Economic inequalities spatial patterns in a sustainable world: a complex systems approach

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Geographical patterns of economic activity

Two centuries ago, before the Industrial Revolution, world regions had comparable wealth as described for instance by Paul Bairoch (1930-1999), who published "Victoires et Déboires" in 1997 about the history of the Industrial Revolution. This is not true nowdays.

The empirical evidence in discussed in Bairoch and in the contributions of geographical economists (J.F Thisse, M. Fujita, P. Krugman, A Venables, J-P Combes etc.)

The "rich get richer" principle $\Longrightarrow$ scale free distributions and spatial inequalities.

We are now familiar with the view that multiplicative noisy growth phenomena generate scale free distribution (H. Simon, B. Mandelbrot, R. Axtell, E. Stanley, S. Solomon etc.) The spatial consequence of economic growth is the existence of rich industrial regions in strong contrast with economically depleted regions.

A physicist view: growth and *non-equilibirum* dynamics explain these large differences as spatial instabilities. The Reaction-Diffusion equations, Patterns, Dissipative structures approach.

Geographical patterns of economic activity

The question

If we accept the idea that the Industrial revolution and the Cornucopian Economy that followed during a couple of centuries are a transient stage in the history of Mankind, what will the future look like after the transition to a sustainable and stationary economy, especially in terms of geographical disparities? A strongly contrasted world with economically active regions as nowadays? Or a more equitable repartition of wealth and economic activity?

Plan

- The simplest model of evolutionary economics due to Solow, the AK model, $+$ a diffusion term, is equivalent to Shnerb etal AB model which gives rise to patterns.
- Build an ecomic model which takes into accounts technological and resource limits.
- Numerical simulations of the spatial model with diffusion terms.
- Simulations of a bounded rationality model, based on a delocalized market for energy.

The AK = AB model

"The importance of being discrete: Life always wins on the surface" Nadav M. Shnerb, Yoram Louzoun, Eldad Bettelheim, and Sorin Solomon, PNAS, (2000), 97, pp. 10322-10324

Based on auto-catalytic process: $K + A \Longrightarrow 2K + A$ where A is technology and K capital.

$$\dot{K} = \lambda(t)A.K - \mu K - D_K \Delta K \tag{1}$$

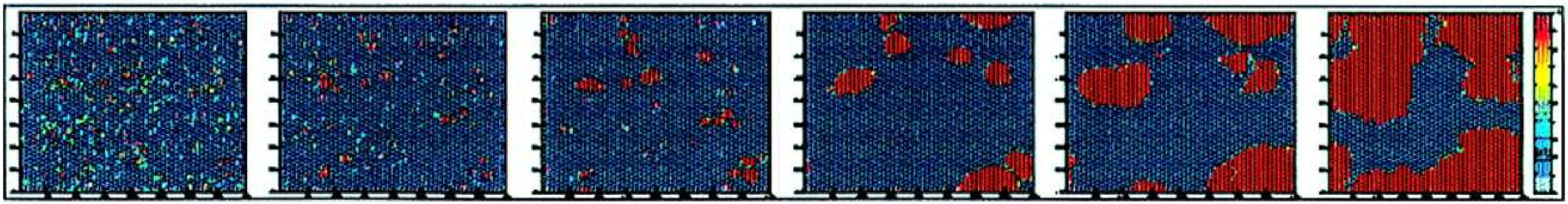
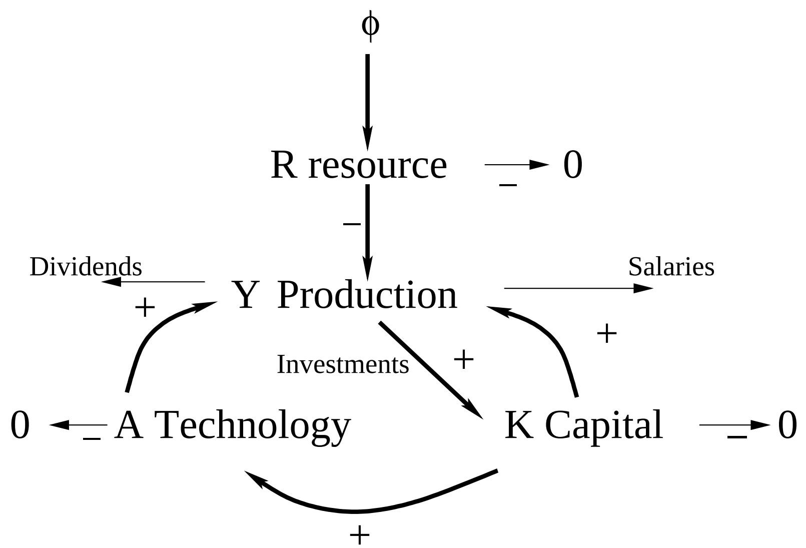


Figure 1: Evolution of local Capital color coded (dark blue=0, red ≥ 10)

When capital K is not bounded, auto-catalysis + noise and diffusion lead to spatial patterns.

Although AK models first proposed by Solow are familiar to evolutionary economists, they are not used in geographical economics.



$$\dot{A} = \mu \frac{K}{K + K_1} - \delta_A A \quad (2)$$

$$\dot{K} = \rho \frac{AKC}{K + C} - \delta_K K \quad (3)$$

$$\dot{R} = \phi - C - \delta_R R \quad (4)$$

$$C = \inf(R, K(\sqrt{\frac{\rho A}{p}} - 1)) \quad (5)$$

Capital K investment drives technical progress A limited by physical constraints.

Production function: constant return to scale, no perfect substitution, development limited by the availability of energy C.

A constant flux ϕ of resource R is available.

Resource used in production C is optimized according to its price p.

Spatial simulations: the reaction-diffusion model

Discretise space: square lattice.

Each cell obeys a reaction dynamics (eq. 2-5) and and passive diffusion across cell boundaries. (Large transportation costs for energy)

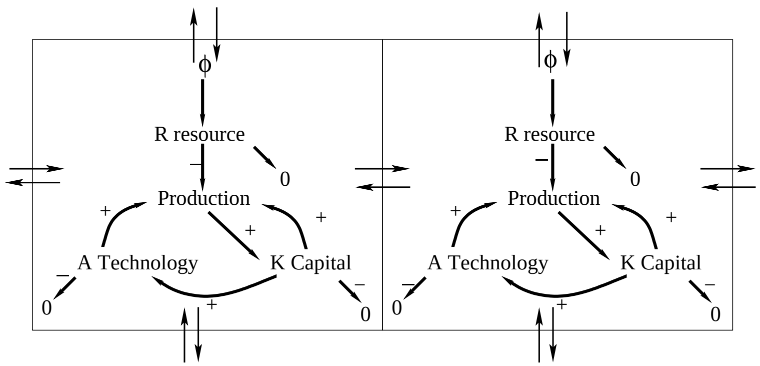


Figure 2: Reaction-diffusion dynamics in 2 cells.

Simulation results: no spatial structure, narrow distributions of variables A, K, R, P. Dynamical behaviour quasi-identical to a sum of independant cells obeying eq. 2-5.

Interpretation: quantities appearing in the positive loops reach saturation; no more autocatalysis, the role of positive loops is negligible.

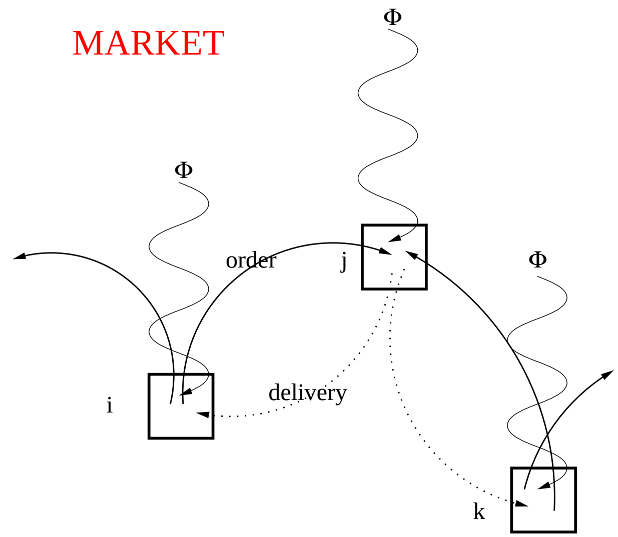


Figure 3: The market model. All cells receive a constant energy flux Φ. Cells i and k order energy to cell j according to a logit function . Cell j delivers to cell i and k, according to availability.

Orders from cell i to cell j obey a Maxwell-Boltzman (logit) distribution obtained by maximization a linear combination of profit and information

$$f(d_{ij}) = \frac{exp(-\beta t_c d_{ij})}{\sum_j exp(-\beta t_c d_{ij})} \tag{6}$$

$$\hat{\Pi} = \sum_j \rho \frac{A_j K_j C_j}{K_j + \sum_j C_j} - (p_0 + t_c d_{ij}).C_j - \frac{1}{\beta} \sum_j C_j log(C_j) \tag{7}$$

$\frac{1}{\beta}$ cost of information, t_c transportation cost and the last term is the entropy of the distribution.

Conditions for the spatial simulations

100x100 square lattice, Von Neumann neighbourdhood (4 neighbours, N, S, E, W), periodic boundary conditions . They last until time=1000, with a time step of 0.003.

Random initial conditions: values of A, B and C distributed according to Poisson distribution with average 1.

Parameters	Interpretation	Values
μ	capital transfer rate	0.03
B_1	capital transfer limit	100.0
ρ	production function coefficient	1.0
k	rate of resource consumption	0.1
σ	Resource source term	10
δ_A	Decay rates	0.03
δ_B		0.15
δ_C		0.03
D_A	Diffusion rates	10
D_B		0.1
D_D		10

Table 1: Table of parameters used in the reported results. μ and $B1$ are resp. the transfert rate of capital to the technology coefficient and its limiting factor, ρ is the production coefficient, k the consumption rate of the resource by production. δ are decay rates and D diffusion coefficients.

Time plots of averaged variables

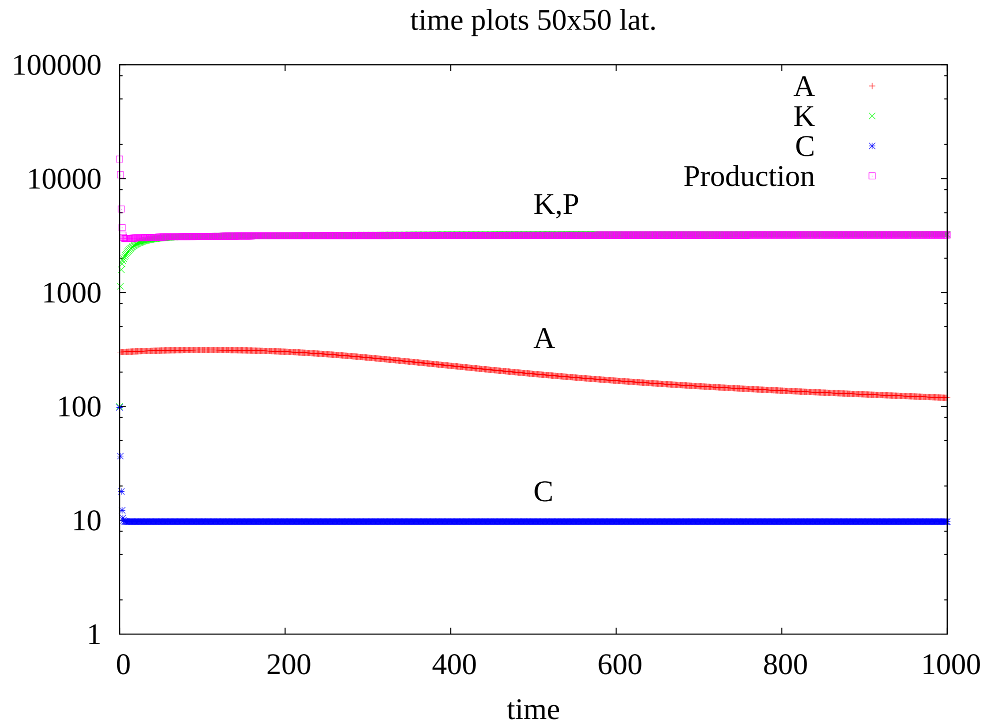


Figure 4: Time variation of average Technical knowledge A, Capital K, resource R and production observed for a 50x50 lattice. $exp(\beta t_c) = 2$. Levels equivalent to homogeneous ODE model except for the decrease of Technical knowledge.

Patterns

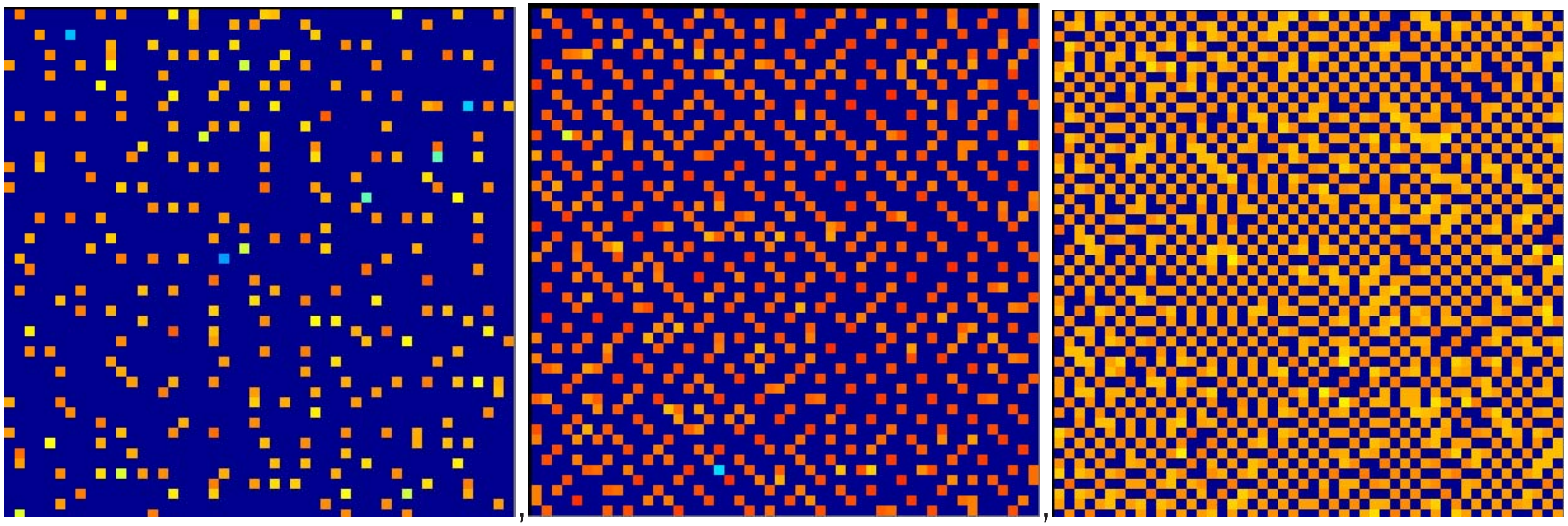


Figure 5: Production patterns at large integration times, 10,000, for different market spatial decay constants $\beta t_c = 1.0$, 0,5 and 0.25 from left to right. Logarithmic color scale, dark blue=1, brown 160 000

Histograms

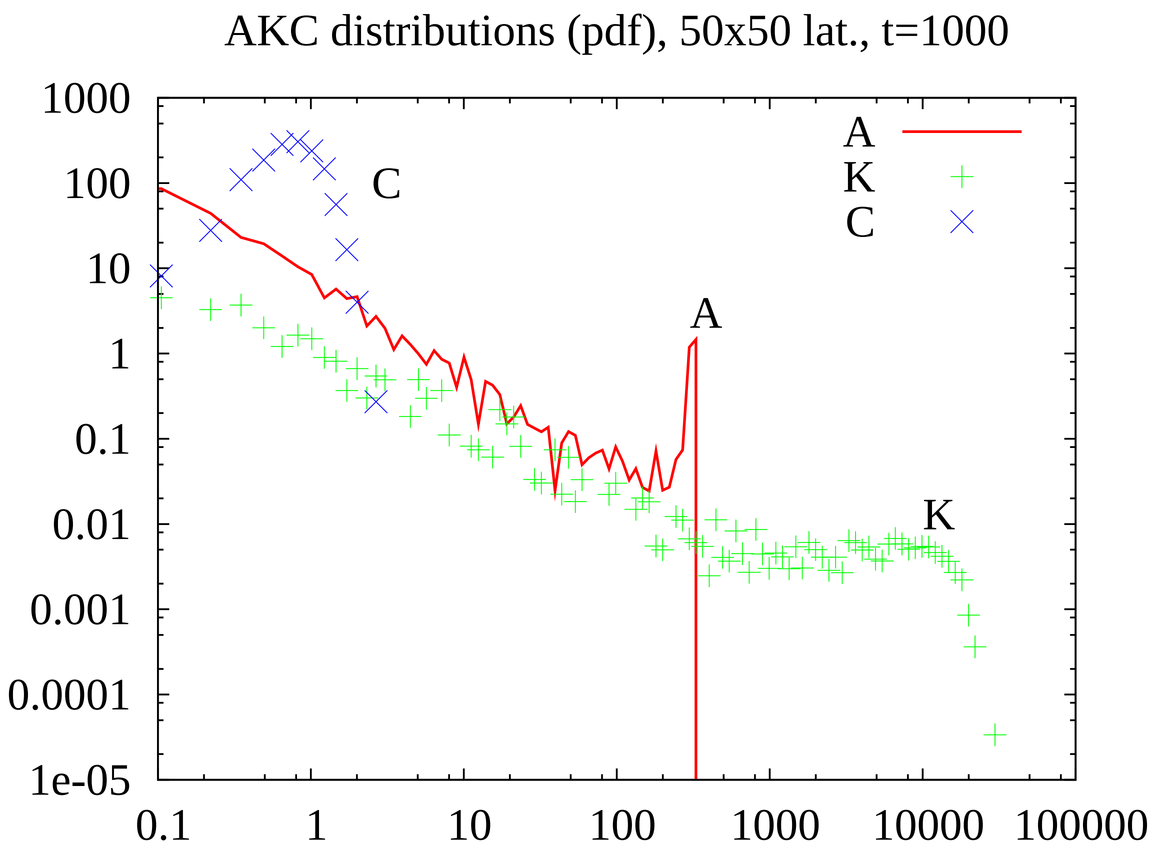


Figure 6: Distributions of Technical coefficient A Capital K, and used Resource C

Metastability

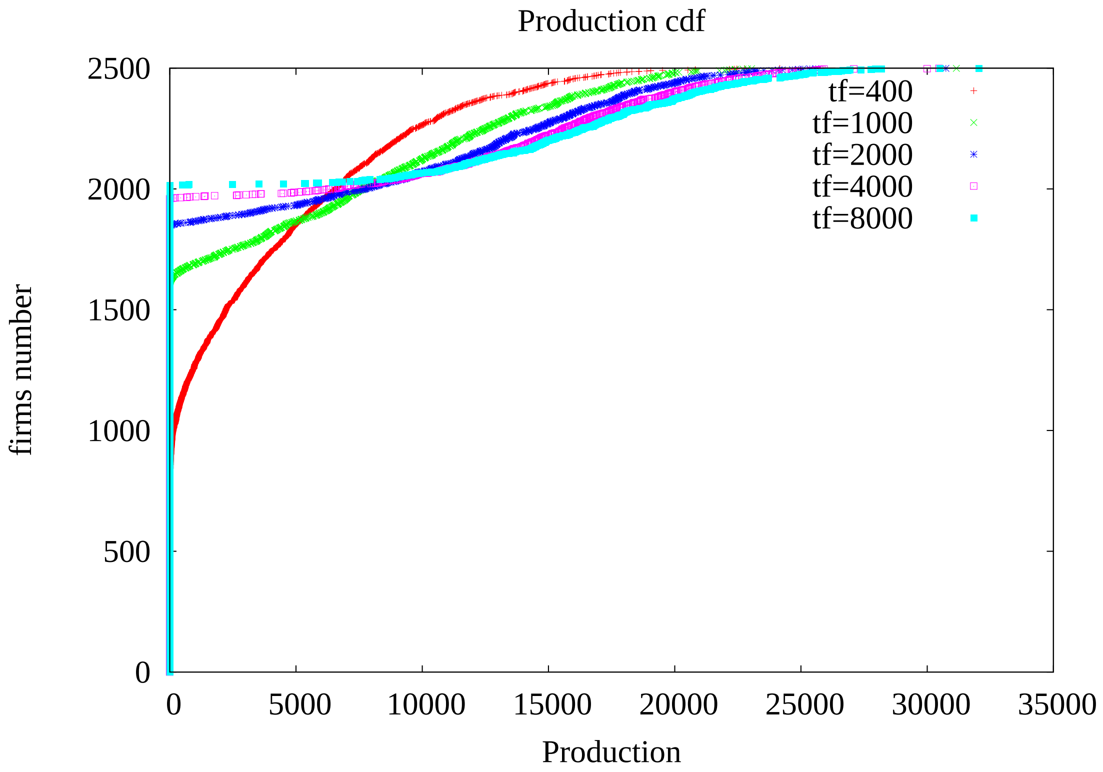


Figure 7: Evolution of the cumulative distribution function of Production at large times.

Conclusions

Hypotheses: New constraints + global exchanges

1. Limitation on resource influx and technological coefficients;
2. Limited substitution of production factors.
3. Global exchanges of resources, capital, labour and technologies.

Simulation results: Non-local resource markets yields concentration of activities in industrial regions much more active than their surroundings. In the new era, positive loops in the reaction part of the systems are saturated while new positive loops due to globalisation contribute and maintain spatial heterogenities.

The scale of heterogeneity depends from the ratio of transportation cost to the cost of information.

Technical choices for energy production and world perspectives:

- Local resource use goes with high transportation costs for the resource: wind mills and photo-voltaic cells generate electricity which transportation is more costly than oil, gas or uranium, because of losses and difficulties in storage.

- If nuclear energy is made available from fast neutron breeders, we will again be in a low transportation cost situation with little limit on the resource and we might expect a strong concentration of economic activities. Other technologies such as high T_c super-conductor technology might also favor low transportation costs.

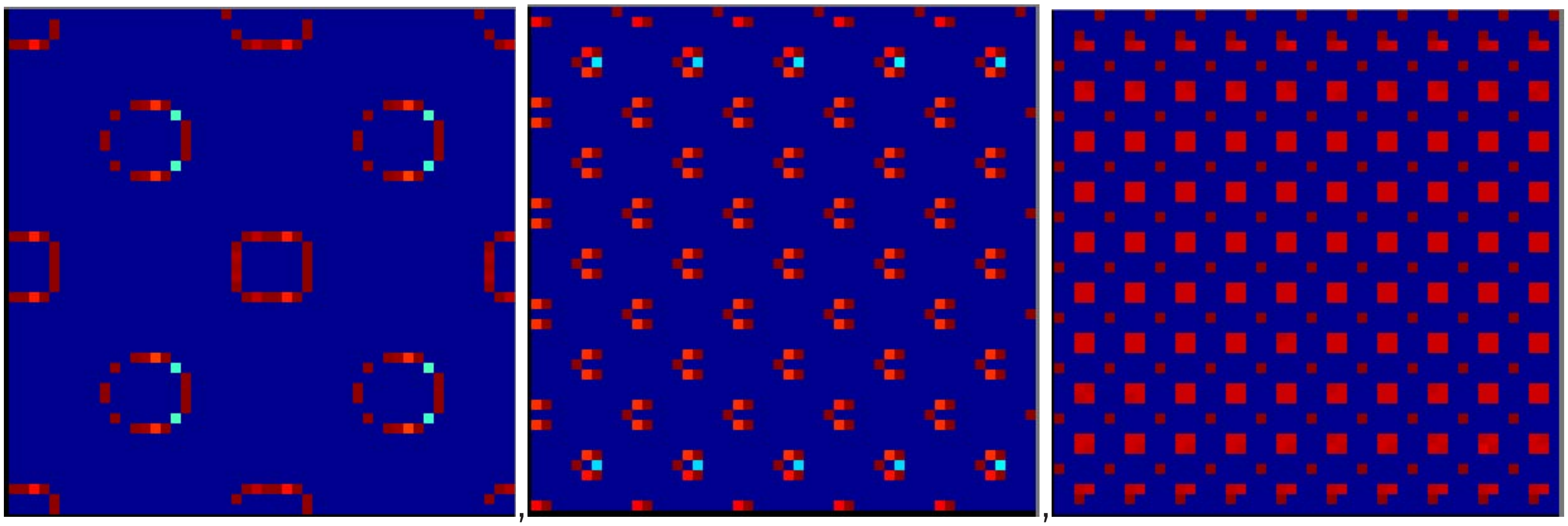


Figure 8: Production patterns at large integration times, 1000, for different periodic initial conditions

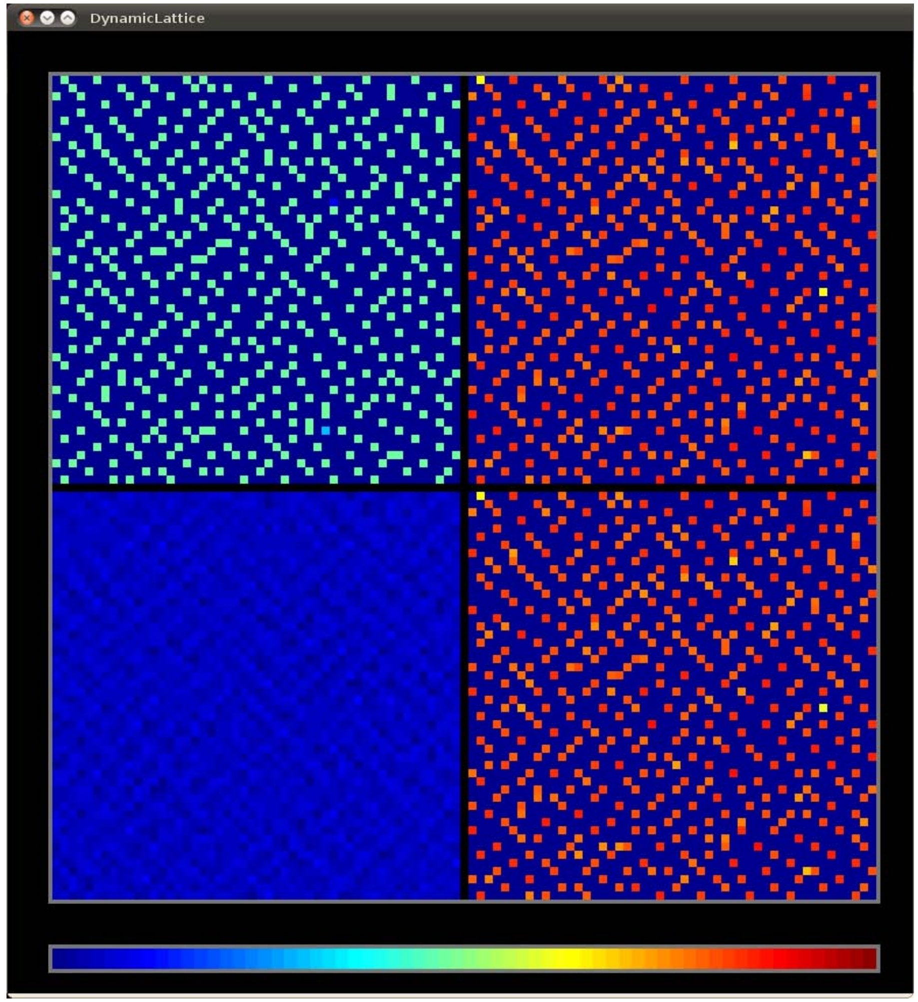


Figure 9: Spatial patterns at time 1000 of Technical knowledge A, Capital K, resource R and Production starting from the upper left square. The color scale is logarithmic: from 0 (dark blue) to 100,000 (dark red).The same lighter cells on the A, Capital K and Production patterns are active spots while the dark blue regions are depleted of any economic activity.