

The evolutionary economic geography of regional economic development in Asia

Hans-Peter Brunner¹
Senior Economist
Asian Development Bank

¹ 6 ADB Avenue, Mandaluyong City, 1550 Metro Manila, Philippines
Tel: ++ 63 2 632 41 59 Fax: ++63 2 636 23 37; hbrunner@adb.org

Hans-Peter Brunner

With **Asian Development Bank** since December 1995. Focusing on economic development and transition through project, policy and sector lending in South and Southeast Asia. Specializing in international and sub-regional trade, investment and finance; corporate and financial governance; project-finance and public-private partnerships; small and medium enterprise restructuring. Interaction with policy makers at the Ministers' level, and up to Prime Ministers. Senior management experience. Taught economics at **universities in Germany**. Consultant to **international organizations** (EU, World Bank) and **governments** (Science Center Berlin and US A.I.D.). My established academic record is linked to my experience in business and development. Peer-reviewed publications in ranked economics journals, such as *Review of Development Economics*, *World Development*, *Eastern Economic Journal*, *Small Business Economics*, *Journal of Asian Economics*. Author of three books.

Education:

Doctor of Philosophy (Ph.D.), **University of Maryland**, College Park.

Dissertation topic: India's Computer Industry: Policy, Industry Structure, and Technological Change.

Thesis Committee: Profs. J. Adams (Economics Dept.), D. Pirages, B. Kaminski, W. Phillips, (all Political Economy), K. Flamm (Brookings Institution).

Fields of concentration: Industrial organization, technological change, trade, economic growth and political development, institutional economics, social choice (Profs. D. Mueller, Mancur Olson, Thomas Schelling).

Master of Arts, School of Advanced International Studies (SAIS, **Johns Hopkins University**), Washington, DC. Special emphasis on international economics (trade), politics and economics of South Asia (Prof. Thornton). One semester of course work at Columbia University, New York, School of International Affairs.

Senior Executive training course at **INSEAD**, Singapore, featuring executive finance, human resource management in Asia, marketing and branding in Asia, supply chain management, innovation strategies.

Intensive Training Seminar at **MIT** [NECSI], Cambridge MA, "Complex Physical, Biological and Social Systems," including simulation project on "Competition and Cooperation in Development Regions."

Degree of "Diplom-Kaufmann" (equivalent to Master of Business Administration in the United States), **Free University of Berlin**.

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Abstract

The paper will review representations of regional development models in terms of their assumptions (peeled away like an onion) and in terms of their level of complexity, very much in the tradition of Peter Allen's classification system. Some applied models of regional economic development in Asia will be presented in more detail and compared to each other in terms of their ability to understand development and to gain knowledge about real world problem solutions. Understanding reality and gaining knowledge about a problem require us to reduce the real complexity of any particular situation to a simpler, more understandable system by making specific simplifying assumptions. It is shown that there exist representations that, while being sufficiently simple to be understood, remain sufficiently representative of reality and yield significant power to make a big difference to regional economic development in Asia when compared to other, less useful representations. For instance, what is important to be explained in dynamic 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 similar aspects of composite structural existence. Traditional mechanical models of regional economic development assume away structural change with the assumption of completeness of network connections among agents in the system, thereby imposing a simplifying homogeneity on economic agents that significantly reduces explanatory power.

JEL classification: B52, C15, O18, O53, R12, R13

I. From simple to complex economic growth and development models – Allen's peeling of the onion

The non-equilibrium modelling approach to spatial economic and demographic change has been developed as the result of advances originating in the natural sciences of open, complex systems (Nicolis & Prigogine, 1977; Haken, 1977; Prigogine and Stengers, 1987). These ideas led to a series of developments and applications in the fields of urban and regional modelling. (Allen and Sanglier, 1978, 1979 a and b, 1981a, b and c, Allen 1981, Allen, 1982, 1984, Allen, Engelen and Sanglier, 1983, 1986, Allen, Sanglier, Engelen and Boon, 1985, Sanglier and Allen, 1989). These developments have been described in Allen, 1997. Allen's 1997 publication represents a major milestone as it leads the way towards models of geographic economic systems evolution. The elements of complexity thinking in social and economic systems, so introduced, are well characterized in *The Handbook of Evolutionary Economic Geography* (Martin and Sunley, 2010). More recently, models are significantly advanced with diverse economic agents on the map, within and across economic geographies which are linked in networks of interaction (Brunner and Allen, 2005). *The Handbook of Evolutionary Economic Geography* (Boschma and Martin, 2010) further outlines the distinguishing features of an evolutionary approach to economic geography. Such approach combines population dynamics where heterogeneous agents compete for economic resources, with a networked interaction among them in an economic landscape, to the effect of re-structuring the complex economic system. The evolution of a population of agents is conveniently modelled within an economic geography, then in the application of the evolutionary theory of international trade (Brunner and Allen,

2005), economic geographies are linked via exchange mediated by transaction and transport costs to see how that affects the dynamics within economic geographies. Such network approach with the emergence of new transaction connections reflecting the essence of complex systems in geography, follows also from Foster 1993, 1994, 1997, Metcalfe, 1997, 1998, Potts, 2001, Metcalfe and Foster, 2004, Metcalfe et al. 2006.

The key objective here is however to show, how complex systems of the kind outlined, can be used in policy decision making in a very specific set of geographies in eastern South Asia.

The behaviour of complex systems offers a rich set of concepts with which to begin a new reflection on human systems. In this new view, non-equilibrium phenomena are much more important, and offer a new understanding of the natural emergence of structure and organization in systems with many interacting individual elements. These ideas are relevant to any system that is the result of evolutionary processes where innovation and selection have been played out over time. This leads to new models of regional economic systems that show how the dialogue between the two levels - individual and aggregate - generate successive spatial structures with characteristic patterns and flows.

One defining contribution of Allen has been the diagrammatic representation of model types on the complex and restrictive assumptions plane. "Models" are our simplified representations of reality. Bar-Yam (1997) defines complexity at a chosen scale of reality in terms of how much information is necessary to describe the observation of reality at that scale. It is the reduction of reality via restrictive model

assumptions that allows the observer to introduce sufficient order to help describe and understand reality.

[Figure 1 about here]

Complex systems and models represent a co-evolutionary behaviour and organization beyond the "mechanical" stages 4 and 5, where the locations and behaviours of the actors are mutually inter-dependent, the system has many possible responses to perturbations, and where the system can change, adapt and maintain rich, diverse and varied strategies (stages 1 to 3). The models applied to South Asia and exhibited in following sections of the paper are simulations based on non-linear systems of equations, incorporating in different degree multi-agent behaviour and math algorithms. The view of sub-optimal behaviours, imperfect information and networks, mistaken inferences and the power of creativity is contrasted with the traditional mechanical representations of human systems. The higher complexity models discussed here offer a new, quantitative basis for policy exploration and analysis, allowing us to take into account the longer-term implications for the system as a whole. For instance, the choice of analytical framework and of concepts not only helps in selecting the best use of funds by international agencies, but facilitates international economic development intervention more likely to lead to desirable outcomes.

II. Peeling the onion for international economic trade theory

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. A technological progress function is used. 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, and as stylized in figure 2 (adapted from Saccone and Valli, 2009, and Brunner and Allen, 2005). This figure is a representation of positive and negative feedback components of the well-known Verdoorn law, where increasing (cost and quality) competitiveness depends on the relationship between wage growth and productivity growth, and fast productivity growth depends on fast output growth in an open trade environment, and fast output growth leads to more exports with increased competitiveness.

[Figure 2 about here]

'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.

Another part of this feedback cycle of structural change needs detailed scrutiny. A rise of productivity leads to a rise in unit values. Unit values provide a reasonable measurement of vertical product differentiation due to additional features or quality that high-wage producers are able to add to their products (Helble and Okubo, 2008; Greenaway *et al.*, 1995). Vertical product differentiation is very pronounced in sectors which allow producers (firms as agents) to produce goods of very different quality. As it is, quality is produced by high wage producers in high income developed economies, which are able to produce with high capital and technology intensity by combining those factors with highly productive labor (Cadot *et al.*, 2008; Hummels and Klenow, 2005). Higher (unit) prices indicate per quality unit and increases in unit values are the result of productivity increases, including increases in transaction productivity. Structural change is about the establishment of economic measures and conditions that allow movement

closer to those areas of product space in which firms can exploit markets through product differentiation at the high quality and price spectrum. For structural change, countries' firms and economic agents need to add capabilities. This is reliant on productivity growth. Such move in product space can occur in developing economies through integration into production chains which are anchored to a lead firm that finally assembles a vertically integrated and differentiated product at the high quality and price spectrum in a high income consumer market. I call this strategy leading to structural change in product space the vertical transformation of product space.

High quality products are also highly networked (Kali and Reyes, 2006) as they come with many additional features – that is these are complex goods that require equally complex production chains. With the lowering of transport and transaction costs due to technology change in the transport and communications sectors, and due to infrastructure investment, production chains have increasingly evolved in geography, which is in real space. Conversely studies have shown that inadequate infrastructure impedes horizontal diversification as market access remains difficult and costs of exploring new markets stay high (Cadot *et al.*, 2008). For regions and countries, which produce at the lower quality and lower, structural change means to move into product components (and services) which are incorporated into high quality products in sectors with high vertical product differentiation. However, such move is only possible if entry into production chains is easy and can occur at low transport and transaction costs. Structural change thus also means the integration of production chains in the region and the linkage of the regional part of the production chain to the global portion(s) of the production chains.

Another facet of a structure change is for economies to diversify horizontally within the product space -- an increase in the variety of trade. Greater variety can go hand in hand with vertical integration, as a greater variety also allows for increasing the focus on products that are highly vertically integrated. Diversification in product space leads to increased opportunities for growth, less vulnerability to economic disruptions (Baccetta *et al.*, 2009) and is shown to increase average unit values in exports and hence induces positive feedback in the growth model (Feenstra and Kee, 2004). However such diversification is difficult when country exports are very concentrated, and hence when firms possess a limited range of capabilities. The benefits from diversification, and from acquisition of capabilities increase substantially the more capabilities are already present, and the more diversified country exports are (Hausmann and Hidalgo, 2010).

Transaction productivity is low in poor and small economies remote from key markets. A high cost of market access makes integration into production chains difficult, it lowers incomes and growth. Regional integration through logistics, information network and connectivity improvement can increase the 'virtual' size of an economy as trade with neighboring countries increases. This leads to substantial benefits from scale, network and agglomeration economies (Winters, 2009). Again this leads to a rise of unit values in exports, and thus to income and GDP growth. Once unit values are high, the cost of transportation per weight unit decreases relative to its value.

Harding (2009) is the only study linking integration in geographic space through improved connectivity infrastructure to increased export unit values from improved quality of existing products (vertical integration) or in terms of moving horizontally into new products. Using changes in transaction cost due to reforms and investment in ten Eastern European countries to evaluate an impact on export unit values at the 4-digit

product level. The study finds that reforms and investment of financial, communication, power and road infrastructure sectors are significantly increasing export unit values.

Feedback growth through agglomeration and economies of networks in an economy is the formation of cities and economic hubs of specialized industries and services in a network of production chains (for India, see Chakravorty and Lall, 2007). 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 networks, economic flows among firms are highly skewed, where a few relationships make for most of the interactions. This is the well-known 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.

III. Complexity in regional economic development: computing it on the Asia map

Because diversity matters so much, for growth and trade, in product space, and in geographic space, recent approaches to regional integration take a feedback systems and network view (and as presented in this paper). For instance in preparation of ADB operations, the northeastern part of South Asia's economy (comprising Bangladesh, Bhutan, Nepal and the eastern part of India, an area with a population of more than 300 million people) has been modeled on a map (Global Development Solutions, 2006, with New England Complex Systems Institute, and Applied Agents under ADB technical assistance, 2011). All major economic activities expected to be affected by trade related transport/logistics and trade supply chain capacity building to firms in the region have been quantified and located on a scaled geographic grid of cells or tiles (see Brunner and Allen, 2005, and Bosker et al., 2010).

Economic agents are approximated as actors in networked geographic space. Each geographic cell in a cellular automaton (CA) establishes trade with the neighbouring cells (or 'tiles' – cells and tiles are used here in the same way and are interchangeable), 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. Movement of goods

between cells is costly, and depends on distance and on the condition of institutional and physical infrastructures. Within cells, movement cost is assumed negligible. Production and consumption can temporarily diverge in a particular location, thus leading to diverging prices and to trade with neighbours. Firms compete with other firms in the same sector, and get selected for their success. Firms cooperate across cells 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). Transaction technology or productivity measures the overall cost of trade, from cell to cell over distance. Emerging trade networks encapsulate knowledge leading to high productivity measured in high export unit values. In evolutionary trade theory (Brunner and Allen, 2005) variation and selection among agents re-coordinates knowledge. Development intervention is directed at structure change.

Brunner and Allen (2005) demonstrate technically the interconnection of numeric model portions with logic model portions under an algorithm. Geographic interventions can be abstracted and represented as a network of vertices with logistic links. Vertices can be positioned on a digital map via a matrix of x and y coordinates (location matrix).

Going back to the northeastern part of India, economic interaction of actors (firms by size, formal labor, sectors and output, income and distribution, all by location and districts) has been mapped across space, along transport and trade corridors and networks (also linked to the rest of the world). Similarly, in an extended model, financial and information interactions among economic players can be mapped via adjacency

matrices. This is a matrix that represents economic interaction among agents as 'ones' or 'zeroes', 1 stands for an interaction (which can also be weighted in terms of strength), and 0 for no interaction, hence the vertices are not adjacent. 'Hubbing' or 'clustering' can also be expressed in matrices, specifically coefficient matrices, where cells are filled with positive or negative numbers, representing locations where economic actors attract activity (positive cells), or repel activity (negative cells).

In our initial application, two economic interventions are timed and coordinated, one in logistics/transport infrastructure and the other one in reducing the transactions cost of trade between economic nodes and along transport corridors (value chain development, or competitiveness increase of small and medium enterprises), and when only logistics/transport infrastructure investment is undertaken in isolation (Figure 3). For each of the simulations, the maps in the top panels represent the spatial distribution of labor and employment. Purple represents available agricultural jobs, blue available high quality jobs. Dark green represents labor in agricultural jobs and light green labor in high quality jobs. Red represents unemployed labor. Time progresses from the left to the right and the panels below the maps are taken from immediately before the intervention, and then at intervals after the intervention to show the effect of the intervention.

[Figure 3 about here]

The differences in terms of impact between the two projected approaches and scenarios are stark. A combined logistics/infrastructure and value chain improvement intervention for small and medium enterprises can double export and production, double

qualified labor wage levels, and significantly reduce unemployment in the remote region. On the map, over time the employment benefits become more dispersed geographically (the sea of light green dots expands). In the second scenario, there are hardly any export production gains (there is actually a visible "emigration of resources" effect from intervention), less income and employment gains, and those employment gains remain concentrated on the map. This is a powerful demonstration of the effect of higher complexity policy making which is only made possible when a model provides higher dimensional design space to the policy maker in an easily accessible and understandable, interactive and visual way.

Expanding the area of policy interest to the economic integration of Bangladesh, Bhutan and Nepal with eastern parts of India, another agent-based model is undertaken (ADB, 2011). Policy takes the shape of soft and hard infrastructure investments that facilitate trade across regions, and so lead to a reorganization of the spatial pattern of production. As discussed above with the CA approach, an application platform simulates the effects of investment scenarios, one scenario with infrastructure/logistics investment only, the other one adding value chain building investment, on an economic map. Full dynamic simulation movies, showing the changes on the map over time, are available.

In this case just like in the previously mentioned CA approach, the study region is divided into economic cells or 'tiles'. These tiles then are populated with economic agents. The model is calibrated using essential demographic data (population). Agents produce (with land and labor), 'consume' intermediate and final goods, work within their economic 'tiles', and trade across tile borders at a cost, and for mathematic modeling this is all detailed in respective equations (ADB, 2011). A land-use parameter plays an

important role, as it constrains production expansion beyond a certain available land in an economic tile. The non-linearity of the model can be increased by changing a production (learning) spillover parameter, or a productivity parameter, from 1, to unequal 1, thus inducing agglomeration and dis-agglomeration or accelerated growth patterns across geography. In the particular simulations undertaken for policy advisory purposes, this further increase in model complexities was not deemed to be the focus of advice, hence these model parameters were set to 1 for time being.

Trading occurs because of price differences across economic tiles, as agents shift their demand to tiles which produce at lower prices, and which have to be lower inclusive of trade transaction costs when traded across economic tiles. When goods are traded across tiles a fraction of the goods value is lost as trade transaction cost, and this fraction increases with distance and transportation time, and with the type of good, be the good perishable (time-sensitive) or non-perishable. The cost data that underlies this study for calibration was gathered from primary sources: ground experts provided information on travel times and freight costs, which are reflective of the current condition of the transportation and trade infrastructures. Trade continues to the point when prices are driven by demand to a level such that it is no longer profitable to trade across tiles. The lowering of trade transaction costs due to geographic investments, leads to a restructuring of the regional economy as the degree of completeness of the trade networks changes.

The model can be used for comparison in two ways. First, policy makers can examine the incremental effects of infrastructure investments in terms of gains in per capita income. Policy makers, who will be aware of the costs of the investments, can then determine if benefits justify costs. Second, in case there is a choice between two

alternative investment projects, policy makers can compare the gains in income and costs under the alternatives. Third, policy makers which come from different political constituencies can see the (geographic) distribution of gains and losses from structural change, and thus they can be enabled to strike better compensation bargains among themselves to ensure that their constituents share more evenly in the cost and benefit distribution across the geographic region. The simulation methods require that we calibrate against a benchmark – how the economy would perform without additional infrastructure and trade investments.

Three specific scenarios are simulated:

(S1) A benchmark scenario in which economic activity with existing (present day) network of roads and trains is simulated

(S2) Economic activity after enhancement of the transport network in (S1) with a set of non-perishable [NP], trade supporting infrastructure investments

(S3) Economic activity after a full set of investments including both the non-perishable infrastructure of (S2), and additional investments in perishable [P] trade supporting infrastructure improvements (e.g. refrigerated or automated warehouses or distribution centers).

Comparisons between the three scenarios S1-S3 can be made both in final outcomes (incomes, etc) and in dynamics leading up to steady state. The results are described at the level of administrative districts, at the level of individual tiles, and at the aggregate level for the entire population affected. We are interested primarily in how much per capita income increases. Policy makers may also be interested in the interregional distribution of income and in mitigating disparities, as well as in trade flows and volumes. In the study and this paper then the focus is on incomes, and their geographic distribution.

For clarity of display in a static, non-digital medium such as this paper, it is best to show the differences between the S1, S2, S3 simulations. The difference in income is observed at the ending time step in each scenario to measure growth achieved through investment. Scenario S1 (benchmark) is compared to Scenario S2 (non-perishable investments only) [GIS Map 1], S2 is compared to S3 (perishable and non-perishable investments) [GIS Map2], and the overall growth from S1 to S3 is calculated [GIS Map 3]. Each map displays actual district boundaries, regional color-coding, and geographic centroid dots. The size and color of the dots in the figures below now represent the magnitude of observed *change* in ending income (computed as average ending income from scenario N+1 *minus* average ending income from scenario N) for each district. Note that Dots that change from Red to Pink are still improving, but at a lower rate.

The level of infrastructure investment in S2, in comparison to S1, leads to higher incomes in some districts (especially peripheral districts), and incomes continue to increase between the mid-point and end of the run. The full investment package (S3) shows further income increase beyond those observed in S2, with all districts experiencing income increases by the end of the run.

GIS Map 4 shows the *change in* Income from baseline (S1) generated by the full implementation of the perishable and non-perishable sets of investments (S3).

Three central conclusions are: *no district is significantly worse off after full investment, all districts show measurable improvement in income, and many districts in the economic periphery enjoy dramatic improvement.*

Figure 4 shows increases in income obtained in scenario S3 (perishable and non-perishable investments) over the levels measured in baseline scenario S1—eg the growth in income attributable to the complete investments considered here. The results

are disaggregated by tile, and shown over time from model initialization until steady state. Overall income growth is positive for most tiles, despite initial turbulence due to simultaneous implementation of all investments. Substantial variation *between* tiles in income gains can also be observed.

[Figure 4 about here]

Last, the table shows in an exemplary manner per country per capita (PPP) income increase due to S2 and S3 sets of investments. The numbers show very significant increases income, and overall aggregate outcome, on the high population level in region of over 300 million people, is high at annual \$ 6 to 7 billion (PPP). The outcome is particularly pronounced in the northeastern part of India, confirming the results visualized in the previous northeastern India focused model simulation. Output tables have also been produced for trade flow increases.

[Table about here]

This type of simulation as in the northeastern parts of South Asia can be moved further in terms of complexity and explanatory power for the practitioner. Economic development interventions can then be evaluated one by one for their economic and geographic impact. This can be done visually in a software application and interface, where development practitioners insert their development intervention, and give details about the dimension of the intervention. For instance a road and logistics connection will establish an extra link between network nodes, and thus lower transaction costs

because the distance from one agent to another is shortened. This can be programmed in an adjacency matrix form where the cells represent not 'ones' or 'zeroes', but actual distances between nodes or the length of the link. 'Distance' can also reflect real distance and its quality and capacity (Allen, 1997: 163). Once the intervention is made the computer software recalculates the network connection between agents.

IV. Conclusion

The paper has shown how complex systems of the kind using economic geography, can be used effectively in policy making in a very specific set of geographies. These new approaches capture economic restructuring across geographies in a way that they can offer policy choices hitherto unseen and unrecognizable. The higher complexity models discussed, offer a new, quantitative basis for policy exploration and analysis, allowing us to take into account the longer-term implications for the system as a whole. For instance, the choice of analytical framework and of concepts not only helps in selecting the best use of funds by international agencies, but facilitates international economic development intervention more likely to lead to desirable outcomes. The movement in the social sciences towards application of complexity and evolutionary models and approaches, and away from stationarity assumptions, was well anticipated in Allen's seminal 1997 publication.

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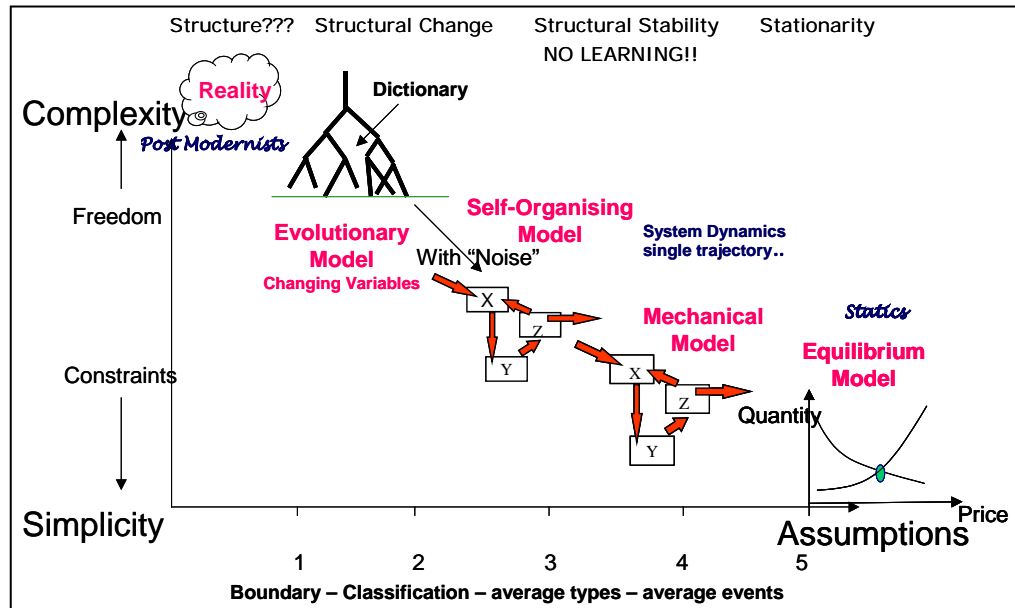
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Number – stage of model	Assumption made	Resulting model
1	Boundary assumed	Some local sense-making possible; no structure, descriptive;
2	Classification assumed	Open-ended evolutionary models; math algorithms and multi-agent;
3	Average types	Non-linear equations, structure and networks;
4a	Stationarity	Self-organized criticality; equilibrium;
4b	Average events	Mechanical equations
5	Stationarity	Catastrophe theory, attractors, equilibrium;

Figure 1: The different kinds of model that arise from successive assumptions

(Source: Allen, *et al.*, 2007)

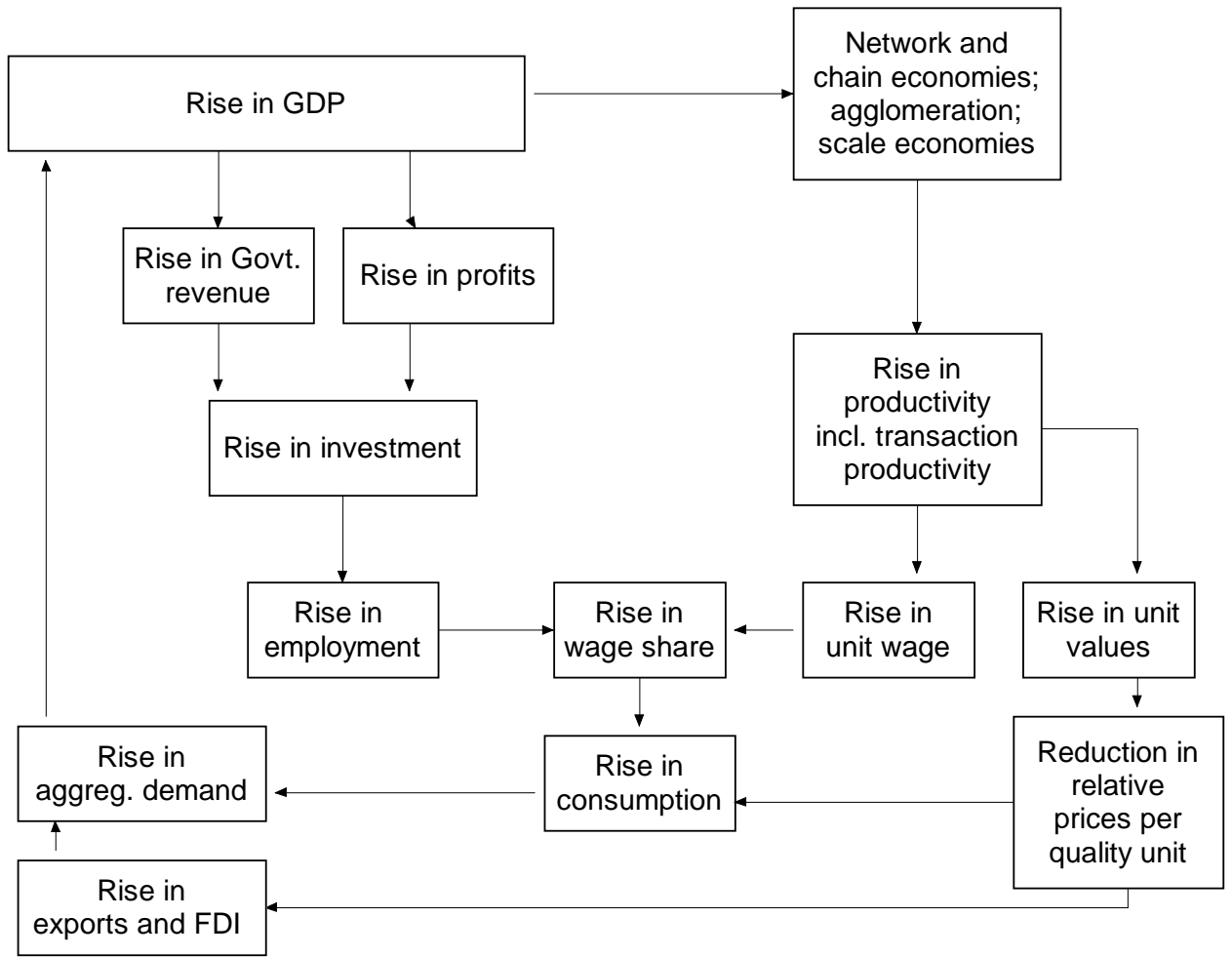
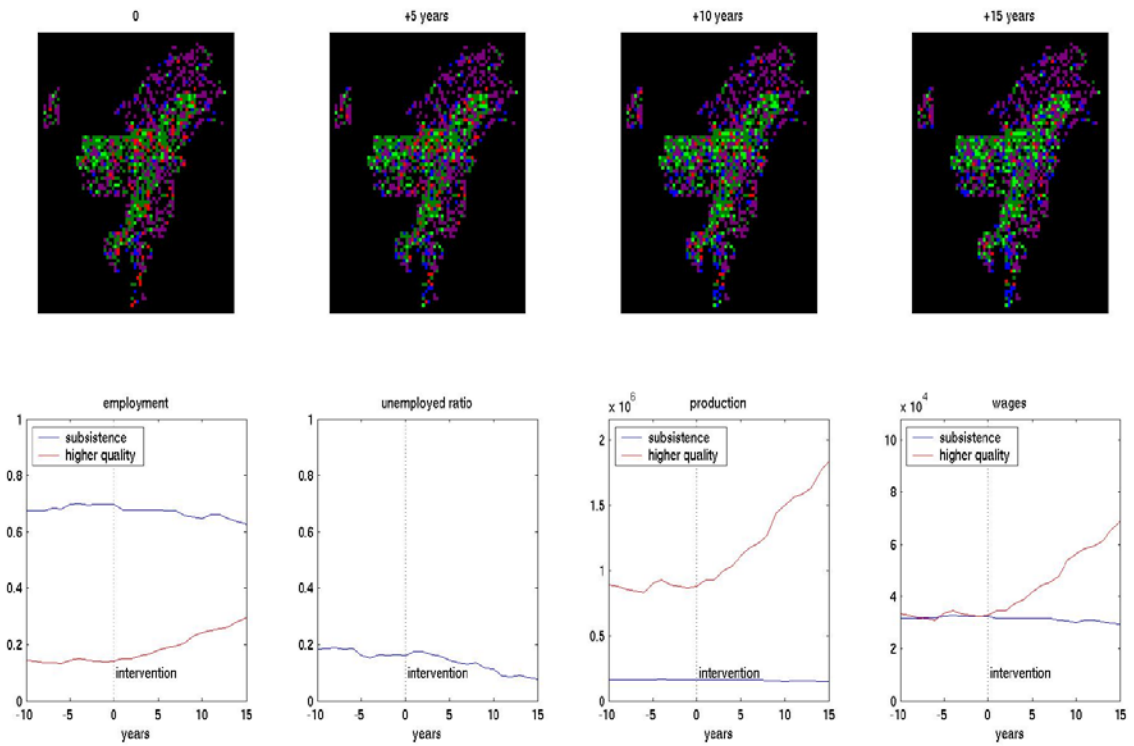
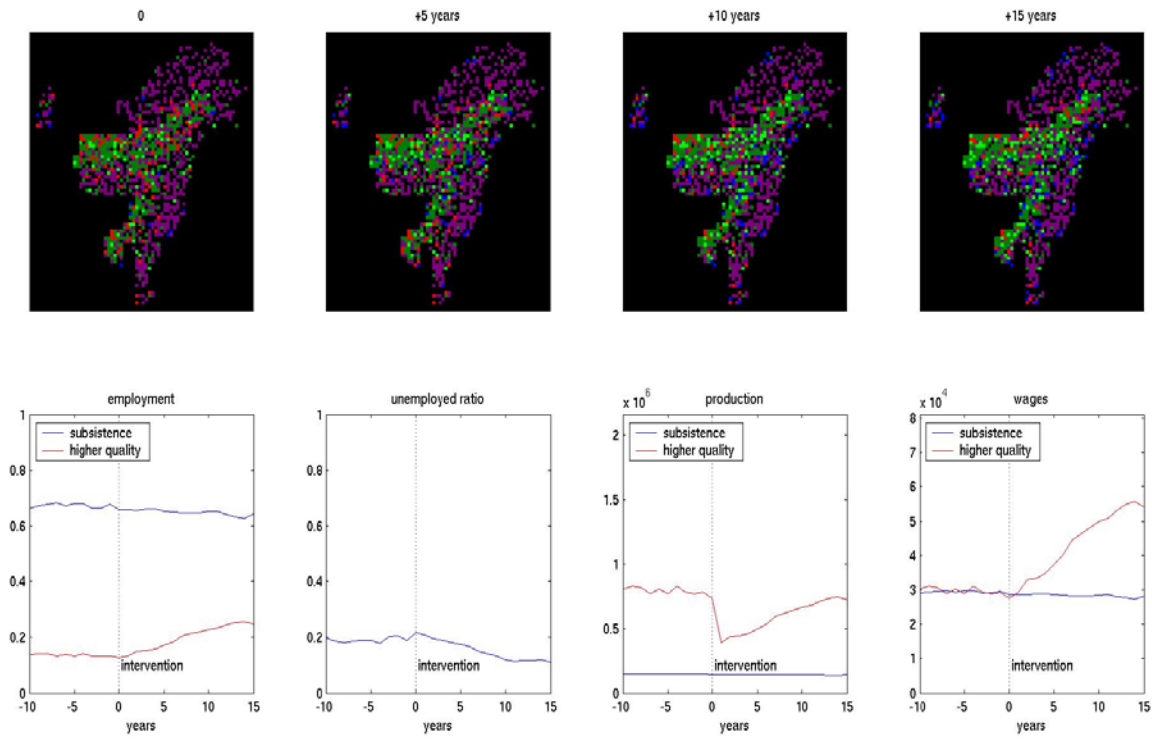


Figure 2: A stylized feedback model of economic growth and international trade



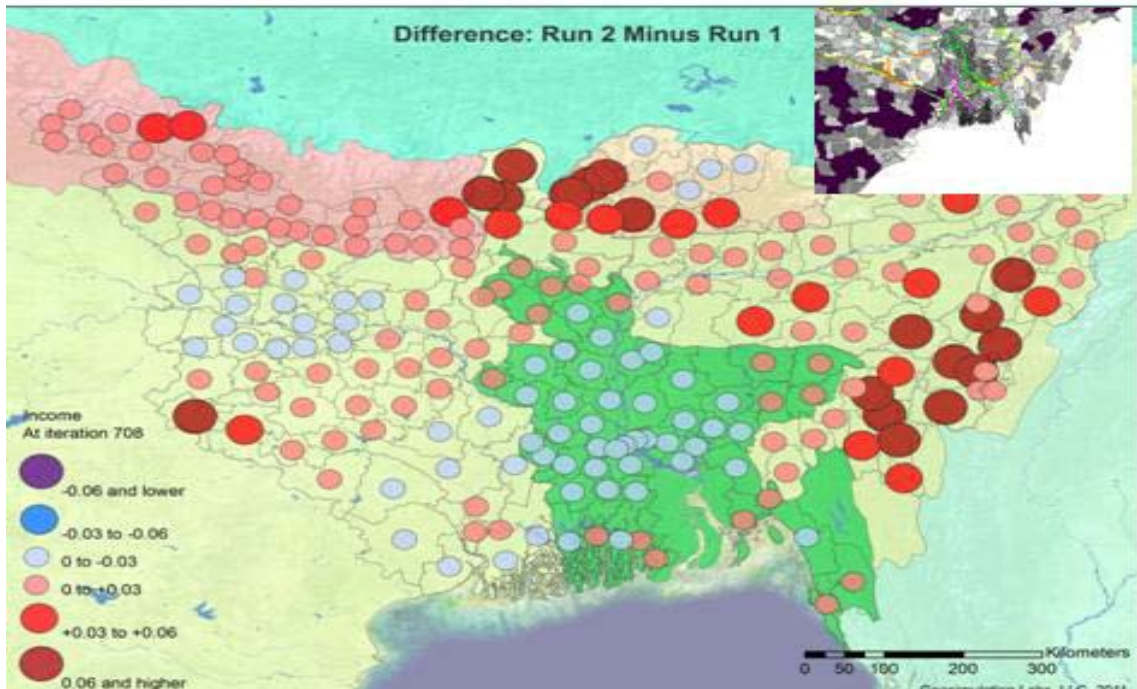
aFigure 3: Scenario 1 - Trade cost reduction with competitiveness and supply capacity increase



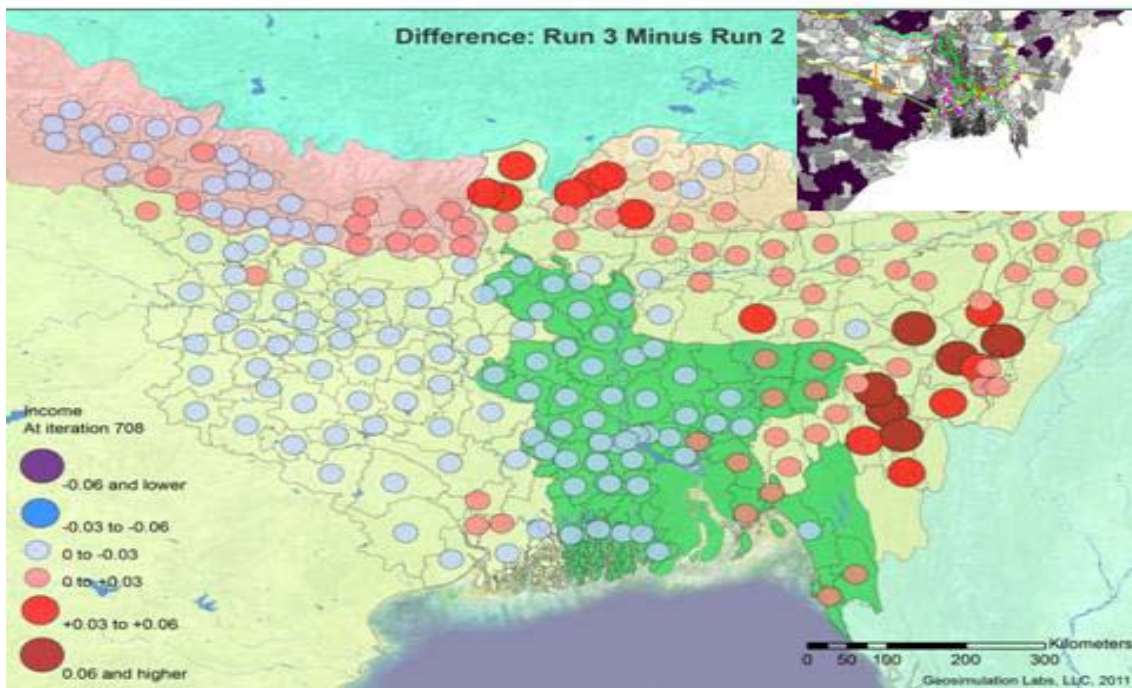
Scenario 2: Trade cost reduction without competitiveness increase.

(Source: GDS-NECSI 2006)

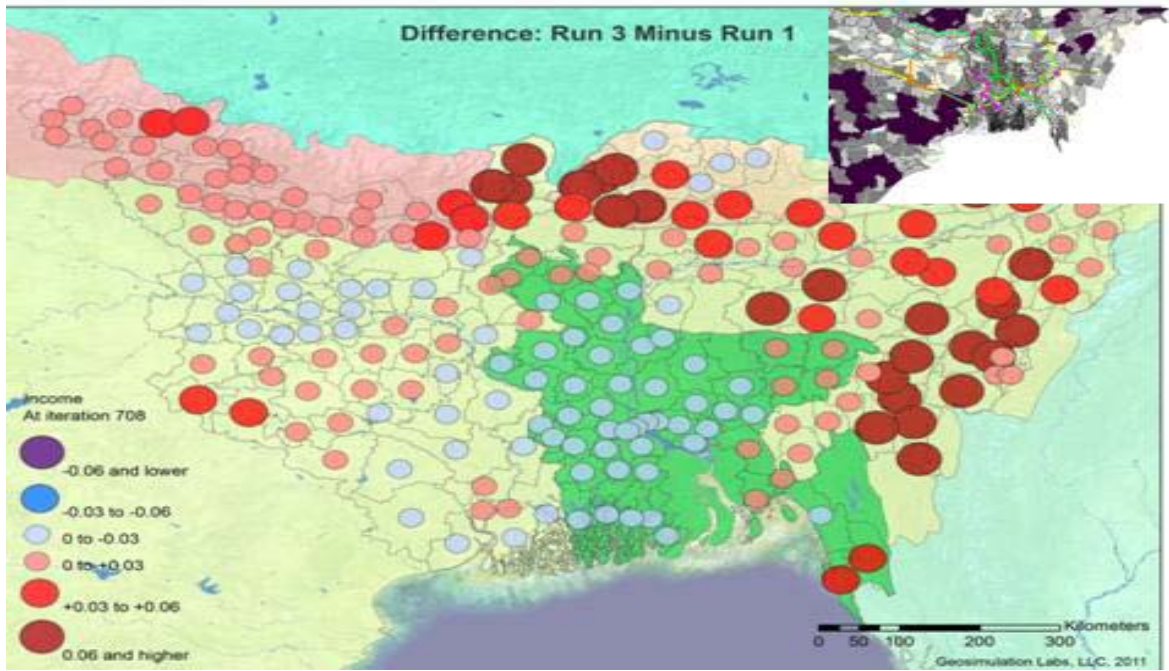
GIS Map 1: District-income income growth above baseline S1, due to S2 investments



GIS Map 2: District-income income growth above S2 due to S3 investments

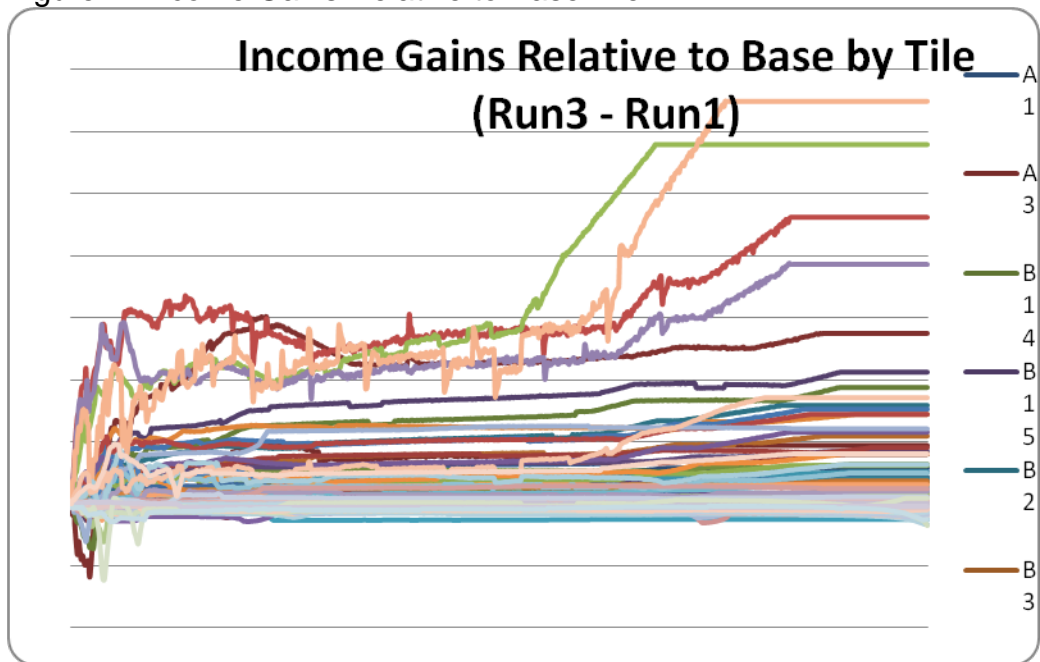


GIS Map 3: District-income income growth above baseline from full AfT investment package



(Source: ADB, 2011)

Figure 4: Income Gains Relative to Base Tile



(Source: ADB, 2011)

Table: Per capita (PPP) income, per country, comparing Runs

	Run 1	Run 2	Run 3
India	2522.34	2554.26	2574.03
Bangladesh	2027.54	2028.80	2030.49
Nepal	2575.61	2603.06	2607.06
Bhutan	2431.13	2467.33	2492.33