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## THE EVOLUTION OF INNOVATION SYSTEMS

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**Abstract:**  
There is an increasing appreciation for the role that facilitating institutions play in successful innovation. Most commonly these institutions are discussed and analysed as innovation systems. National Innovation Systems were the first type identified, and a range of other forms of innovation system have been identified including local clusters, Regional Innovation Systems and Sectoral Innovation Systems. Innovating agents tend to be similar across and within these different systems, and include individuals, firms, collaborative networks, research institutes, financial institutions and universities. However, each system tends to co-ordinate the activities of these actors in different ways, and this is what differentiates the systems. This paper uses the micro meso macro analytical framework from evolutionary economics to provide a new view of innovation system evolution. The key implications of this perspective are: innovation systems are best analysed as populations: the different types of innovation system interact at the level of innovating agents, and which one dominates in a particular situation will vary: innovation systems and innovating agent co-evolve rather than thinking that agents must conform to the constraints of the systems they work within, it is important to realise that they can also shape these systems through innovative action. Conceptualising innovation systems in this way leads to testable propositions that will provide a different way of analysing their evolution.

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The evolution of innovation systems

## **Abstract**

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**Keywords:** innovation systems, evolutionary economics, micro meso macro analysis

**JEL – codes:**

## 1.0 Introduction

There is increasing appreciation of the role facilitating systems play in innovation. National Innovation Systems (NIS) were the first type identified, and a range of other forms of innovation system have been suggested including local clusters, Regional Innovation Systems (RIS) and Sectoral Innovation Systems (SIS). The theory of innovation systems – from the Classical theory of Friedrich List (1856) to the modern evolutionary-institutional theories of Chris Freeman, Richard Nelson, Charles Edquist and Bengt-Ake Lundvall, among many others – explores how agents use resources and existing knowledge to produce new knowledge that creates new economic value. In this way, the study of innovation systems is the study of the evolutionary mechanisms of economic growth and change.

Yet while it is axiomatic that innovation systems cause economic evolution, they are not often themselves viewed as evolving. Even the multi-generational models of innovation process (e.g. Rothwell 1994) still presume that this is not actually an evolutionary process, but rather an upgrading of increasing complexity in a predictable direction of network openness. Indeed, just as earlier industrial macroeconomic analysis sought to map a presumed static industrial structure (e.g. I-O tables), so too has the study of innovation systems sought to map, with similar implicit static thinking, the structure of the innovation system. The research program implicit in this is very much focused on identification and description; it tends to eschew questions of how innovation systems change from within, or even of how agents interact with the innovation system. Behind this lies an implicit analytic notion of *innovation system equilibrium*, in which all agents have fully adapted, and in which there is nothing corresponding to changing innovation technologies or rules. In such an equilibrium, the proper first question is rightfully that of an inventory of content and account of structure. But, if innovation systems evolve, and if this evolutionary process further impacts on the ‘first sector’ – the real economy – then a theory of how innovation systems evolve matters.

Consequently, the two questions with which we are concerned in this paper are: how do the different types of innovation systems interact? And, how do innovation systems evolve?

The presumption that innovation systems are themselves ‘parametric’ structures is a suitable analytic approximation only so long as innovation systems are everywhere the same, and slowly changing. Yet both presumptions are manifestly false. Like industrial structure, *innovation structure* (as is an innovation system at a point in time) is continually evolving as new ‘knowledge about knowledge’ enters into this ‘second sector’, inducing the same creative destructive processes in the innovation system that occur in the real economy. In this paper, we shall argue that we may nevertheless use the same analytic framework as we use to study the evolution of the ‘operational’ economic system (the first sector) in order to study evolution in the innovation system. Specifically, we argue that the *micro meso macro framework* (Dopfer and Potts, 2008) – which is an analytic fusion of the Schumpeterian, Hayekian and Institutional analytic frameworks – can provide a general analytic structure and language for the study of the *evolution of innovation systems*.

At the core of this argument lies the basic relation between coordinated economic activity and innovation systems: namely, for each structure of operational activity, there must exist an innovation system. Without this adaptive capability, or ‘dynamic investment’, a system cannot survive in a changing environment. Innovation systems are thus ubiquitous, but mapped from the existence of *any* economic organization, structure or system. Call this a ‘macro-economic unit’, whether a firm, industry, region of national economy. A macro-economic unit is thus composed of two levels (or sectors, as in a two sector model): (1) an *operational system*, referring to the set of structures and processes that produce the final valued output of the economic unit; and (2) an *innovation system*, which is also a structure of resource use and knowledge, yet it does not produce new goods and services but rather produces the new knowledge and capabilities that in turn produces new goods and services. To every ‘macro unit’ in the economy, there is a corresponding innovation system. A national economy has a corresponding national innovation system. So too does a supra-national, regional, subregional (cluster) and sectoral economy have a corresponding supra-national, regional, local and sectoral innovation system. Indeed, there are perhaps innovation systems yet to be discovered as new groupings of economic activity are defined.

Dopfer and Potts (2008) argue the micro meso macro framework can be used to describe the evolution of the ‘first sector’. They attribute the innovation system as the content of what they call ‘2<sup>nd</sup> order rules’, corresponding here to the

notion of a second sector.<sup>1</sup> But we may also conceive of the evolution of the innovation system itself using the micro meso macro framework. This takes us from recognition of the role of the innovation system as a ‘driver’ of economic evolution to a new view of how the efficacy of the innovation system itself may change through time as new rules and knowledge about the innovation process are developed. This is not so much a ‘third sector’<sup>2</sup> – i.e. a system for producing new knowledge about how to produce new knowledge for new economic operations – but rather an outcome of *co-evolutionary feedback* between creative agents in the economy (the first sector) and those in the second (the innovation system), as well as result of the introduction of new innovation system rules in to different macroeconomic systems.

We shall begin by briefly reviewing the innovation system literature and the micro meso macro framework of economic evolution before applying it to the evolution of innovation systems. We shall use examples to illustrate the development of propositions here are based on fieldwork conducted over more than a decade.

What do we find? Conceptualising *innovation systems* in this way leads to several insights into two emerging research questions. One concerns how the various innovation systems interact with each other at the level of innovating agents within an economy. These agents often have choice over which competing institutions can provide them with best support. They thus ‘shop’ among innovation system substitutes (and complements). This leads to differential adoption (of innovation system rules), a process we propose as central to the evolution of innovation systems. Consequently, the question of which innovation system dominates will be contingent. This leads to the second implication – that innovation systems are best analysed as populations. Within a nation, region or sector, there will always be competing innovation rules. Like competing technologies in a market, they will be differentially adopted, resulting in a population dynamic within a ‘market’. Innovation systems are themselves complex adaptive systems composed of complex structures of complex populations.

An innovation system is a *complex system* – it is composed of a complex structure of connected elements (Potts, 2000). But it is also an *evolutionary system* in that this dynamic is, in essence, a population dynamic. Furthermore,

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<sup>1</sup> Note Dopfer and Potts (2008) also speak of a *0<sup>th</sup> order sector*, composing the constitutional ‘rules of the game’ in the form of the social, political, cultural and legal institutions that underpin the 1<sup>st</sup> order or sector.

this evolutionary dynamic is driven by variety in the form of continually emergent heterogeneity from new innovation rules. These emerge as innovating agents devise new macro rules, and by the process by which these rules diffuse through the population of firms in an innovation system. The final key point then is that innovating agents (entrepreneurs, consumers of novelty) and innovation systems *co-evolve*. It is not simply the case that innovation systems determine what the agents embedded within them can or cannot do. Rather, agents have the ability to change their innovation systems by generating and adopting for continuing use new innovation rules. Economies can evolve because innovation systems exist, but innovation systems exist because macro-economic systems, ultimately, compete by innovation. That is why they co-evolve.

## **2.0 Theoretical Background**

### **2.1 Innovation Systems**

While the formal study of innovation systems is a relatively recent phenomenon, the intellectual roots of this research are deep. List (1856) was the first to discuss in depth the importance of innovation and knowledge as drivers of differential economic growth among countries. Marshall's (1898) work on industrial districts addressed issues relating to the impact of knowledge and innovation on localised economic growth, and Schumpeter (1912) emphasised the uneven diffusion of innovations, both through regions and through industries.

While many of the major themes of innovation systems research were touched on by these earlier scholars, their study has expanded rapidly over the past twenty-five years. Building on results from earlier works (e.g. Landes (1998), Gerschenkron (1962), Rosenberg (1971)) which show an empirical connection between innovation and economic development, the seminal work of Nelson (1993) contains a collection of papers that propose that this connection is facilitated through differences in NIS. Crudely, the subsequent approaches to studying NIS split between focusing on either the institutions supporting innovation or on the relationships between firms and other organizations. The first view places an emphasis on institutions (government, universities, research

institutes and firms) which provide both opportunities and constraints within NIS (Nelson, 1993). Research in this stream studies changes in proxy measures for innovation such as patents, education levels, and research output which follow changes to the system's institutional structure. In the second research stream, relationships between firms within NIS were argued to be the primary driver of innovation (Lundvall, 1992). Research in this perspective tends to look at the impact that cooperation and trust has on firm/network level innovation, and extrapolate these results up to national level. These perspectives have developed in sophistication, both empirically (OECD, 2002) and theoretically (Edquist, 1997; Edquist and McKelvey, 2000) and the NIS concept is now widely accepted as being an important contributor to understanding differences in innovation performance between nations.

As the study of NIS developed, it was found that innovation systems operate at levels other than simply the national one. Saxenian (1994) compared Silicon Valley in California and Route 128 in Massachusetts, demonstrating significant differences in innovation systems within a nation. Further research in this area has led to the development of the concept of Regional Innovation Systems (RIS), which have also been found in Europe (Cooke, 1992). The most recent advance has shown that in some cases, institutions are more consistent within sectors than they are within nations (Breschi and Malerba 1997; Malerba 2005). This has particularly been the case in Europe, where the Sectoral Innovation System (SIS) in many cases has a greater influence than the NIS, particularly in the IT and Biotechnology industries, but also in several manufacturing sectors.

There are two important recent developments in the study of innovation systems. The first is exploration of how to integrate the two approaches – the 'relational' and 'institutional' – into a comprehensive model. The recent government review of Australia's national innovation system, for example, refers to the need to study the institutions and connections facilitating the stock and flow of knowledge (Venturous Australia, 2008). This relates closely to the second issue in which the two perspectives are starting to be combined to develop models of innovation system dynamics. However, as Lee and von Tunzelmann (2005) point out, in order to understand the dynamics, we must first understand the interactions between the agents and institutions that make up the system. Attempts to track the evolution of a NIS must document and *explain* the changes in these relationships (an idea also supported by Malerba, 2005). Consequently, recent work investigating innovation system dynamics

tends to address both of these questions together. Bergek, et al. (2008) provide a useful analytical framework for doing this, which sets out a methodology for investigating the interplay between structural components (agents, networks and institutions) and the functions of innovation systems (e.g. knowledge development, resource mobilisation).

## **2.2 Micro-Meso-Macro Analytical Framework**

We frame the study of the dynamics of innovation systems as a process of economic evolution. Specifically, this is analytically defined in terms of what Dopfer and Potts (2008) call *micro meso macro*. Just as we can study the real economy in terms of micro meso macro analysis (Dopfer, Foster and Potts 2004; Dopfer 2005), so too can we study the evolution of innovation systems as a micro meso macro process.

Micro meso macro defines three distinct levels of analytic structure in relation to knowledge, or ideas, and the knowledge base of an economic system. A micro unit is the analytic core, being composed of an idea – a rule, a ‘process-structure’ of knowledge – and its population of carriers of that idea. A meso unit is the product of a *meso trajectory* that begins with the origination of a new idea or rule, and then continues through the phase of adoption and retention of that rule. A knowledge base is composed of multiple meso units as a complex system. This is a macro unit: e.g. a market, a sector, an industry – any coordinated structure of knowledge.

A micro unit refers to any carrier of knowledge, such as an agent. A micro ‘carrier’ acquires knowledge through a process of origination, adoption and retention. Each micro unit – which is the carrier of the economic knowledge base – carries different knowledge and can change the knowledge it carries. This is also true of innovation systems. Micro agents are engaged in building their innovation system through a *micro-meso* trajectory, but so does the pattern of *meso-macro* innovation systems change by the process of differential adoption of innovation system rules. This total process is a macro change in the structure and process of an innovation system.

This highlights two aspects: coordination and change. First, an innovation system is a coordinated structure of its elements: e.g. firms, venture capital,

incubators, universities, etc. But the structure of coordination between elements is not just about whether ideas fit together, but also whether the populations of carriers of ideas fit together. Even when a structure of ideas fits together, coordination may yet fail if population structures also do not fit together. This is what we mean by the question of what an innovation system is composed of, how it fits together, and what material outcomes this particular coordination structure (i.e. system) achieves.

The second aspect is change, by which we refer to a new element in the innovation system. The analytic logic flows over from standard evolutionary economics, by which we refer to the effect of a new idea, or generic 'meso' rule. The innovation system is itself a complex structure of many rules that compose the ideas that make ideas. Each of these rules is a meso unit, an element of the complex 'macro' system that is an innovation system. In turn, innovation system evolution is a change in the macro system by the entry of a new meso unit, a new element of knowledge in the innovation system that feeds into the knowledge base of the real economy. The key idea is that we can equally describe this evolutionary process (of an evolutionary mechanism) with the same evolutionary framework.

In the micro meso macro framework the economy is made of ideas, or 'generic rules', each of which is the root of a meso population. Each idea is carried by a population of agents. The value an agent can create is thus proportional to the ideas it carries. This is complicated by the problem of coordination: namely that the value an agent can create is a function of what rules other agents carry. In a real economy, two generic processes occur: (1) *coordination between rules* occurs as agents differentially adopt rules (ideas) as a function of the current state of other rules; and (2) *change in rules* as new rules are originated, adopted and retained through a process of de-coordination and re-coordination of the innovation system. The study of innovation systems from the evolutionary perspective thus seeks to account for the micro meso macro framework in which: (a) micro refers to the adoption of new innovation system rules; (b) meso refers to the resultant set and respective populations of innovation system rules; and (c) macro, in turn, refers to the emergent complex structure of meso rules composing the (macro) innovation system. The 'micro meso macro' framework may in this way offer a useful analytic framework for both conceptualizing and decomposing analysis of innovation system dynamics.

### **2.3 *Micro meso macro analysis in innovation systems***

To understand the evolutionary dynamics of change within Innovation Systems, it is useful to analyse them as heterogeneous macro rule systems. In this way, change is shown when the relative frequencies of competing meso rules change over time. The analysis of innovation systems must then be undertaken at the three levels of generic economic evolution (Dopfer and Potts, 2008).

At the micro level, the analysis is interested with how innovating agents actualise meso rules concerning the innovation process. These can either be rules that originate from an innovation system within which the agent is embedded, or they can be novel rules that are generated by the agent. The proper level of analysis for assessing the interaction of competing rules is at this micro level. The first aspect of micro analysis of innovation systems then is the study of agent choice with regard to competing meso rules. When there is conflict between rules derived from different innovation systems, which is used? How often are firms able to choose, rather than having rules thrust upon them? These are two of the questions to address in micro analysis. A second line of micro analysis concerns the origination of new meso rules concerning innovation processes. While not explicitly using this approach, Murmann's (2003) study of the co-evolution of firms and innovation systems provides an excellent example the benefits of concentrating analysis at this level.

There are also several analytical questions to investigate at the meso level. This is where a population dynamics methodology will be most useful. It can be used to address questions such as: How much variety is there in meso rule actualisations throughout particular innovation systems? How do rules diffuse through and between innovation systems? Where do new meso rules originate in innovation systems? This is also the level at which population accounting will be useful. Important changes within a NIS start with very small populations, but can spread rapidly. Population dynamics can be used to measure the speed and scope of their spread.

Finally, macro analysis within Innovation Systems is primarily concerned with how different meso rules best fit together. An important point here is that when meso rules spread between and within Innovation Systems, their differing actualisations lead to variety. As two individuals belonging to the same biological species are never identical, neither will two actualisations of the same meso rule be the same. Studying the impact of different macro rule structures on the actualisation of meso rules is an important endeavour. These studies will investigate issues like: what combinations of meso rules work most effectively? Are there particular meso rules that do not interact well, and if so, why not?

### **3.0 Proposition Development**

Analysing innovation systems using the ‘micro meso macro’ framework provides insight into the two questions with which we are concerned. While this is somewhat of an oversimplification, in many cases innovation systems are depicted as being stable, homogeneous at the unit of analysis, and as systems that exist independently of the actors within them. However, there are many empirical examples of which are inconsistent with this view of innovation systems, and which are better explained by using the ‘micro meso macro’ approach. We will now examine some of these empirical paradoxes and use them to develop propositions derived from viewing innovation systems as complex adaptive rule-based systems.

The first paradox is that innovation systems are not homogeneous. There is nearly always variety within them. The key idea is that different innovation systems interact at the level of the agents, through the process of micro-evolution. New meso rules originate at the micro level, when an agent tries out something novel. Macro-level rule structures both enable and constrain this process of novelty generation. There may be situations where one innovation system dominates others, but they all address these issues of constraint and enablement – so the correct unit of analysis is agents, and the correct way to understand the interaction of different types of innovation systems is to assess how they all come together to influence the innovative activity of these agents.

At the micro level, since agents are simultaneously embedded within regional, national and sectoral information systems, all of these systems are able to contribute meso rules that might influence the process of innovation. In other words, innovation systems as macro rule systems are conduits for the spread of meso rules throughout the economy.

This process is illustrated by recourse to the study of the co-evolution of innovation in the biotechnology industry and the funding regime that supports research in this sector in Taiwan (Dodgson, Mathews, Kastelle and Hu, 2008). Investment in biotechnology began in Taiwan in the mid-1980s. At the time, the meso rule for funding Research & Development (R&D) was similar in all of the industry sectors within Taiwan – with the funding of R&D a consistent percentage of revenue across high technology industries. In Hsinchu Science Park (HSP), one of Taiwan's key innovation-supporting institutions, R&D investment in integrated circuits, computers and biotechnology was relatively similar across all three sectors until 1992. This level of investment was sufficient to fuel substantial growth in the integrated circuits and computers industries (Dodgson, Mathews & Kastelle, 2006).

However, biotechnology innovation and revenue was not growing commensurately. This is large part due to the fact that the type of research required for success in biotechnology is quite different to IT, and it generally has a longer incubation period before payoffs are realized (Hine and Kapeleris, 2006). In other words, the most common generic rule for investment in the biotechnology sector is different than that of the IT sectors – biotechnology requires much more upfront investment in order to support the much longer development period, and the higher costs that are incurred during this time. Consequently, there was a policy change in 1995 that resulted in a large increase in the level of government investment in biotechnology R&D (Hsu, Shyu and Tzeng, 2005). The percentage of revenues invested in biotechnology doubled at this point to 43%, ten times the average amount across all industries that were active in HSP at the time.

The biotechnology funding regime in Taiwan still was not aligned with the predominant funding rule within the biotechnology sector, which was that finance for R&D primarily derives from venture capital firms rather than governments. Consequently, there was a further policy change in 1999, resulting in changes in the tax burden on venture capital funding, and a lowering of the minimum amount of money required to start up a VC fund (STIC, 2001). These changes resulted in a funding regime for biotechnology in Taiwan that now more closely resembles that found throughout the sector internationally (Chiesa and Chiaroni, 2005). This led to a sharp increase in the amount of VC money invested in biotechnology, as well as in the number of biotech firms funded.

This illustrative case shows how there are often multiple competing rules existing within one Innovation System. In 1995, a new meso rule was introduced, seeing R&D funds more readily available for biotechnology firms in Taiwan. At the micro level, these new funds were taken up by firms and networks that were undertaking biotechnology research. Consequently, as more firms learned of the revised funding regime, the population of agents adopting the new rule grew quickly. This process is even more apparent with the introduction of the second new meso rule in 1999, the increase in R&D funding for biotechnology from venture capital funding. Micro level adoption of this rule is seen in the number of venture capital firms in Taiwan jumping sharply after 1999, while both the accumulated cases of investment and the accumulated amount invested also accelerate dramatically. The accumulated cases of investment more than tripled over the next six years, while accumulated investment increased 2.5 times. This indicates widespread adoption and embedding of the new funding rule within the Taiwan biotechnology sector.

At the macro level, the first step was de-coordination. Prior to the introduction of the first new funding rule, all R&D in Taiwan was supported in roughly the same manner, and at the same level. The introduction of the new funding rule required some firms to de-couple from the existing set of rules, and adopt the new rule. The Taiwan NIS then re-coordinated the set of rules guiding innovation to accommodate two different possible approaches to R&D intensity.

This pattern was followed again in 1999, with the end result being a new configuration of rules within the NIS.

This understanding leads to:

**Proposition 1:** Innovation Systems will usually consist of multiple, competing rules. The best way to understand the interaction between different Innovation Systems is to analyse how the meso rules from overlapping IS relate to each other at the level of innovating agents.

The second key idea follows closely from the first - Innovation Systems and agents co-evolve, and we only fully understand this if we analyse these as systems that include agents. The micro meso macro framework emphasises the interplay between the three levels of analysis. While change originates at the micro level, the generation of novelty at this level is dependent on the macro rule structures within which the agent is embedded. Within different innovation systems, the direction of influence is often assumed to be flow from the system down to the agents. However, by shifting the locus of system innovation to the agent level, our model assumes that change can flow in both directions. Co-evolution is a common feature of complex adaptive systems, and it is certainly a feature of the evolution of complex economic systems.

Returning to the example of Taiwanese biotechnology, this is demonstrated by the changes induced by the alliance between *AbGenomics* and *Boehringer Ingelheim*. *AbGenomics* is located in the Biotechnology Plaza in the Nankang Software Park in Taipei. *AbGenomics* focuses on the discovery and development of medicines to treat cancer, inflammation, autoimmune, infectious and metabolic diseases. The company has 55 employees and has posted average annual net losses of NT\$100 million since its establishment in 2000. The generic rule concerning biotechnology drug development within the Taiwan NIS is that development takes place within networks of cooperating firms and government research agencies. The formation of these networks is facilitated by another of Taiwan's key innovation supporting organizations, the Industrial Technology and Research Institute (ITRI). *AbGenomics* was part of one of these networks, cooperating with other biotechnology firms and the

government-sponsored research institute Academia Sinica – all co-located within the Nankang Software Park.

*AbGenomics*' collaborative network arrangement is consistent with those found throughout the Taiwan NIS. This model originated in the collaborative R&D networks in the IT industry. In the current case, the NIS provided a template of the way in which collaborative biotechnology R&D networks could be constructed, and *AbGenomics* followed this model. However, while collaborative R&D networks are a common part of the biotechnology SIS, they are normally structured differently. The meso rule most common in this SIS is that these networks will include at least one major multinational pharmaceutical firm, with the task of taking inventions to market (Chiesa & Chiaroni, 2005). At this point in time, *AbGenomics* was embedded within two different IS, with two different models for how to best structure their R&D network. In mid-2005, *AbGenomics* signed an exclusive licensing agreement with the German company, *Boehringer Ingelheim*, providing it with the worldwide exclusive rights to develop *AbGenomics* products, bringing expected revenues of between US\$ 90 million and US\$ 135 million from royalty fees during the development stage. This was the first major development deal signed by a Taiwanese biotechnology company with a multinational pharmaceutical firm.

Once this new model of R&D network configuration was introduced within the Taiwan NIS, it spread quickly. Other alliances were formed between Taiwanese biotechnology firms and multinational pharmaceutical firms from Germany, Malaysia and the Netherlands. The change in the Taiwan NIS accelerated in October, 2008, when *Merck* opened its Asian Technology and Training Center (ATTC) in Taipei. The objective of the ATTC is to facilitate the formation of many ties between *Merck* and the local biotechnology R&D networks (Biotech East, 2008). Consequently, the meso rule for biotechnology R&D network configuration in Taiwan is starting to more closely resemble the rule used by the biotechnology SIS rather than that of the Taiwan NIS. This example shows how meso rules can be diffused. The rule for R&D network configuration went from the biotechnology SIS to *AbGenomics* when the firm adopted it, and it has subsequently spread through the Taiwan NIS within the biotechnology sector. The key point, however, is that it is not simply the case

that the biotechnology SIS enabled innovation by *AbGenomics*, or that it was constrained by the Taiwan NIS. Just as importantly, the innovative action of *AbGenomics* has actually changed the macro rule structure of the Taiwanese NIS. *AbGenomics* and the Innovation Systems within which it is embedded are co-evolving.

It might be thought that this process of co-evolution only occurs in the case of idea diffusion. However, there are numerous examples of this also happening through the introduction of ideas that are genuinely novel. Murmann (2003) illustrates this with a number of examples, such as the move by the German chemical firms *Levinstein* and *Bayer* to hire chemists from abroad. At the time, the industry was just shifting to the model of corporate R&D laboratories (a new meso rule itself!), and there was intense competition between firms located in Germany, the United Kingdom and the United States. The larger chemical firms in all three countries formed R&D laboratories in the second half of the 19<sup>th</sup> century, and the success of these labs was predicated on the quality of chemists populating them. Consequently, there was intense competition to hire and retain the best available talent. Up until about 1900, this competition was exclusively domestic, with firms in all three countries only hiring residents. This changed when *Levinstein* and *Bayer* decided to try to hire chemists from the UK. At the time, immigration rules made it illegal for firms in Germany to do this. However, intense lobbying from the firms resulted in a change in the law. This gave the German chemical firms a distinct competitive advantage over those in the UK and the US.

This was the first time that any industrial firm had hired international research talent – it was a genuinely novel move. Before it occurred, the NIS in Germany, the UK and the US were all excluded from such actions. By successfully lobbying to change the immigration laws in Germany, *Levinstein* and *Bayer* not only provided themselves with the opportunity which they sought, they also changed the entire German NIS. As the meso rule for the formation of corporate R&D laboratories spread through other industries, within the German NIS firms in these industries were also able to take advantage of the new meso rule for hiring international researchers.

Another historical example is provided by the case of Josiah Wedgwood and the development of the Staffordshire pottery industry in the 19<sup>th</sup> century. *Josiah Wedgwood & Sons Ltd* had major impacts on all of the innovation systems in which it was involved (Dodgson and Gann, forthcoming). The invention and production of new pottery designs and ceramic materials introduced new meso rules for within the SIS. Similarly, the opening of a Wedgwood retail store in London generated novelty. This was the first factory retail outlet opened in a capital city by a manufacturing firm, and the introduction of this meso rule transformed the retail industry in the UK. Wedgwood also played a central role in the construction of English canals. His firm needed these in to speed the delivery of raw materials in to the factory, and of finished pottery out of it. This constituted the origination of a new meso rule concerning the transport of industrial goods. The rule quickly spread as other firms in the Staffordshire RIS took advantage of the new transport system.

Finally, it is not only large and powerful firms that can introduce novelty capable of changing innovation system. Garnsey and Leung (2008) provide a case study of a small biopharmaceutical firm in the UK and its experience in trying to bring a new drug to market. The drug itself was novel, and required innovative production processes. After failing to find domestic manufacturers capable of meeting the regulatory requirements for manufacture, the firm developed relationships with other firms for the main parts of the production process. It formed an alliance with a US company and together the alliance developed an innovative new way to culture cells. A second alliance was formed with a domestic firm to produce the specialty tubing and biologics vialling needed. The partner firm had never worked in the biopharmaceutical industry before, but it recognised an opportunity to enter a market with substantial international potential. The introduction of the new drug eventually failed. However, the impact of the supporting innovations persisted. In particular, new processes developed relating to biologic vialling have continued to diffuse throughout the biopharmaceutical SIS.

These examples show how innovative agents can change their innovation systems. New meso rules originate with these agents, and then spread through the innovation systems involved, leading to:

**Proposition 2:** innovative agents and innovation systems co-evolve. It is not simply the case that innovation systems enable or constrain actions undertaken by the agents within them. The generation of novelty by these agents also changes the macro rule structures of the innovation systems within which they are embedded.

The third idea has already been demonstrated in the examples we have discussed, which is that innovation systems are best thought of as populations. This is inherent in the definition of meso as a rule and its set of actualisations. The actualisations form a heterogeneous population. Consequently, innovation systems can be analysed using population dynamic methodologies.

This in turn suggests that all innovations systems will be heterogeneous, as variety is necessary for evolution through population dynamics. An example comes from the discussion of the evolution of the venture capital system in Taiwan. Prior to the early 1990s, the funding methods within the Taiwan NIS were relatively uniform. As ITRI tried to encourage the development of the biotechnology industry, a new meso rule was adopted from the biotechnology SIS, and some firms now had much higher levels of upfront expenditure in R&D. At this point, the Taiwan NIS became more heterogeneous, and within a few years about 8% of the country's total R&D expenditure was invested in the biotechnology industry using this different model (STIC, 2004). This is a typical evolutionary process – variety increases, there are differences in selection pressures, and populations increase or decline through reproduction. Similar heterogeneity in institutions supporting innovation is demonstrated by Verspagen and Srholec (2008) in a study of innovation in thirteen European countries.

This shows the way that a different macro context can change a rule. As shown, several of the rules that were implemented within the Taiwan biotech industry were 'imported' from the biotechnology SIS, but once they were implemented, they were changed. For example, in most OECD countries, biotech innovation networks include large pharmaceutical companies. Taiwan has imported the

rule ‘biotech innovation is best done within networks’, but because there are no large pharmaceutical companies present there, that part of the rule changed.

That was the state prior to 2005 – all of the biotechnology R&D networks followed the same basic pattern, which included a number of small domestic biotechnology firms collaborating with either university or science institute research labs (or both). Once *AbGenomics* initiated their partnership with *Boehringer Ingelheim*, variety was introduced within the population. This new meso rule for R&D collaborative networks spread throughout the local system, and with the arrival of *Merck’s* ATTC this rule is likely to spread even more rapidly. Observing and measuring changes such as this are a crucial part of understanding the dynamics of innovation systems evolution, and this is the type of change that is captured well through a population dynamics approach.

Heterogeneity has also been demonstrated within sectors. Leiponen and Drejer (2007) study 700 firms in Denmark and Finland distributed across a wide range of manufacturing and service industries. They then use Pavitt’s (1984) taxonomy to show substantial variation in the institutions supporting innovation within each industry. Eighteen of thirty-five industries surveyed have a mode of innovation which describes more than 50% of the firms in the industry, but only two have a dominant mode followed by more than 70% of firms.

As there are significant variations both within NIS and SIS, we put forward:

**Proposition 3:** Innovation Systems are populations. To evolve, all require variation, selection and replication. Consequently, all innovation systems will be heterogeneous across important practices. Those that lack variety will be unable to change.

## 4.0 Conclusions

Viewing innovation systems as sets of macro rules within a micro meso macro rule system has implications both for the way we study, and particularly for the ways in which we try to govern, them.

There are two important research implications. The first is that innovation systems must be viewed as populations. Consequently, their analysis should not just describe whichever rules are currently dominant within it, we should also consider the variety within related rules. This will allow us to evaluate the dynamics of the system by measuring relative changes in the populations of rules.

The second research implication is that it is important to study Innovation Systems at all three levels of analysis – micro, meso and macro. Most current research emphasises only the macro aspect of innovation systems – the description of which rules are currently present within particular systems. Introducing micro level analysis helps us to understand how agents actively shape the systems within which they operate. This will lead to a clearer understanding of the co-evolutionary processes through which innovation systems change. It will also provide the ability to analyse the interactions between innovation systems as they contribute competing rules that agents are then able to choose between. Finally, meso analysis will show how new rules originate and spread through populations of agents.

The primary lesson for agents within innovation systems follows from this point. In many cases, members of firms, universities, research institutes and other agents are treated as the objects upon which the rules of various innovation systems act. However, viewing innovation systems as complex adaptive rule-based systems brings agency back to agents. There are many examples of innovation systems being transformed by innovative action undertaken by agents in many different contexts: within large firms, small firms, universities, government agencies, and research institutes. It is important

to approach innovation systems as structures and relationships that can be changed through co-evolutionary processes, rather than as unchanging parts of the external environment.

There are also issues raised by this approach for innovation policy. One is that it might be much more difficult than expected to adopt 'best practice' in policies for innovation systems. Because these best practice meso rules are introduced into an often wildly differing macro rule structure, there is no guarantee that they will travel well between locations. This is not necessarily an argument against picking winners, rather a suggestion that a winner in one context will not necessarily perform equally well in a different context.

A second implication is that NIS and RIS will only change through a process that involves failure. This is often a challenging idea for policymakers to embrace (Potts, 2009), yet it is central to the evolutionary understanding of economic growth. As differing meso rules compete, some will inevitably die. This implies that innovations within an innovation system will be unsuccessful. A system in which every single idea works is probably not generating sufficient levels of variety to grow.

This leads to a third policy point, which is that innovation systems grow through improvements in variety generation, replication and/or selection processes. Consequently, policy changes should be specifically targeted at improving one of these processes. Rather than saying 'our region must have a biotechnology cluster in order to grow', it is more useful to ask 'what institutions can be put in place to facilitate the origination, selection and diffusion of innovative ideas, products and processes?'

Changes in an innovation system are also innovations, and should be expected to follow the same patterns that are seen in product, service and process innovation: high failure rates, skewed returns and s-curve diffusion. This must be considered when attempting to enact policy changes designed to improve innovation systems.



## 5.0 References

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