APPLICATION OF COMPLEX SYSTEMS RESEARCH TO EFFORTS OF INTERNATIONAL DEVELOPMENT

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Abstract Fundamental research on complex systems has shown relevance to efforts of international development. This paper canvasses some practitioner friendly approaches to international development. Development is about interventions in a highly complex system, the society. Complex systems research tells us that development interventions should not be overly planned, rather the fundamental uncertainty of a changing social system requires a diversity of interventions, and rapid learning from development success and failure. Developing economies are functioning at a low level of effectiveness and resource use. Complex systems are change resistant, and intervention requires understanding the autocatalytic nature of a process of change. International development is about the stimulation of a society's innate autocatalytic / self-organizing processes through interventions that stimulate enough to overcome change resistance, but which do not overwhelm the system. Since the size of financial interventions may in some cases be a substantial fraction of the existing economic activity, disruption is a likely outcome. Crucially, one must avoid having the socio-economic activity organized around the intervention itself, since then an undesirable dependency of the economy on the intervention arises. Stimulation of the innate modes of activity results in the development of socio-economic organization around energy, material and financial flows. The primary generator of effectiveness is an appropriate network structure of interactions and relationships. This paper summarizes traditional development efforts and their outcomes as well as a plausible description of the process of complex systems motivated interventions. Examples are given of recent approaches which aim to appropriately stimulate international development.

I. Society and its economy as a complex system

As Matutinovic (2005, 873) states ”An economy is a complex system consisting of a myriad of agents that may be placed in three broad categories: firms, households, and government. Agents' interactions come under the broad umbrella of cooperation and competition while their production and consumption activities constitute the functional fabric of the economic system. Economic activities often span several hierarchical levels of functional interdependence.” Complex systems are highly networked systems. They achieve their stability with the existing interdependencies of economic agents. Large scale disruptions through intervening external agencies can destabilize a complex system, and push it into an undesirable steady state or equilibrium. This also means that existing interactions are fully aligned with the way the system works, and external change agents will encounter resistance from the system to introduce change unless the intervention is designed sufficiently large and in a way that it is compatible with the existing system (Bar-Yam 2004). Hence international development is about the stimulation of a society's and economy's innate autocatalytic/self-organizing processes through interventions at the meso-level of hierarchy (mostly intermediary institutional level, and not at the individual agent or at the macro level). The interventions have to be sizeable enough to overcome change resistance, but which do not overwhelm the system.

The paper explains the autocatalytic nature of a change process, and it describes the network structure of complex societies. With illustrations of traditional development efforts and with examples which take a complex systems view of society, the paper makes a plausible case for appropriate, practitioner friendly development approaches. The choice of analytical framework and of concepts not only helps in selecting the best use of funds by international agencies, but facilitates international development intervention more likely to lead to desirable outcomes.

II. The autocatalytic, self-organizing nature of a process of change

'Autocatalysis' refers to “any cyclical concatenation of processes wherein each member has the propensity to accelerate the activity of the succeeding link” (Ulanowicz 1999, 41-55). Autocatalysis in an economic system presumes a variety of economic actors (= vertices or nodes of a network) interacting in a network of economic links. The network structure of interaction will be detailed in a following section. Economists have used positive and negative feedback loops to model the autocatalytic nature of economic change. Brunner (1994) has formalized mechanisms underlying the creation of populations of economic actors such as firms leading to macroeconomic change. Productivity change is driven by fluctuating population size in an institutional setting for economic rules. The population is subjected to variations in frequencies of events and performance characteristics. The frequency of firm attributes in a population is the result of a stochastic process of innovation and imitation. Productivity increase can be detected and felt at the higher, macro level, but the change is the outcome of individual behavior that fluctuates and that is susceptible to three distinct forces, competition and cooperation in networks, technological diversity, and 'appropriability' conditions (the legal and institutional frame for instance intellectual property rights). In positive and negative feedback loop models, autocatalysis streamlines energy, material, and financial flows towards more efficient members of the population. Heterogeneous agents continually adjust to the macro situation they create collectively. The whole population is ratcheted up on the macroeconomic level until the constituent members of a population touch a physical or spatial constraint and a negative feedback loop constrains growth (Matutinovic 2005, 872).

III. Traditional development efforts and their outcome

Traditional equilibrium development theory is based on full information, complete networks and systems such that disturbances at any node spread evenly in the system. Moreover when explanation happens at the macro level, agents are assumed to be of an average quality and consistent with aggregate behavior (Arthur 2005), and change impacts on all agents evenly. As Potts (2001) shows in detail, the traditional microeconomic development framework is based on 'field-theory',[1] whereas a complex systems approach does not define all connections between nodes or points in a field as complete. In this non-traditional way the explanatory focus becomes the change in the structure of an incomplete system to a less complete or more complete (complex) system as a result of a development intervention. What is to be explained in socio-economic systems is the structural change in terms of degree of heterogeneity of agent populations in space, the modularity and hierarchy of a system, and other aspects of composite structural existence. According to Potts (2001, 14, 19), the economic concept of a field is the extreme and unrealistic case of the geometry of economic space. If a set of interactions cannot be collapsed to a field of actions as in traditional development theory, then the geometry of development space must be mapped by a set of specific network connections among agents.

Traditional economic development theory posits an equilibrium setting, with an economy generally being in equilibrium or in a steady state, then being disturbed by random shocks returns to different equilibrium or steady state. Change is not the result of the complex system's innate, self-organizing properties of populations of heterogeneous agents. Very central to the approach is the market clearing mechanism of supply or demand imbalances over the price or quantity adjustment mechanism. Events are explained at a macro level usually contra-positioning supply and demand, savings and investment and so on, without recognizing the underlying complex microeconomic autocatalytic processes inducing supply and demand, savings and investment imbalances. As a result the traditional approach relies conveniently and exclusively on tractable mathematical, numerical methods of representation, for instance on the use of difference or differential equations.

Very widespread is the application of the two-gap differential equation model of economic growth where growth is constrained by either domestic savings or foreign exchange earnings from exports. A development intervention shocks a constrained-growth equilibrium by releasing a growth constraint, thereby moving the macro-system onto a higher development equilibrium. It is a mechanistic approach based on field-theory. Thus the conventional model approach leads development policy to mechanistically direct resources to increase investment, or to change relative factor prices, or to increase factor endowments.

Conventional recommendations for trade policy for instance to remove a foreign exchange gap are based on models with constant or diminishing returns in technological capabilities (Arthur, 1990, p.98). Such models settle for single equilibrium points (in contrast to autocatalytic or positive feedback approaches which can lead to multiple equilibria, some of which can be undesirable). Traded goods settle at a fixed world price („Law of one Price") as conditions of zero transaction and information costs prevail. The traditional Ricardian model of trade excludes all costs of transacting. No institutions, no transport is necessary. Information and knowledge about products, markets, and so on, is transmitted instantly and costless. Because of these field-theory assumptions, the traditional Ricardian model of trade allows simply for the numerical analysis of the effect of changing relative factor prices on the structures of production.

The venerated Heckscher-Ohlin approach is the neoclassical prototype equilibrium model. In all such trade models the location of production is determined by relative (comparative) advantages based on factor endowments on a macro level. When however resources are created by different, heterogeneous market participants in different locations, and by a dynamic process of competition and cooperation leading to innovation and imitation, then it is far from obvious that patterns of trade are determined by changing relative prices, or factor endowments. Induced micro-dynamics in an adequate institutional setting, where policy interventions do not overwhelm the system but stimulate innate autocatalytic processes of productivity

[1] A field is a space in which all points are connected to all other points in the space, thus conjuring full information among agents.

improvements lead to new trade patterns. When trade patterns shift, we encounter the complexity of an out-of-equilibrium economy, and international development design needs to be based on a model different from the mechanistic and purely numerical one. Only a complex systems approach to international development will help us calibrate interventions to a complex system such that an intervention stimulates enough for significant and positive change, without creating systems dependency on it. International development thus leads to more desirable outcomes with the complex systems approach.

IV. The 'small-world network' structure of economy interactions and relationships

One example of autocatalytic, self-organizing structure formation in an economy is the formation of cities and economic hubs of specialized industries and services in a network of supply and value chains. According to Barabasi (2002) the economic hubs play a special role in the stability of an evolving economic network. Structure formation and international development result from a change of the economic interactions and of the functional relationships in trade connections of economic actors. Such trade connections can be represented as a directed network ('small-world network'), where incoming links k_a refer to supply flows and outgoing links k_b to selling flows, so that the degree of an actor or vertex in network terms is the total number of its connections, $k = k_a + k_b$ (see Matutinovic 2005, 873-77 for a detailed description of an economy as 'small-world network'). A small-world network is characterized by short average paths connecting any two agents in the economy, by a small number of hubs populated with few firms that have a large total number of connections in the network. Firms are connected to their suppliers, buyers, and other firms in cooperation; households are connected to consumer product markets and service categories; government provides services both to firms and households and is linked to a large total number supplies incoming from firms. In small-world network, economic flows among firms are highly skewed, where a few relationships make for most of the interactions. This is the well-know 80/20 pattern, where 80 percent of business is conducted with 20 percent of suppliers and customers. Product markets and service categories are defined by a dense topology of connections which represent supply- and value chains.

V. Examples of recent approaches

Recent approaches to international development take a complex systems and network view. Microeconomic behavior of economic agents, when constrained by institutions and expectations interact with each other to produce macroeconomic outcomes. Firms are economic actors and they make constrained rational decisions about production, investment, and marketing strategy among others. Firms operate in an environment of procedural and substantial uncertainty and their behavior is dominated by trial and error, learning is a continuing process (Matutinovic 2005, Nelson and Winter, 1982, Brunner 1994). New goals, skills, and technology result in new behavior. Novelty arises spontaneously in response to problems -- novelty diffuses among a population of firms and through networks of interaction. New solutions lead to new problems. Fluctuations and novelty at the macroeconomic level arise from a nonlinear dynamic process among market actors.

Brunner and Allen (2005) in their book present development policy experiments with the help of complex system, evolutionary trade models. Such models combine the mathematic, numeric approach where differential equations determine macroeconomic outcomes, with a logic (time-indexed) sequence model which defines the trade network interaction of heterogeneous economic agents at the micro level. Development intervention is enacted at the meso-(institutional) level of a hierarchically structured economic system. In those experiments trade is foremost influenced by the policy induced change in *capability* of economic agents to engage in trade. Economic agents use their trading power to buy further technological capability. Trade is productivity driven and the evolutionary trade models in this book link productivity change to structural differences occurring in terms of export product variety and quality. Structural changes in trade are linked to increases in employment, incomes, and in growth rates. In the models, export success feeds back into a positive loop, or (non-linear) autocatalytic process of increased productivity leading to increasing economies of scale and agglomeration effects.

Economic agents are approximated as actors in networked geographic space. Each geographic cell in a cellular automaton (CA) establishes trade with the neighboring cells, mainly based on the productive capability of an export-oriented firm within the cell. Put into an agent space of the CA, the economic model combines a numerical mathematical model with a logic time-indexed sequence of agent states. Each geographic space thus produces output and consumes at the same time. Producers earn rent for their efforts. Consumers earn wages. Production and consumption can temporarily diverge in a particular location, thus leading to trade with neighbors. Firms compete with other firms in the same sector, and get selected for their success. Firms cooperate in networks of suppliers of inputs, knowledge providers, consultants, marketing, industry and service cooperatives and associations. Trade networks emerge. The whole combination of factors in a variety of trade services is characterized by a combined “transaction technology”, which is incorporated in export unit values of South Asian exports to OECD countries (import data of the OECD countries). Emerging trade networks encapsulate knowledge. In evolutionary trade theory variation and selection among agents re-coordinates knowledge. Development intervention is directed at structure change.

The next non-equilibrium model in chapter 4 (Brunner and Allen 2005), extends the previous model with a population and labor force as well as natural resource sub-model. From the view of spatial structure, the demographic, economic, and environment variables in the modeling framework are disaggregated into those of different regions and sectors, similar to the CA structure in the previous model. The extended model introduces three dynamic drivers that are represented through the use of three 'attractivities'. These are the demand attractiveness, the migration attractiveness and investment attractiveness. These attractivities affect the decision making of the actors (individuals, firms, investors etc.) within the model and capture their responses to differences in price, reward and productivity. As a result, initially small differences can be amplified through autocatalytic processes and eventually lead to a spatial re-structuring of the system, and a change in the trading pattern across zones. Economic incentives emanating form the development interventions and investment attractivities create the opportunity of employment, increase vacancies and raise labor productivity, which causes the increase of jobs and wages. Improved or decreased income earning opportunities will alter relative economic conditions among the regions and sectors, changing the pattern of attraction and flow of the workforce between regions. This will in turn alter patterns of demand for services and the relative investment behavior of sectors.

On the one hand, as a result, there will be further incentives favoring further investment in the region, which will in turn lead to further migration from other regions. On the other hand, the further growth of population could lead to the degradation of the environment, particularly of water supply, waste disposal, congestion and increased utility costs in this region. The potential degradation could lead a decrease in comparative advantages with regard to further increases in economic activity and population. Instead of a model of inter-regional trade that moves towards a single, predictable outcome of equity or structured activity, in our model there exist a combination of positive and negative feedback loops that can lead to different spatial structures of economic activity and population depending on the order and rapidity responses of the different agents, and their abilities to innovate and to trade successfully. The balance of advantages can potentially evolve in different directions, and change the spatial pattern of economic activity and population migration.

One of the notable characteristics of the complex system approach is that the economic models are built upon an interregional matrix. The economic variables, such as demand and supply, import and export, productivity accumulation and consumption, costs, wages and profits, link directly with the interregional matrix or input-output system. The flow equations are then calculated in the simulation models, thus enabling adequately calibrated development intervention and effective use of economic resources. Since the economic sectors of different regions are differentiated there is a constant tendency to instability mediated by market mechanisms, mainly prices. So, this interregional matrix which is suggested here establishes the relationship between the whole economy, the regional/sector economy and local decision making process that is the relationship between 'macro' economic behaviour and 'micro' economic structure.

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