (Chu 2001), hard disk drives (Kimura 2001) and other product configuration changes. At this point, research crosses over the global production networks research. Currently, there is only a nascent development of a systems level empirical approach (see Feenstra 1998, Hummels *et al.* 2001 and Chen *et al.* 2005) to the fragmentation thesis. As such, there is little evidence presented on the degrees to which different industries are dependent on imports, nor differentiated between re-localisation and fragmentation[6]. Researchers thus seem to have overlooked the evidence that it is both particular resource processing and high technology activities that have been fragmenting the most in OECD economies (see table 3 below). Further, and notwithstanding, East Asia's ability to capture a significant share of activity in electronics, traditional advanced economies are still, in many instances, deepening their interdependence on each other.

The systems of innovation paradigm

The systems of innovation framework started with nation states (see e.g. Lundvall 1992, Nelson 1993 and Edquist 1997a for an introduction) but has grown to include;

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[3] See e.g. Egger and Egger (2001).

[4] See e.g. Deardorff (2001), Kohler (2001), Deardorff (2005), and Bond (2005).

[5] See e.g. Egger *et al.* (2001), Helg and Trajoli (2005) Geishecker and Görg (*2005)* and Dluhosch (2006).

[6] Possibily performed through examination of value of production with shift share analysis and analysis of market share penetration.

technological systems, regional systems and innovative[7] clusters and sectoral innovation systems. This broad literature explores the role of national institutions, government policies and industry development trajectories that form the contexts that shape the structure and trajectories of innovation. One author has recently commented that 'it would be difficult to overemphasize the extent to which the national innovation systems (NIS) concept originated as part of a direct attack on modern mainstream economics' (Sharif 2006: 753).

In Edquist's (1997b) view, *systems of innovation*, which encompasses a range of spatial scales (not just nation states), is a framework for investigating the development and evolution of technological capabilities, concentrations and specialisations. Edquist provides a guide to the systems of innovation perspective, emphasising it:

- is 'holistic and interdisciplinary' – for constructing a extensive understanding of the 'determinants of innovation' (1997b: 17);
- is a presentation of the 'historical perspective' on geography and natural resources access etc (1997b: 19);
- focuses on the 'differences between systems and non-optimality' (1997b:19) – all systems are different and defining a priori an optimal system is not sensible;
- stresses 'interdependence and non-linearity' (1997b: 20) – as it is 'an approach in which interdependence and interaction between the elements in the system is one of the most important characteristics' (1997b: 21);
- focuses on 'product technologies and organisational innovations' (1997b: 22); and
- places institutions at the centre of analysis.

These seven features of innovation systems are researched within three broad domains, which Dosi (1999) suggests are production systems, innovation system operations and knowledge accumulation.

However, the frame of reference for all this work is typically the nation state, even when the focus is on sectors or regions.

The emphasis on location (political jurisdictions and nations) appears to go back even to the early work of Josef Schumpeter, who is one of the intellectual fathers of studies of technological innovation. In the introduction to the special issue of a journal devoted to analysing a recently translated English version of the seventh chapter of Schumpeter's

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[7] Economic geographers are also interested in industrial clusters. The difference, where there is one, is that one focusses on the ability of clusters to generate new technologies and innovations and the geographic basis for *knowledge* dependencies, rather than for example existence, location and production aggregation.

book the 'Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest and the Business Cycle', Matthews highlights both that the chapter had a focus on endogenous capabilities and the significance of that focus:

> The chapter ... sketches a highly original summation of his model of internal economic development, where transformation is generated *from internal dynamics* represented by entrepreneurial initiative – in contrast with the prevailing doctrines which saw change in economic circumstances, and growth, as responding to external stimuli, such as population growth, or technological innovation, or the opening up of new geographic markets (emphasis added 2002: 2).

This same interest in the intra-regional dynamics (nation or cluster based) remains an overwhelmingly important theme within the innovation systems literature today. In part this framework is for theoretical reasons[8] but it is also because of the significance attached within the community of innovation scholars to being relevant to policy makers (see Lundvall and Maskell 2000: 215).

Perhaps it is for these reasons that the majority of the effort to understand internationalisation from an innovation perspective has been focussed on the location of R&D and the role of MNCs in organising the development of technologies. Of particular interest are the R&D location strategies of MNCs[9]. Examples of this line of work include Hollenstein and Arvanitis (2006), Singh (2006), and Rabbiosi and Piscitello (2006), all presented at a recent conference. This research tends to suggest that there is a non-globalisation of innovation (specifically R&D), an argument that is supported by evidence from the OECD that suggests that R&D is being increasingly but slowly relocated[10], but there is still a home country bias (2005).

However, the grand concern with the internal dynamics leaves innovation systems analysts with no obvious way of integrating external change and the current evolution of global structural patterns. This in turn creates the opportunity to start developing a framework that is consistent with past findings and opens up new research terrain. The following extensive quote from a recent article by Carlsson is most explicit:

> 'in view of the fact that most studies of innovation systems focus on *national* innovation systems, it is not surprising that little direct evidence is found that innovation systems are becoming global. The main focus in this literature is on institutions at the national level. But national institutions may influence innovation

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[8] Technological capability is now understood to be a process that develops across time and arises from the interactions between different actors business users and producers etc and has spatial dispersions effects where it clusters and dissipates away from particular hotspots.

[9] See for example the work program for a prominent research centre UNU-MERIT http://www.merit.unu.edu/research/index.htm#rt4

[10] 'More multinationals are setting up offshore R&D laboratories, and many R&D activities have become more internationalised and more closely linked to production abroad' (OECD 2005: 32).

> systems at regional, sectoral or technological levels differently. However, at these lower levels there has been little work done with a view toward internationalization of *systems* (as distinct from corporate innovative activity). Also, not all institutions are national. For large firms, national institutions may be most important, while for small and new firms, subnational institutions may also be important' (2006: 65).

The next section of this paper examines how this might be done by examining current systems approaches are analysing which is most usefully and easily extended to facilitate analysis of recent structural change in the world economy.

3. The Parameters of an Internationalised 'Systems of Innovation' Approach

Types of systems of innovation

Over the nearly two decades since the emergence of the national innovation systems paradigm (Freeman 1987), a number of other system level analyses have emerged.
The different systems frameworks can be defined as follows:

- National and Regional innovation systems;
- Clusters;
- Sectoral innovation systems; and
- Technological systems of innovation

National innovation systems. As noted above, this was the first step by the EITC School to show that innovation is more than the product of entrepreneurs and companies but relies upon a foundation of systemic properties. This was a valuable contribution and related research continues to highlight valuable findings (Freeman 2002). Unfortunately, this perspective is so firmly entrenched (see Sharif 2006) that there are very few studies of the internationalisation of innovation systems (Carlsson 2006 and Wixted 2005).

Regional innovation systems and clusters. Typically, this type of innovation systems analysis is the most specific both in terms of identifying geographic places and the actors (industries and firms) operating within those places (see OECD 1999 and 2001). One serious problem with this area of research is the flexible definitions of clustering (see Martin and Sunley 2003) and the lack of agreement on appropriate measures of the scale of the phenomena (sub-metropolitan through to national macro clusters). However, this literature is rich with case studies of the development of particular economic and technological strengths of particular places. As such it is an important counter weight to the arguments of nebulous 'globalisation' forces.

Although, the clusters literature is dominated by an intra-cluster focus, as is the case with the national studies, this is beginning to break down. Recently Wolfe and Gertler (2004) emphasised the finding that clusters were often plugged into the global economy both in terms of accessing knowledge and inputs. But this is as far as it has developed, the

literature on 'global pipelines' (e.g. Bathelt et al. 2004) does not reveal specific connections between clusters, and thus continues to emphasise the local factors in cluster development.

Sectoral innovation systems is a relatively small niche area of analysis and has be defined by Malerba (2002) to include products, agents (firms etc), learning processes, basic technological inputs / demand and linkages, processes of competition and institutions (p250-251). Although, theoretically a sectoral perspective could be operationalised to be international in scope, this is not the current vision as shown from this quote from Malerba.

> 'Geographical boundaries are an important element to be considered in most analyses of sectoral systems. Not always ***national boundaries*** are the most appropriate ones for an examination of the structure, agents and dynamics of these systems. Often a sectoral system is ***highly localized*** and frequently defines the specialization of the whole local area (as in the case of machinery, some traditional industries, and even information technology). For example, machinery is concentrated in specialized regional areas. Similarly, sectoral specialization and local agglomeration has overlapped in Route 128 (for minicomputers) and in Silicon Valley (for personal computers, software and microelectronics) (Saxenian, 1994)' (emphasis added 2002: 260).

This conceptualisation of the framework is re-emphasised in a later analysis by Malerba of various techno-economic systems (2005). Therefore once again, although there is an opportunity to extend the analysis across political jurisdictions, the challenge is left aside.

Technological systems of innovation, the last mainstream systems perspective, is like the sectoral perspective not instantly identified by a reference to a spatial scale. It has been defined by Carlsson and Stankiewicz as focussing upon:

> 'a network of agents interacting in a specific *economic/industrial area* under a particular *institutional infrastructure* or set of infrastructures and involved in the generation, diffusion, and utilization of technology. Technological systems are defined in terms of knowledge/competence flows rather than flows of ordinary goods and services. They consist of dynamic *knowledge and competence networks'* (emphasis in original 1991: 111)

This analytical lens is thus focussed on the development of particular technologies. They can be understood within an international context or a local setting. The studies, within this research field tend to emphasise the historical development of technologies from a technical as well as an economic (firms and institutions) perspective. So for example Carlsson and Jacobsson (1997) trace the development of semiconductors from World War II through to the mid 1990s noting the technical advances and the involvement of US defence procurement.

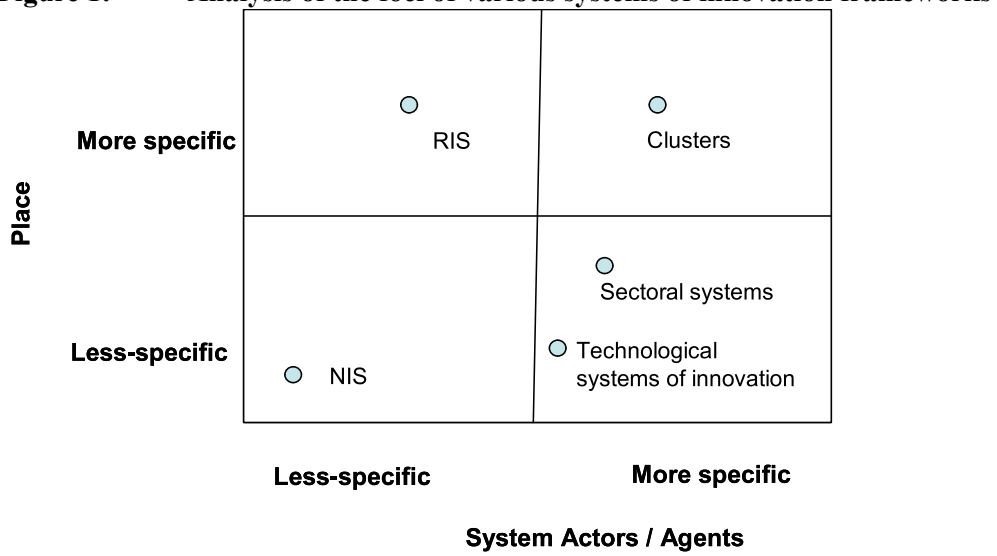
Therefore, each of these four 'systems' frameworks have advantages and disadvantages in terms of their usefulness as a framework for analysing internationalisation and can be assessed on a number of criteria. Place and actor specificity have been chosen for a number of reasons.

Treatment of Place:
Place can be justified as a primary criteria, firstly on purely realist terms, people live and work in particular places. Production of goods and services occurs in particular places. There are exports and imports between places, but stuff happens somewhere. In terms of innovation, it is worth noting that an internationalisation framework cannot ignore the wealth of material which supports the role of place in the innovation process. As Carlsson notes 'there is ample support for the claim by Pavitt that the innovative activities of firms are significantly influenced by their home country's national system of innovation' (2006: 64).

Treatment of Actors:
A second important criterion is that the approach enables an analysis of the 'system' to easily identify the players involved. Which companies are involved, what are the characteristics of the underlying technologies and what has been the involvement of government or universities?

We can then depict these system frameworks on a 2 X 2 grid.

Figure 1: Analysis of the foci of various systems of innovation frameworks



Regional and national innovation systems literatures are by their nature and definition difficult to extend to look beyond *national* borders. Their coverage is typically so wide and as the interests are often policy driven they are not appropriate for extending across borders. There have been ideas floated of examining supra-national innovation systems, but there have been few developments in this regard (Caracostas and Soete 1997). However, such suggestions are usually directed towards entities which are defined by some jurisdictional and policy limits such as the European Union or the North American Free trade Area. This helps a little in looking for international innovation systems framework but once again predetermines the shape of the system (e.g. NAFTA or the EU).On the other hand the other systems perspectives all offer particular advantages, in many ways they cover the same material with slightly differing emphases. Cluster studies having a slightly greater focus on production activities and industries. At an international scale, there is probably not much difference between emphasising clusters or sectoral systems, however, advantageously, a clusters framework aligns with the long standing research on the development of global cities as nodes within multi-city networks.

The rest of this paper explores the use of cluster analysis as the basis for an international perspective on innovation systems.

Cluster studies

The foci within clustering research has been on why it happens, how they work internally and what benefits clustering provides to those inside a particular cluster (see e.g. Maskell and Kebir 2005). Martin and Sunley (2003) emphasise that many of the definitions of clustering rest on the concept that particular geographic places have a dense network of

inter-connections between companies and supporting organisations. The primary taxonomy of interdependency divides traded (the supply of goods and services) from untraded (uncodified knowledge) interactions. To this a third should be added; user-producer relations because these relationships, which are based in both the transfer of goods, services and knowledge, are often the basis of new technologies and innovative products (von Hippel 1988, DeBresson 1999).

Porter (1990) suggested that local supply chains and demanding customers are important for cluster development but it was Steinle and Schiele (2001) who have provided a quasi-theoretical exploration of the types of production systems that are likely to cluster based on their product characteristics. However, it is increasingly apparent that supply chains are not pre-eminent in cluster formation. Wolfe and Gertler (2004) put forward a strong argument for why supply architectures are relatively unimportant in cluster development. Their detailed observations based on the study of 26 Canadian clusters reveals that the local availability of traded goods and services is not a primary factor in co-location.

Thus, the most obvious reason for clustering that of being close to suppliers (for transport reasons), is not actually thought to be the dominant factor. Instead, tacit knowledge is the most frequently cited as a prime rationale. This form of knowledge is typically perceived to be context dependent giving those with access an advantage, but as its spread is also understood to be geographically limited, there are incentives to be within innovative milieu. Breschi and Malerba summarise this point of view:

> 'In turn, the importance of proximity in lowering costs of knowledge transmission has to do with some basic properties of the knowledge base relevant for firms' innovative activities, particularly its complexity and its tacit nature. Due to these features, knowledge can only be effectively transmitted through inter-firm contacts and inter-firm mobility of workers both of which are eased by close geographic and cultural proximity' (2001: 818).

However, Breschi and Lissoni (2001) disagree that tacit knowledge is so important, arguing that it is not *untraded*, but is regulated by the market, nor indeed that it is the availability of such knowledge that influences clustering. Instead they note that there is more evidence to suggest that clustering is influenced by the availability of a deep labour market to a greater extent than by local knowledge spillovers[11], a position that is supported by Wolfe and Gertler (2004).

The third type of interdependency, user-producer relationships although not seen as the driver of clustering, have nevertheless been understood to be a significant feature of the development of innovations. Long term businesses relationships where trust has been established are important for the creation of new products and services (see DeBresson (1999) and have been explored particularly with national settings and which have been shown to have a similarity with input-output industrial structural interdependencies (e.g.

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[11] One interesting possibility for how tacit knowledge may influence clustering has been raised by Maskell and Lorenzen (2004) who suggest that clustering may reduce market risks and uncertainties.

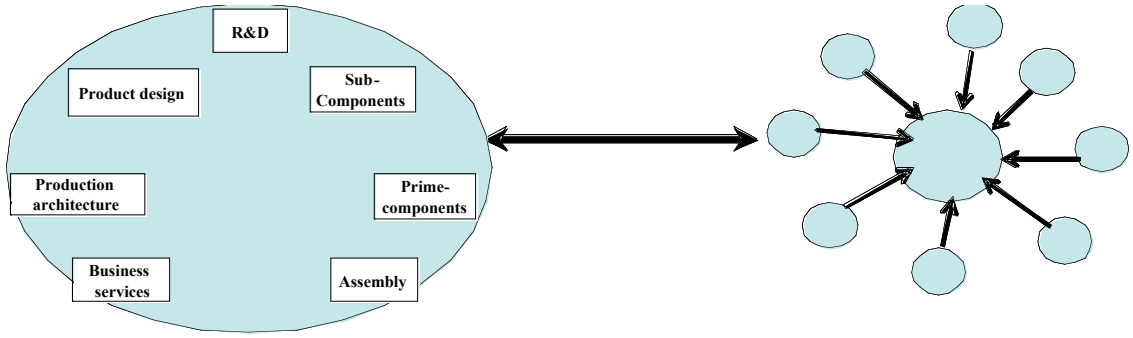
Debresson *et al.* 1998). Maskell and Lorenzen (2004) add to this concept by making this observation that clustering could be aided by being in close proximity to potential suppliers as it assists with the development of trust in the supply chain relations.

There is still much to learn of the internal dynamics of clusters. 'We continue to ask ourselves: when, or under what circumstances, does spatial proximity matter, and why?' (Wolfe and Gertler 2004: 1090). Curiously, although this is an important topic, research that purely focuses on why proximity matters with intra-cluster research without a sense of the overall strategic position and structuring of clusters may not be able to answer the central question. A broader project of clusters research (and value chains research) should be more informative.

Clusters and inter-regional interdependencies

If we return to start of this paper and compare the existing frameworks we are left with the impression that there is either clustering or production fragmentation. In the work by Porter, Maskell and others the intra-cluster emphasis, as explored above, can leave the sense that clusters need to be 'complete' or in some way self-sufficient[12], where all the essential ingredients (suppliers, buyers etc) exist in the same geographic space. Alternatively, the work of Feenstra (1998) or Jones and Kierzkowski (2000) amongst many others, would suggest that value chains are becoming de-spatialised. This presents a choice between clustering and fragmentation (Figure 2).

Figure 2: The Clustering Continuum: from completely *clustered* to completely *fragmented*



Curiously, there remains surprisingly little work that analyses interdependencies between places (beyond merely trade analysis). Regional specialisations can, it is argued here, play an important part in global value chains. Important questions then are what is

[12] Which should not be confused with sustainability (see Holbrook 2003).

happening at the spatial level, what role do particular places play in global production? If we could begin to examine the network relations between geographic places for particular production systems such as motor vehicles[13] or aerospace or ICT[14] (or other production systems) within the context of knowledge production and the firms than inhabit them, it would be the beginnings of an *internationalised systems of innovation* framework.

Although, the concept that clusters should be seen as nodes in longer value chains is not particularly new (see e.g. Amin and Thrift 1992 or the world cities research field e.g. Beaverstock *et al.* 1999), the perspective has not developed as major thread in the research literature on manufacturing industry based clusters. Even as recent research highlights the significance of external relationships for knowledge sharing, this has not been extended to examining the linkages within a spatial structure – to who does each cluster connect to? The current emphasis on global pipelines Bathelt *et al.* (2004) reveals no interest in the spatial architecture of systems.

Analysis of such systems of systems, researched in the urban studies field since the 1950s (see the review article by Berry 1964) could be termed the exploration of cluster complexes. What flows between clusters (goods, services, knowledge, people), what is the structure of flows, and which clusters are larger and more economically powerful; the flows networks and hierarchy model that is commonly adopted for analysis of businesses (see Storper 1997).

4. Evidence on the Clusters Complexes

This paper has not the space to examine all the different dimensions of a cluster complexes perspective, and in any case the necessary information is not available. It does however aim at sketching out some of the knowledge that we do have already and some that requires further research. The current paper takes advantage of recent work to develop a series of inter-country input-output models that calculate the interactions between countries arising from trade in industrial components. These models make it possible to analyse the interactions and interdependencies of industries across national borders. The research presented here suggests that the imports of materials and components are probably more important for many industries that previously implied in the literature. Further, the research using these models indicates that a number of high R&D intensive industries are more reliant on intermediate imports than other industries and are trending towards increasing dependency (see Table 3). This provides an empirical dimension to the central theme of the current paper which is the theoretical dimensions of understanding clusters as nodes within cross-border production systems.

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[13] This is the topic of Wixted 2006.

[14] Wixted and Cooper (in press).

The conceptualisation of clustering as primarily an interest in the local intra-cluster dynamics and capabilities inevitably leads to debates over cluster borders. As Malmberg and Maskell highlight clustering operates at different scales.

> 'One problem relates to the issue of spatial scale. The notions local and regional, which are often central in analyses of spatial clustering, are extremely elastic. First, the two notions are often used more or less as synonyms in the literature. Furthermore, they may denote a number of geographical scales, extending from the local neighbourhood (a street or block in a city, or a small town) through to entire nations or even groups of nations. Similar mechanisms or forces are held to explain both why advertising agencies flock together at a particular street (Madison Avenue) in New York, and why the 'European banana' developed as a core area of heavy industrialization during the 19th century, an area which is extended across several countries in the heartland of what is now the European Union. It does not, however, seem possible to define, once and for all, a specific geographical scale at which one could argue that agglomeration economies exert a particularly strong influence. Rather, it seems reasonable to allow the scale to vary according to which type of phenomenon that is emphasized in the analysis' (2002: 442).

A cluster complexes perspective does not make such a debate over cluster boundaries but it does re-contextualise it. No longer is the site and capabilities of the cluster the over-riding feature, but the context of the cluster gains in importance. Is the cluster (advertising) connected to a larger business services cluster or global city, are industrial districts located close to one another but taking advantage of political and other advantages (Detroit – Winsor auto clusters) amongst other examples. The connections and connectors thus become central and the geo-political alignments become valuable information in understanding the incentives for systems to be configured in particular shapes.

Cluster connections

Smith and Timberlake (2002) suggest there are three kinds of trades between places – human, material and information. However, in terms of information economics, the picture is somewhat more complex. Information can be carried by people (tacit knowledge [in person or via long distance communications]), goods (embodied knowledge in technology), services (codified knowledge transfer in designs, drawings, reports, publications etc) or existing in the global collection of codified knowledge (accessible via libraries, physical places or via the internet). Although there is a general emphasis on the expansion of trade in goods and services, there is also an expansion of travel and communications trans-border commerce (see Cohen 2002). There is a growing amount of research that points to external cluster linkages whether in the form of travel

contacts[15] or products[16] as being very important for some clusters. Gertler (2005) has divided Canadian clusters into those that rely to various degrees on local and global knowledge (Table 1).

Table 1: Global and Local Knowledge in Canadian Clusters

Knowledge Base	**Geography and Knowledge Flows**		
	Strong global sources	**Global and local sources**	**Strong local sources**
Synthetic		Ontario steel	Sudbury mining S&S[1] Windsor auto Parts / TDM[2]
Hybrid	Montreal aerospace	Okanagan (BC) wine Niagara (Ont) wine Toronto speciality food	Toronto medical technologies
Analytical	Saskatoon agri-biotech	Vancouver biotech Ottawa telecom / photonics	

Note [1] supply and services. Note [2] Tool, Die and Mould.

Source: Gertler and Wolfe (2005).

The Wolfe and Gertler analysis is a useful first step in linking regions with a spatial perspective on their knowledge base. A different layer of data can be added if we look at the international sourcing of components by industries, which can also be used as a proxy for innovation related user-producer relationships. Based on inter-country input-output modelling[17] for 15 European Countries (base year 1995) and nine OECD countries, Wixted (2005) has showed that many of the national clusters[18] with the most internationalised production systems were scale and science based.

Table 2: Modified Pavitt taxonomy – counts of top five internationalised clusters

	EU model # / 75	**OECD model # / 45**
Science based	**6**	**8**
Specialised supplier	**4**	**3**

[15] Bresnahan and Saxenian

[16] See e.g. Simmie 2002, Simmie 2004 and Simmie *et al.* 2002.

[17] See Wixted and Cooper (forthcoming) or contact the author for technical details.

[18] The results from the input-output modelling of the requirements from different industries in different countries for a given increase in production have been aggregated into *national clusters* – thus an increase in production in a particular motor vehicles national cluster requires inputs from industries in its home country and others as well.

Scale intensive*	**41**	**20**
Labour intensive	**11**	**5**
Resource intensive*	**4**	**9**

Note 1. These are based on OECD (1996) definitions but *Resource intensive* has been modified to remove non-ferrous metals and put it back into the scale intensive group. Scale intensive includes activities such as paper & printing, chemicals, rubber & plastics, iron & steel, shipbuilding, motor vehicles, and other transport). Science based includes: aerospace; computers; pharmaceuticals and instruments)

Note 2. The numbers represent the national clusters that rely on the highest share of value added which is imported – the five most internationalised were tallied for each country. There were 15 countries in the EU model so there is a total of 75 highly internationalised clusters.

Source: Wixted (2005: 178).

Wixted and Cooper (forthcoming) have more recently shown that the science based category will probably increase its share of internationalized production systems, as ICT becomes increasingly dependant on imported components. The following table (Table 3) was designed to investigate the question of system shift. That is, across time, which production systems are requiring more imports? The table was created by tallying the five[19] national clusters in each country with the highest requirement for international imports. Although the dataset cannot capture domestic inter-*regional* (states or provinces) interactions it does emphasis the scale of movement of goods and services across national cluster boundaries. By doing this for different time periods it is possible to reveal a little of the evolution in the organisation of production for 9 OECD countries between 1970 and 1995. For comparative purposes the table also includes the results for the full year 1995 – 20 country model.

Table 3: The evolution of industries with the highest imports as % of value added

Top Importing Clusters	**1970 (9)**	**1990 (9)**	**1995 (9)**	**1995 (20)**
Petroleum & coal products	9	8	8	14
Office equip & Radio TV & communications equipment	2 (of 14 series)	7 (of 14 series)	11 (of 17 series)	27 (of 38 series)
Motor vehicles	3 (of 8 series)	5 (of 8 series)	5	12
Aircraft	4	4	5	9 (of 13 series)
Non-ferrous metals	6	6	4	9
Iron and steel	4		3	8
Shipbuilding & repairing		1	3	3
TCF	5	5	2	2
Industrial chemicals	2	4		2
Other transport	3	2	2	2
Paper, paper prods & printing		1		
Wood products & furniture	2	1	1	2

[19] Because each country has a different degree of dependency on the rest of the world, data driven approaches whilst attractive are problematic. The number five although somewhat arbitary is enough to capture the high frequency industries as well as the tail of just a few representatives of various industries.

Rubber & plastic products		1		4
Other manufacturing	2			
Mining & quarrying			1	1
Professional goods	1			
Food, beverages & tobacco	1			
Transport & storage	1			
Pharmaceuticals				2
Electrical Machinery				2
Computer services				1
Total	**45 (9 * 5)**	**45 (9 * 5)**	**45 (9 * 5)**	**100 (20 * 5)**

Source: Wixted Yamano and Webb 2006.

It is clear from this table that the number of countries in which the requirements for production ingredients for petroleum, aerospace and motor vehicles remained relatively high and quite constant between 1970 and 1995. On the other hand, other production systems (e.g. industrial chemicals) moved in and out of the list of leading internationalised production systems. The ICT related manufacturing activities are clearly distinctive because of their trend towards an ever greater dependency on imports.

At first this data is striking because it isn't the low cost, low technology industries that are requiring the highest import content. But perhaps it shouldn't be so surprising. A recent paper has suggested that networking intensifies as the need for integrating knowledge intensifies[20]. The evidence presented above that some of the most internationalised clusters are also technologically intensive would seem to support this hypothesis. This is important information because it shows that high technology industries far from being more secure from fragmentation are under greater competitive pressure. The flip side of the analysis presented in Table 3 is that it does not analysis industry relocation, where industries such as clothing and footwear are perhaps moving off-shore, more or less completely.

Alongside this evidence that the level of external content integration is important to some clusters, there is evidence that it extends beyond embodied knowledge. Untraded knowledge flows and user-producer relations may be expand longer further that is usually understood. Saxenian and Hsu (2001) argue that tacit knowledge can flow beyond the local domain through frequent face to face visits, which is illustrated by them through their study of the personal connections between Taiwan and Silicon Valley. Interestingly, Rauch (2001) has shown that migration patterns are correlated with export growth and that social ties alongside networks of unrelated (in terms of ownership) businesses are important factors in the development of trade patterns. Thus a growing social connection between places occurs alongside trade increases (determining cause or effect is difficult), but it is suggestive of a flow of tacit knowledge on businesses, capabilities and markets.

[20] 'Only when there is a low degree of relatedness, so that a major input in one good is only minor in the others, do we see high benefits from integration of knowledge and high network density' Ozman (2006:18).

This evidence could in turn be linked to the argument by Maskell and Lorenzen (2004) that clusters are a means of reducing business risks. They suggest that businesses might position themselves inside clusters to reduce their risk and to create reduced markets of potential suppliers. Instead of needing to consider all potential suppliers, a purchasing firm can reduce its risk by increasing its knowledge of suppliers by choosing those from within the same cluster. As relevant buyer risks are multiplied in new territories for a particular business it would seem logical that Maskell and Lorenzen's argument would be of even more worth as an operating model in new export or sourcing markets.

Cluster Complexes: the spatial structures of linkages

Particular, clusters types then, rely on external resources (often technological in nature) and some classes and increasing reliant on traded goods and information (e.g. ICT). But these flows go beyond being merely global pipelines as suggested before. The trade patterns have shape, the networks are both limited in nature and are constructed around nodes that are of greater or lesser importance (first and second tier clusters). The structure of interdependencies between national clusters has been reported by Wixted (2005) examining the spatial structure of ICT, aerospace and motor vehicle production for the mid 1990s (across the EU and OECD countries). Wixted and Cooper (forthcoming) map the evolution of the spatial structure of ICT related manufacturing between 1970 and 2000, while Wixted (2006) has explored the spatial organisation of the motor vehicle production system. These studies highlight the individuality of the structures. Both *Radio, Tv and Communications Equipment* and *Office Machines and Equipment* based structures have numerous first and second tier supplier centres, while the motor vehicle production system has fewer and the aerospace production system is very concentrated and hierarchical. This architecture of cluster complexes presumably reflects the both the underlying technological structure and transport costs of these production systems. ICT is based more in modular parts that can be designed and built n more locations and shipped both more easily and cost effectively than other technology / industry combinations. On the other hand automobile parts are more costly to ship and aerospace requires a high degree of integration capability and transport is more costly still, thus defining to some extent the structure of systems of systems.

5. Drivers and dynamics of structure formation: some new research questions

There are many questions that arise from the research results that are available thus far on the emerging cluster complexes perspectives. Some of these are old questions that require new investigative angles such as the border effects puzzle (see e.g. Helliwell 1995 and subsequent literature). This existing area of analysis reveals that contrary to standard economic theory, borders (national or provincial) diminish the level and extent of trade. Regional innovation analysis could through new light on this 'problem' with cluster based insights. A second necessary contribution would be more research on the nature of politico-institutional incentives for production activities to locate in particular places.

Again this goes back to a more traditional interest of political and mainstream economists in barriers to trade and industry incentives. But again and innovation systems based presentation would be helpful. What are the costs and benefits of these on the global configuration of activity? Are some worthwhile and others not?

However, a question that innovation researchers may find of more immediate relevance is examining the connection between new technology management approaches in complex and modular technology based activities and the effects of such approaches on the spaces of innovation. Within this bundle of issues are the separate but relates topics of production modularity, network management and the spatial distribution of production.

Ethiraj and Levinthal (2004) make the point that one of the driving forces behind the product modularisation has been its advantages for managing product development when the degree of complexity makes it extremely costly or impossible to specific all the components and their individual interactions. A number of authors have indicated that the shift to modular production can be accompanied by a shift to from integrated manufacturing corporations to production networks (see e.g. Gereffi *et al.* 2006). Sturgeon notes that the move towards both adopting a modular production structure and a networked organisational structure is ongoing in a number of production systems.

> The modular production network model is derived from research on product-level electronics manufacturing (computers, communications equipment, consumer electronics, etc.), where the organizational shift from in-house to out-sourced manufacturing, has been dramatic in recent years. However, other research strongly suggests that comparable changes are underway in many other sectors as well, such as apparel and footwear, toys, data processing, off-shore oil drilling, home furnishings and lighting, semiconductor fabrication, food processing, automotive parts, brewing, enterprise networking and pharmaceutical production.

However, the rise of product modularisation and production networks doesn't necessarily imply the break down of the importance of economic geography, *per se*. This then brings us full circle to the start of this paper. We began by highlighting a number of key perspectives that have emerged for analysing the global economy, but just as our notions of the 'firm' and 'production' splinter so does our capacity for a sense of the macro-dynamics.

6. Implications and Conclusions

The existing innovation systems literature draws a boundary around 'systems' that at their outermost edge are synonymous with nation state political borders. As the dust jacket for a recent book on clusters states '… the authors are able to explore the role that national innovation systems play as a framework in which clusters operate' (Pressi and Solimene 2003). The innovation systems perspective has correctly pursued an interest in the internal dynamics of places (regions, clusters or nations), to counteract the over emphasis on externalities to be found in traditional economics. In the economic geography field it

seems plausible to suggest that Porter's model (1990) of clustering remains persuasive. Such clusters would need to include many of the ingredients (suppliers, buyers, production etc) and could be essentially characterised as a model of relatively 'complete' clusters. For various reasons, different researchers have emphasised a similar perspective on development. However, such idealised types of 'complete' clusters is not a useful model (Wolfe and Gertler 2004), probably comparatively rare in everyday business life and with the increasing fragmentation of production (Arndt 2001), growing rarer year by year.

Yet while the perspective is limiting, the findings on the relevance of clustering or national systems of innovation, should not be ignored. System environments are likely to continue to be an important context for continued innovation, competitiveness and specialisation

Products, networks, and macro structures

However, as final products in a number of categories grow ever more complex no one cluster or national system can master all the necessary technologies. Thus systems will tend to specialise (see Leamer and Storper 2001), production (products) will continue to internationalise, and key businesses will expand their role as integrators and assemblers. Thus it is important to understand the geo-political model of innovation, for what it is, useful but increasingly a hindrance to the developing better models of the macro structural changes in world commerce. There is a need for a framework that can synthesise the spatial findings of innovation research and integrate them with the patterns of trade and new cluster emergence and development. This paper has proposed that a 'cluster complexes' approach could fill the current gap. Because it links places in economic space it can incorporate analysis of the flows, networks and hierarchies of clusters in the world economy.

At the beginning of his book on innovation systems Edquist (1997b) nominates interdependencies as one of the key forces shaping innovation, and it has already been mentioned here that DeBresson *et al.* (1998) linked the economic structure of a few countries with their innovation user-producer structures. It is valuable, therefore, to point out here that the framework of cluster complexes is grounded in one of the core features of innovation studies, that the production of new technology is not an isolated event. Why then isolate geographic entities from their economic contexts and wider user-producer relationships and expect that these too won't be significant?

Implications for system theory

Unlike the use of the emerging dichotomy between 'local' and 'global' knowledge (Bathelt *et. al.* 2004 and Gertler and Wolfe 2005) the goal of this paper has been to articulate an approach which takes an interest in the specific extra-regional spatial structure of cluster relations. In developing a framework of inter-cluster dynamics and the internationalisation of systems it can most easily be understood in connection with global

value chains, but the movement of people and knowledge links are recognised as different layers in a total map of interdependencies. That is not to say that there should not be a continuing focus on the internal dynamics of clusters, only that new dimensions should be added to the debate. The paper has highlighted a number of high *R&D intensive* activities, which are commonly understood to gain benefits from being regionally clustered, are also *import intensive*. This connection between import intensiveness and regional specialisation needs to be explored further with detailed information on the technological capabilities, technologies and product positions of various regions.

Clusters are far from being isolated atolls of innovation, they are linked to other places via the movement of people, goods and knowledge and every cluster holds a different strategic position in terms of skills, knowledge, technology, production capabilities and economic relationships. An important implication of this framework is the need to look at clusters in terms of their location, their inter-regional flows, where they fit into a global product system and how these characteristics change across time. As Saxenian and Hsu concluded from their work on the connection between the Taiwanese IT cluster and Silicon Valley: 'as governments around the world clamour to establish venture capital industries and technology parks in efforts to replicate the Silicon Valley experience, the Taiwanese case suggests that new centres of technology and entrepreneurship cannot be created in isolation' (2001: 917).

Implications for cluster policy

Cluster policy has often been portrayed as something distinct from other policy areas (see e.g. Andersson *et al.* 2004). While this may continue to have some legitimacy, the material presented in this paper indicates that there is a need for greater recognition of the integration of cluster policies within general innovation, technology, export promotion, investment and value chain development programs.

Acknowledgements

I would like to thank Robert Dalitz and Brian Gordon for their comments on various drafts of the current paper. Naturally any errors remain the responsibility of the author.

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