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Innovation Systems, Economic Systems, Complexity and Development Policy

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This paper is a draft of a paper written for a Feschthrift for Professor Peter Allen on his retirement from the School of Management, Cranfield University. It is due to be published in March 2011. Norman Clark is Professor of Innovation Systems and Development at the Open University, UK. He is also Senior Adviser to the DFID-funded Research into Use programme

I Introduction

Innovation systems analysis as an aid to development in poor countries is comparatively new though its use is consistent with classical general systems theory which has a much longer pedigree. The science of general systems theory has been explored in some detail by a series of authors starting with von Bertalanffy in the pre-war period, through Lotka, Koestler, Ashby, Emery and others in the post-war period and then adapted by Allen, Checkland, Holling and others in the 1980s and 90s to explore the evolutionary properties of natural and social systems (such as urban development and fisheries). The introduction of the 'innovation systems' notion was proposed by Freeman in the mid-1980s to help explain differential GDP growth patterns that could not be explained by investment activity across countries and adapted by Hall and others to a specific under-development agenda over the past decade or so.[1]

This paper will take as its starting point Peter Allen's attempts to build evolutionary models to aid in the practical process of development policy. Indeed much of his contribution has centred on the evolutionary behaviour of natural and socio-economic systems. Really for the first time and drawing on the work of his mentor, Prigogine, he has shown how it is possible to use interdisciplinary dynamical models as an aid to understanding the properties of such systems and how this understanding may be used in system intervention. His earlier work on the Senegal model and more recent work on complex systems theory are now being further developed in a series of recent papers[2]. This paper will try to link much of this thinking to the notion of an 'innovation system', which has increased presence in development discourse, particularly in relation to possibilities for poverty reduction in very poor countries. I shall call these the *least developed countries (LDCs)* typically enjoying incomes per head of less than some $10 per month. While the idea of innovation as a systemic phenomenon is comparatively recent and still not fully understood or accepted by development analysts, nevertheless it is very much on the current agenda. My objective will be to show how the ideas it encapsulates are very close to what Allen has been arguing for some time. In particular it opens the way to a fresh exploration of how economic change takes place and how related public policy interventions might be better managed.

I shall start by summarising Allen's original Senegal model[3] as an attempt to put some realism behind long-term economic development policy. In so doing, however, it revealed what many had come to realise, namely that specifying the behaviour of evolutionary systems in the long term is an unduly complex activity. Although Allen's aim was always that the model should be used mainly as a planning tool designed to integrate policy discussion across professional groups its impact has been much weaker than hoped. Section III goes on to explore how the notion of an innovation system is very much a tool that has its roots in evolutionary complexity albeit that its use is more qualitative. Nevertheless it can perhaps

[1] A good general reference for the early material is contained in Emery (1970) which contains a number of classical papers. The application to management of innovation in socio-economic and natural systems is comprehensively covered in Clark and Juma (1992). A summary of use of innovation systems as applied to rural technology development is summarised in Hall et al (2003) and in World Bank (2006). See also Freeman (1991) and other references cited at the end of the text.

[2] See for example Allen (2009), Allen and Vargis(2009)

[3] The Senegal model itself is described in some detail in IERC (1991) and Clark, Perez-Trejo and Allen (1995)

be used productively from an aid policy perspective. Section IV explores these ideas with a specific case, the DFID funded Research Into Use programme while section V draws some general conclusions.

II Economic Systems as Complex Systems

In the development of the Senegal model Allen took as read the proposition that standard economic models could not by their very nature be useful guides for development policy. Instead what was needed was a tool that would focus on long-term behaviour that would at the same time capture knowledge contributions from all relevant professional disciplines. But to do this he returned implicitly to basic neo-classical economics in the form of the circular flow of income. Here the macro economy is conventionally divided up into two sub-systems: viz (i) the production system (P) which transforms resources (inputs) into commodities (outputs) and (ii) the household system (H) which owns the means of production (natural resources, labour and capital), earns income (Y) from them by selling them to the production system and (finally) uses this income to purchased the commodities (C) produced by that system. Where both the P and H sectors spend all their incomes accruing to them over a specific time period, the macroeconomic system is a closed one in which all resources are conserved. Graphically these relationships may be portrayed in terms of the well known circular flow of income diagram which is often then modified to include specific categories of 'systemic openness', viz. foreign trade, government activity, and disturbance arising out of the behaviour of savers and investors.

In the first case households are taxed (T) and the state uses these resources to spend resources (G) on behalf of the consumer. In the second case households spend incomes on imports (M) which are of course produced by other (overseas) economic systems, and in order to pay for these our economic system has to export (X) commodities of an equivalent aggregate value. In the third case households save (S) part of their incomes and these savings are used (via the capital market) for the purchase of investment goods (I) by the productive sector. Equilibrium is established where

$$Y + T + M + S = C + G + X + I \qquad \textbf{(1)}$$

but since the economic agents are not identical there is a constant tendency to instability mediated by negative feedback mechanisms (mainly price). The theory of macroeconomics is concerned largely with the determinants of economic behaviour on the part of the agents involved and with the conditions under which the macro system will achieve and maintain equilibrium consistent with full utilization of available resources. Where equilibrium does not obtain, macroeconomic analysis (and controversy) focuses on what measures need to be taken to re-achieve it, for example through monetary, fiscal and foreign trade policy. The constituent elements of the H & P sectors (i.e. the individual households and firms) represent the 'microstates' of the wider macro system. As with the macro economy these are analysed in relation to their mutual interactions - i.e. as exchanges of commodities and resources at prices which broadly reflect the forces of supply and demand. The economic study of these individual market relationships is called microeconomics and tells us how the market for any particular commodity (or resource) behaves, what properties it has and how efficiently it does its job. It also tells us something about the behaviour of the agents involved - how much, for example, the firms in any specific industry are able to monopolize production and thereby raise prices above marginal costs of production.

What economic analysis does not do, however, is to provide any direct insight into how the behaviour of microeconomic agents affects the macroeconomic context. In particular there are important questions about how the (macro) economic system evolves. How, for example, does its capacity to produce goods and service increase? Or how does its structure change? How do new industries arise and how does new technology impinge on the economic fabric? The answer to these and many similar questions is, sadly, that the apparatus of economic analysis, at least in its pure (or 'mainstream') form, has little to say since most of its attempts to model the behaviour of economic systems have tended to be unduly mechanistic. It is here that Allen made a key contribution through the development of a regional dynamical model for Senegal. In contrast he portrays complementary long-term behaviour as migratory behaviour, on the part of households, and investment behaviour, on the part of firms--in each case across regions or zones into which the country has been divided. Such behaviour is clearly strategic in nature since it is only normally undertaken with a view to payoffs expected to accrue over many years, and may thus be distinguished from the shorter term 'optimising' behaviour of conventional economic analysis.

The Senegal Model was developed as a decision tool for policy makers in Senegal. It consisted of sets of interacting equations each of which represents the change in some characteristic variable occurring at a particular time and place. This could be, for example, the change taking place in a zone (or region), of the resident population, in an economic or subsistence activity, in the amount and quality of the soil there, or in the water availability at the location.[4] These changes occur because of the existence of processes, events and mechanisms operating at the different locations within the system. For example, population change in any region occurs because of births, deaths, and in- andout-migration, and similarly water which is used flows into and out of the region, and may also be produced there by wells and springs. Each of these terms reflects the rate of occurrence of different processes and individual events, of which there may be different types, and this rate of occurrence may itself be influenced both by the values of internal variables (e.g. the size of the population, the area of some crop) and parameters (e.g. soil fertility, the fecundity of the local population), as well as by exogenous parameters such as rainfall, river flow, and migration.

Each equation in the model is made up of terms representing the effects of such mechanisms and processes. Most of the equations fall into two main groups corresponding to the types of agents whose behaviour is fundamental to spatial evolution: (i) the households whose migratory behaviour determines population movements, (ii) the producers whose behaviour determines the nature and extent of economic activity in each region and the flow of resources between regions. When fully developed it was expected the model would also include a third group of equations concerns changes in ecological populations - e.g. of water availability, of soil and minerals, and of noxious deposits. The Senegal Model and its underlying

[4] For a detailed discussion of this type of modelling procedure, see for example, Allen and Sanglier (1979; 1981)

principles has made some impact on public policy interventions but in development terms has not made make much impact both because of its underlying complexity and because it use cannot be understood within standard macroeconomic modelling.

III Innovation Systems

An alternative way of looking at public policy for development from a systems standpoint is to go back to analysts like Bob Rosen who has contributed significantly to the understanding of the mechanics of complex systems.[5] Rosen is a systems ecologist whose original background lay in the analysis of complex biological systems, but who has also tried to show that similar metaphors are applicable to the dynamical behaviour of socio-economic systems as well. He takes the view that conventional science works best with physical systems or biological systems that are reasonably stable. Conversely in the case of living systems (ecologies) that are creative, and as a result experience evolution of internal structure, we need an experimental approach that allows us to capture the inevitable indeterminism of their behaviour[6]. Such an approach needs above all to avoid constraining the analysis of the system under investigation by presuppositions about its 'true nature' and in particular, that of imagining that it can be modelled deterministically.

In formal terms Rosen (1987) puts the issue in terms of ecological creativity. Imagine an ecosystem in which there are n species each having either a predator-prey or a symbiotic relationship with its fellows, and we wish to construct some kind of model of that system. The first conclusion we shall immediately come to is that to model such an ecosystem in terms of deterministic relationships amongst its constituent species, would not be a useful exercise. Rosen shows that this is because determinate systems in general are merely limit cases of a wider class of complex system whose relationships are informational but not exact. For example, in a predator-prey model the relationship between predator and prey can be pictured as the quantity u_{ij} where:

$$u_{ij}(x_1......x_n) = \delta/\delta x_j(dx_i/dt) \qquad (2)$$

x_i, x_j are examples of various species x_1, x_2 ....x_n co-existing in a given ecological space and t = time. The u_{ij} represent values giving the rate of change of the production of x_i as a result of a change in the production of x_j over time. If the two species are symbiotic u_{ij} will be positive, but if x_j is a predator on x_i then u_{ij} will be negative. Rosen shows that the equation set (2) is indeterminate - it cannot be solved for specific values of the u_{ij}. However, under specific limiting conditions (2) can approximate to a conventional dynamical system which takes the form:

$$dx_i/dt = f_i(x_1, x_2, x_3, ... x_n) \qquad (3)$$

[5] See also Kline (1985) who was writing about the non-linear properties of innovation systems at roughly the same time
[6] See also Allen (2008)

and is then a determinate system. However, no living system could survive if it behaved according to the relationships outlined in (3), simply because unpredictable and creative behaviour would be impossible by definition. All species would be wiped out. The point is that for a system to be alive and to evolve creatively, its behaviour must be relatively indeterminate. It follows that to try to model it deterministically is tantamount to turning it from a living system into a dead system, and conversely that we need to develop models which somehow capture the essential creativity of living systems. Now if this is true with natural ecologies it must be even more the case with socio-economic systems since these are both more complex and subject to much more rapid evolution. In addition whereas the "information" relevant to predator-prey relationships is relatively simple (species x_i very quickly learns whether species x_j is friend or foe and can take appropriate action), that for creative socio-economic systems is infinitely more complex.[7] That being the case it is likely that the capacity to assimilate, process and use relevant information in a rapidly changing context will be crucial in any development context.

But how is this to be done? In another article Rosen attacks the problem by focusing on the lack of clarity (fuzziness) surrounding many of the concepts associated with development policy. He argues that not only have analysts no clear idea about what constitutes "development", they are often actually incompatible and contradictory. In fact ".....even among those who happen to share the same views as to the ends of development, there are similarly incompatible views as to the means by which the ends can be attained"[8]. But, Rosen goes on, if "so many distinct and contradictory views-----can be held by (so many) able people---(then)---a first step in dealing with such concepts is to try to identify and remove the source of the fuzziness"[9]. And an important source in his view is that different analysts "live intellectually" in a variety of different "analytical worlds" where the underlying concepts used often have different meanings to each analyst. Sometimes, unfortunately, they are not fully understood by the analysts themselves even in terms of their own "world". However, if we begin to separate out these worlds and characterise them unambiguously, then we shall have made an important first step in clearing up much of the confusion.

Rosen's solution is to abstract from the Newtonian mechanics which underlie most models of system behaviour (including system dynamics), and in particular to introduce the notion of "anticipation". This is done by imagining a model world in which time trajectories are allowed to move faster than "real time", but where the real system (S) and the model system (M), are coupled in a policy sense through an effecter system (E). He then formalises the analysis by allowing informational feedback from E to M depending upon whether the trajectory of M is held to be "desirable" or not. Notice that since S + M + E is in total an anticipatory system (S*), the M trajectory will always tend to forecast that of S, although the forecast will never be perfect unless M is a perfect model. We know of course that that can never be the case because S is an evolutionary system in the strict sense that the future is unknown. Now a moment's thought will show that there are therefore an infinite number of possible planning models to choose from,

[7] See Clark (2002) for a detailed discussion of this point in relation to underdevelopment.
[8] See Rosen (1974), p 245
[9] Ibid p. 246.

since every analyst will have his/her own "world" in mind in relation to the "real system" that happens to be under investigation. Each analyst, or perhaps it is better to concentrate on each *analytical ideology*, has his/her (its) own social construction of reality which guides the policy questions asked and the answers that are ideologically acceptable. Rosen's argument is that at least the recognition of this fact should help to clear (some of) the intellectual baggage that obscures the policy process.

We all know of course examples of such ideological confusion. Economists are well known for seeing any particular issue in terms of resource allocation and the price mechanism. What usually differentiates them from a policy standpoint is the position they take up on 'market failure' in relation to that issue. Those on the "right" tend to believe that a "market solution" is the better option, whereas those on the 'left' will tend to favour intervention on the part of some central authority to correct market failure'. Their 'worlds' are predetermined in this narrow, ideological sense. Similar differentiation occurs across disciplines. For example on issues of environmental degradation, physical geographers will not see the problem in terms of the efficiency of the price system but will tend rather to concentrate on purely physical processes such as climatic changes and soil and water stress. Political scientists will eschew both in favour of an analysis concentrating upon power structures. Finally it should be noted that such social construction goes well beyond intra- and inter-disciplinary battles, but relates more widely to strongly held views on the part of many powerful and highly motivated pressure groups. As Thompson (1993) has pointed out in graphic detail, the passion with which rival adherents typically cling to their respective 'worlds' can potentially waste many billions of dollars. It is in this profound sense that policy analysis is not a costless exercise.

From my point of view, however, there are two important inferences to be drawn from this discussion:

> (i) If development policy is to be successful there has to a way of allowing permanent model revision. Not to do so (and therefore to rely on one timeless model) is to open the door once again to confusion amongst the analysts (and even more so, those further down the hierarchy) whose 'worlds' will continue to vary and to evolve even though the model itself does not.
>
> (ii) Information is a crucial component of the whole exercise since necessary (and continuous) model revision will depend on the accuracy, speed and general efficiency of information flows from S to E to M, and vice versa. And it is for this reason that 'information search', sometimes called 'policy research', has become a significant factor in modern development analysis.

Allen of course was very well aware of Rosen's argument. Indeed the Senegal Model was an attempt to build a facilitating tool that would precisely build bridges across professional disciplines. The model's failure in this respect was due in my view probably to the problem that many disciplines have in relating to evolutionary dynamics. It is hard to relate to such dynamics when your world view is Newtonian. It is here, however, that the notion of an innovation system can prove useful. By thinking of technological change as the result of systemic use of information from many sources it is possible to craft policy interventions in an interdisciplinary and 'cross-professional' way. Also interventions can be used crucially as vehicles for learning by ensuring that they are part of a design that promotes comparative analysis across projects and continuous feedback throughout the life of each project. It is this approach that has guided the case study outlined below, the *Research into Use programme* (RIU) funded by the UK's Department for International Development (DFID). RIU is on-going as this book is going into press and provides in my view an excellent example of the qualitative use of systems principles to inform the conduct of public policy.[10]

IV Research into Use Programme

In 2006 DFID published its third white paper[11], setting out the UK government's policies for eliminating poverty worldwide. The white paper was preceded in 2005 by DFID's Agriculture Policy Paper on Growth and Poverty Reduction, which focused on promoting growth in this all-important sector through the spread of new technologies. This paper also outlined DFID's commitment to enhancing the resilience of farming households to external shocks such as drought or disease, which can plunge already vulnerable households into deeper poverty. It emphasized the need to improve access of poor people to knowledge and technology, through both public- and private-sector institutions. In the same year DFID's Central Research Department (CRD) published its Research Funding Framework (2005-2007) which identified agriculture as one of its priorities. Subsequently, a Strategy for Research on Sustainable Agriculture (SRSA) was prepared. The Research into Use (RIU) programme became the first to be developed under this new strategy. It proposed to contribute to this objective by adopting a pro-poor innovation systems approach to getting research into use and to increase the understanding of how this is done.

The research that would be 'put into use' derived from projects funded under DFID's Natural Resources Research Strategy (RNRRS), which consisted of some 1600 projects running from 1995 to 2006. The focus of RNRRS had been to improve the livelihoods of the poor through better management of natural resources. The ten research programmes launched under the strategy were designed to generate new knowledge and promote its uptake and application. They addressed the needs of people living in a range of agro-ecologies including semi-arid areas, high-potential areas, highlands and tropical moist forests; and those at the forest/farm, land/water and rural/urban interfaces. The breadth of projects reflected the multiple routes by which research can have an impact on poverty. The RNRRS saw significant evolution over its life. This included a shift in focus from generating research and producing scientific publications to emphasizing the impact of research on poverty. The focus also moved from outputs to outcomes and long-term impacts. At the same time, interdisciplinary research, the policy environment and the livelihoods of the poor began to receive greater attention. One of the most influential legacies of the RNRRS was the use of innovation system principles in the development of new partnerships, products, processes, markets, institutions and organisations that are better equipped to put research into use.

[10] For those interested in looking more closely at the RIU a good source is www.researchintouse.com

[11] DFID (July 2006) Eliminating World Poverty: Making Governance Work for the Poor.

In the context of RIU, innovation has meant the use of new ideas, new technologies or new ways (processes) of doing things in a place or by people where they have not been used before. Of course innovations in this sense have been happening for millennia by the actions of rural communities themselves, but the intense pace of global change and the threats from climate change and environmental degradation means the poor in developing countries must rapidly adapt just to cope. Innovation, meaning the use of new knowledge often involves working with and re-working the existing stock of knowledge (research into use). It is often the key to building better and more sustainable livelihoods, because new knowledge is required to deal with the rapidly changing environments that face farmers and other rural people. It often involves local creative imitation and adaptation, rather than the development of something radically new. It is usually achieved through many small improvements (e.g. in production technologies, processing, and institutions) rather than through a few big sweeping changes. And it involves greater ownership of the process by poor people themselves.

The RIU approach has therefore been to shift the focus of attention away from the important tasks involved in the generation of new knowledge to the way in which that knowledge can be put to productive use. An innovation system is usually seen as a network of organisations and individuals involved in generating, modifying, and using new knowledge. The networks might be national, sub-national, regional or international. They comprise not only the users of the knowledge (farmers, consumers, artisans, labourers and traders) and the producers of new knowledge (researchers) but a host of intermediary organisations including extension workers, NGOs, enterprises in the supply chain, credit agencies and government. This systems approach considers not only the totality of the entire research, development and extension spectrum, but also the institutions, systems of production, and social relations in which these activities take place.

In practice RIU has been focused on south Asia and sub-Saharan Africa. It started by carrying out a series of country assessments to match local demand in selected countries to the supply of RNRRS derived technologies. These assessments were conducted as an interactive activity with local stakeholder and government groups. On this basis a range of project interventions were chosen according to the following broad criteria:

1. Links to earlier RNRRS research networks whose tacit knowledge will aid in relevant development
2. Likely impact on incomes for poorer sections of populations
3. Likely impact on improving gender balance on these groups
4. Likely impact on employment creation
5. Ability of projects to foster the creation of networks that cut across professional hierarchies
6. Capacity of projects to attract private sector interests
7. Capacity of projects to foster local innovative capabilities
8. Capacity of projects to be sustainable after withdrawal of DFID aid

There has followed a phase of establishing national teams to scale out chosen technologies and procedures for enabling policy dialogue with government and other related agencies. Careful attention has also been given to proper accounting procedures and other due diligence requirements so that technological 'scale-out' is carried out efficiently and effectively. However, two fundamental requirements for the whole programme relate to the points above derived from Rosen's anticipatory model; that is the need for procedures to enable continuous project revision as projects unfold and the handling of new information and knowledge as it impinges on project development. Key properties of RIU are those of action learning and capacity building.

These properties are being handled by treating all projects also as research and learning projects run by a team of innovation research specialists. This team are carrying out the following functions:

1. Gathering immediate quantitative and qualitative data on the current state of projects
2. Conducting regular (monthly) workshops with local teams
3. Collating regular data on project progress
4. Assisting in in-country interaction with local and regional policy groupings
5. Providing regular monitoring reports to RIU management and advisory staff
6. Presenting periodic review papers at 6-monthly RIU workshops where all projects are expected to present and discuss progress
7. Playing a key role in any decisions to be made on adaptation/modification of project activity
8. Interacting closely with RIU advisers and management on the preparation of working papers and other outputs

It is expected that in this way not only will RIU as a whole learn about how to put research into use but at the same it will effectively mentor local staff such that by the end of projects they will be in a good position to ensure sustainability and be more autonomous in the development of related policy and practice. Finally it is worth emphasising the principles of *complex systems* thinking that guide the programme as follows:

- In all countries the projects are expected to run as discrete 'innovation systems.' Such systems have both an *economic* and a *knowledge* system with flows of resources and information taking place among their component nodes and across their respective boundaries. The resource flows will comprise finance, materials and labour inputs.
- These *knowledge flows* will include formal and tacit knowledge associated with the technologies concerned.
- Systems will be *evolutionary* since new knowledge is constantly entering them and leading to behaviour modification*.* There will be no return to an already established 'equilibrium'.
- Undoubtedly systems will exhibit *complexity* in that knowledge and resource flows are constantly moving across many stakeholder groups
- This in turn will require careful *organisation* to minimise and manage complexity.
- Systems will be *adaptable* and *resilient* while resources flow across their boundaries.
- Systems will behave *holistically*. That is each system will each behave as a totality and therefore analytically its behaviour will not be reducible entirely to that of its component nodes.
- *Networking* will take place and will be designed to facilitate information interactivity that improves system efficiency

V Some Concluding Points

In this paper I have tried to highlight how one of the many contributions Peter Allen has made has indirectly begun to affect development policy in and for very poor countries. While more general use of the Senegal Model itself (or one like it) is still to come, I believe its second-best equivalent can be well illustrated by the current DFID RIU. What Allen did with the Senegal Model was to show how it is possible to understand the evolution of socioeconomic systems in ways that allow different professional groups to talk to each other in ways never before really accomplished and in so doing allow development policy-making to achieve new levels of integrated verisimilitude. In a sense the Senegal Model became a crossroads where all disciplinary pathways could meet. Its time, however, has yet to come. In the meantime we should do the best we can with policy analysis procedures that are qualitative but disciplined. The innovation systems approach grounded in complex systems theory is well placed to contribute both in terms of technology development itself but also as a device to ensure its long term sustainability.

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