IPD/JICA Task Force on Industrial Policy and Transformation
Amman, Jordan, June 5-6, 2014

COMPLEXITY AND INDUSTRIAL POLICY

Luciano Pietronero

Measuring the Intangible Growth Potential of Countries

Collaborators: M. Cristelli[1,2], A. Gabrielli[1,2], A. Tacchella[1,2], A. Zaccaria[1,2]

[1] Institute for Complex Sistems, CNR, Rome, Italy;
[2] "Sapienza" University of Rome, Italy
[3] London Institute for Mathematical Sciences, UK; [4] IMT, Lucca
Web Page: http://pil.phys.uniroma1

SAPIENZA UNIVERSITÀ DI ROMA

istituto dei sistemi complessi

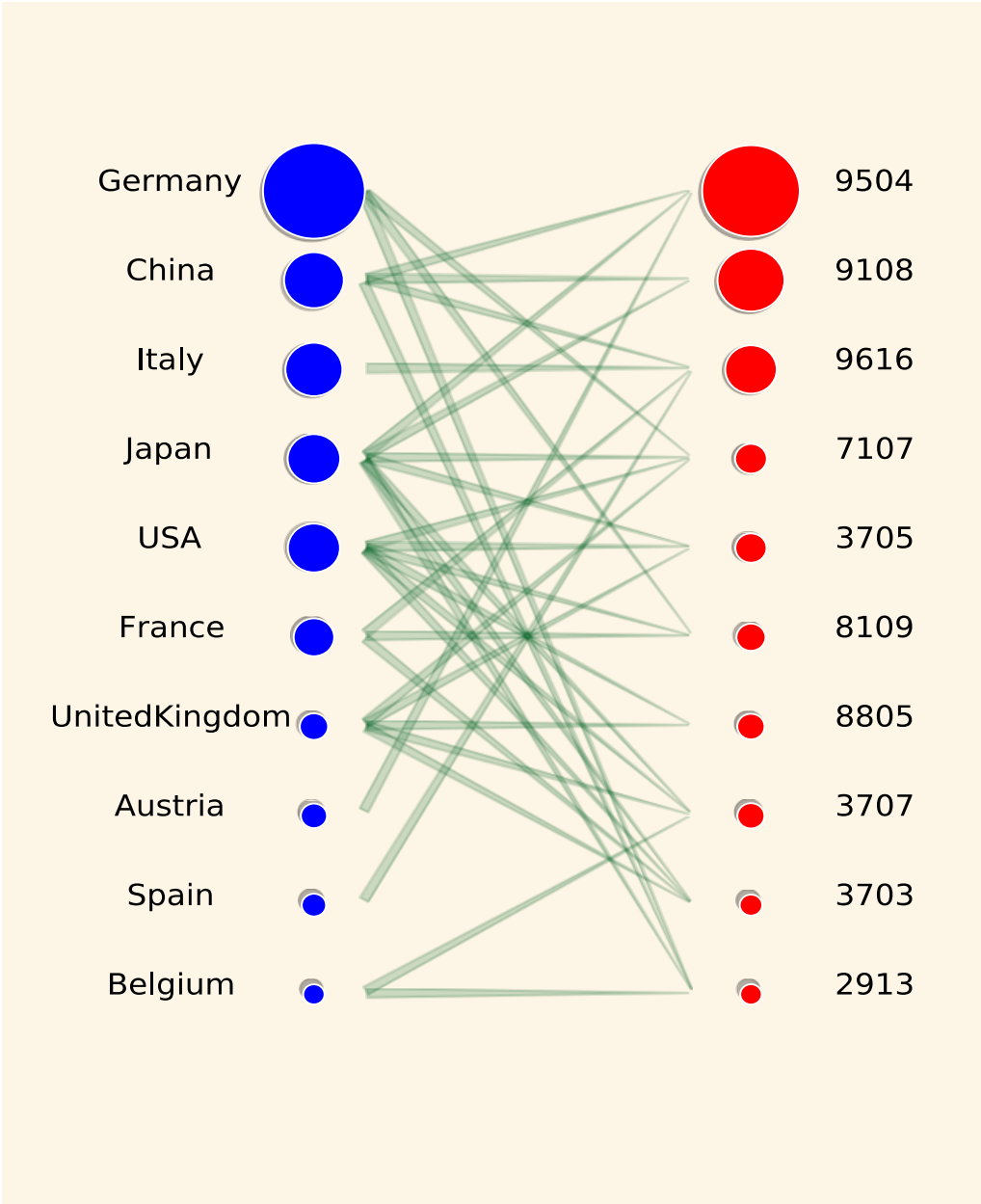
CRISISLAB
ANALYTICS FOR CRISIS PREDICTION AND MANAGEMENT

COMTRADE database:
Which country exports which product

Bipartite Network:
New algorithm to extract information for

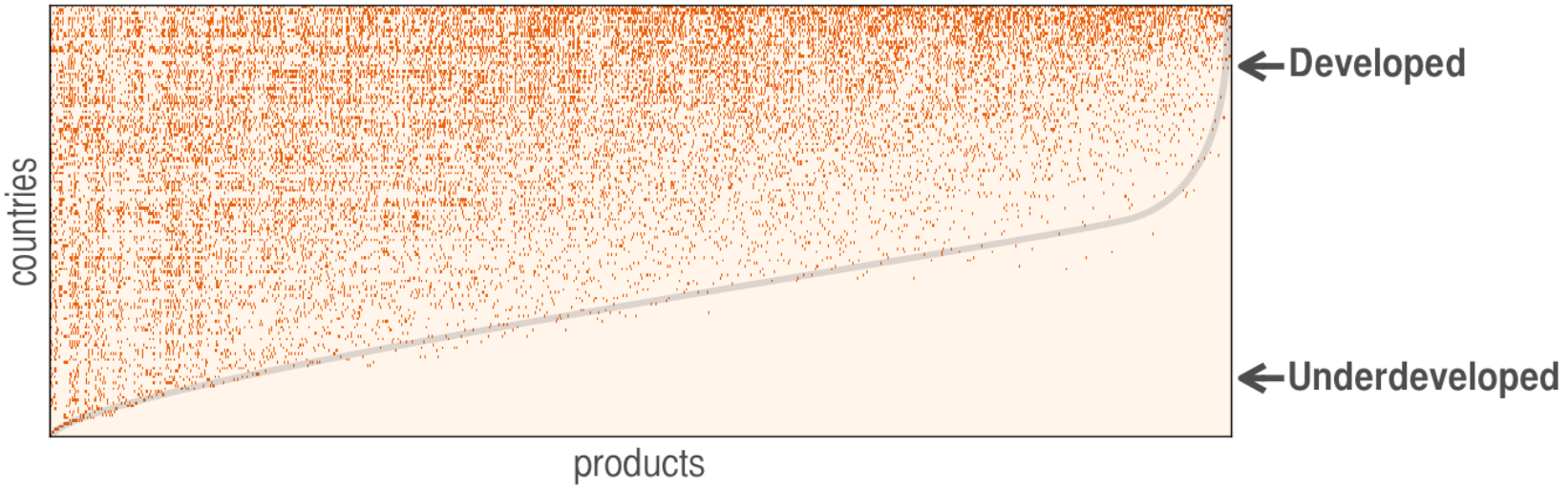
- Fitness of Countries
- Complexity of Products

NB: this is not an analysis of the export volumes.
The information is derived from the nature of products



SPECIALIZATION VS. DIVERSIFICATION

DATA DRIVEN APPROACH:



Evidence for leading role of diversification with respect to competitive advantage (specialization)

- Globalization
- Ecosystems
- Evolvability
- Adaptation

From Qualitative to Quantitative

- Math. Problem: minimal elements to have a triangilar matrix
  Complex Hierarchical structure, nestdness etc.
- For sectors and companies the situation evolves towards specialization

MEASURING INTANGIBLE PROPERTIES

New metrics for Fitness of countries and Complexity of products

Fitness:

$$\tilde{F}_c^{(n)} = \sum_p M_{cp} Q_p^{(n-1)}$$

$$F_c^{(n)} = \frac{\tilde{F}_c^{(n)}}{\langle \tilde{F}_c^{(n)} \rangle_c}$$

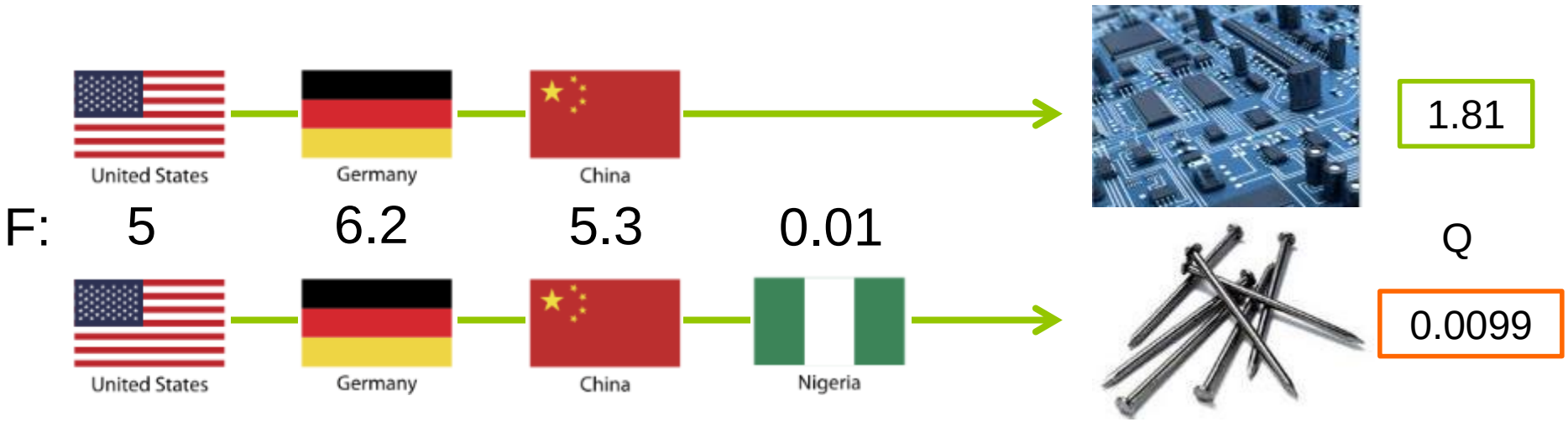
Complexity:

$$\tilde{Q}_p^{(n)} = \frac{1}{\sum_c M_{cp} \frac{1}{F_c^{(n-1)}}}$$

$$Q_p^{(n)} = \frac{\tilde{Q}_p^{(n)}}{\langle \tilde{Q}_p^{(n)} \rangle_p}$$

F_c: diversification weighted by complexity

Q_p: Extremal non-linear complexity of products.
A **single low fitness producer** implies low complexity



The Economic Dynamical Ecosystem:

Data driven approach from micro to macro

- Countries: diversified in products
  Countries and Products: Google like approach – Big Data
  Countries: Fitness index
  Products: Complexity index
  Dynamics: Monetary vs Intangible metrics – Hidden potential

- Subsystems: Regions, Districts, Cities (London, Shanghai)

- Industrial sectors: Various levels of grouping
  Evolution of their Complexity
  Policy making: virtual experiments, what if?
  Criteria for optimization

- Companies: specialized in products
  But diversified in terms of Technologies in their control
  (ie patents)

The Unified Metric System for Economics

A basic step for a systematic scientific approach

PROJECT PROPOSAL: LP + INET + World Bank + ???

THE FUNDAMENTAL ECONOMIC DATABASE

- Who produces what: The complete economic production for all
- Countries, Regions, Cities etc.

- Using coherent and comparable variables and including services, finance etc.

- Data are basically available, the problem is to embedd them in a coherent and systematic framework.

- Great value with limited effort. Even if beginning will be difficult it points to the direction to go

S. Inoua, *On the Complexity Approach to Economic Development*, 2013
http://vixra.org/pdf/1301.0182v1.pdf

How the model works:

1. Probability of having a product with *combinatorial complexity C (number of capabilities)* is

$$p(C) \sim \pi^C$$

Meaning of π: how effective is a country in making more products by combining capabilities

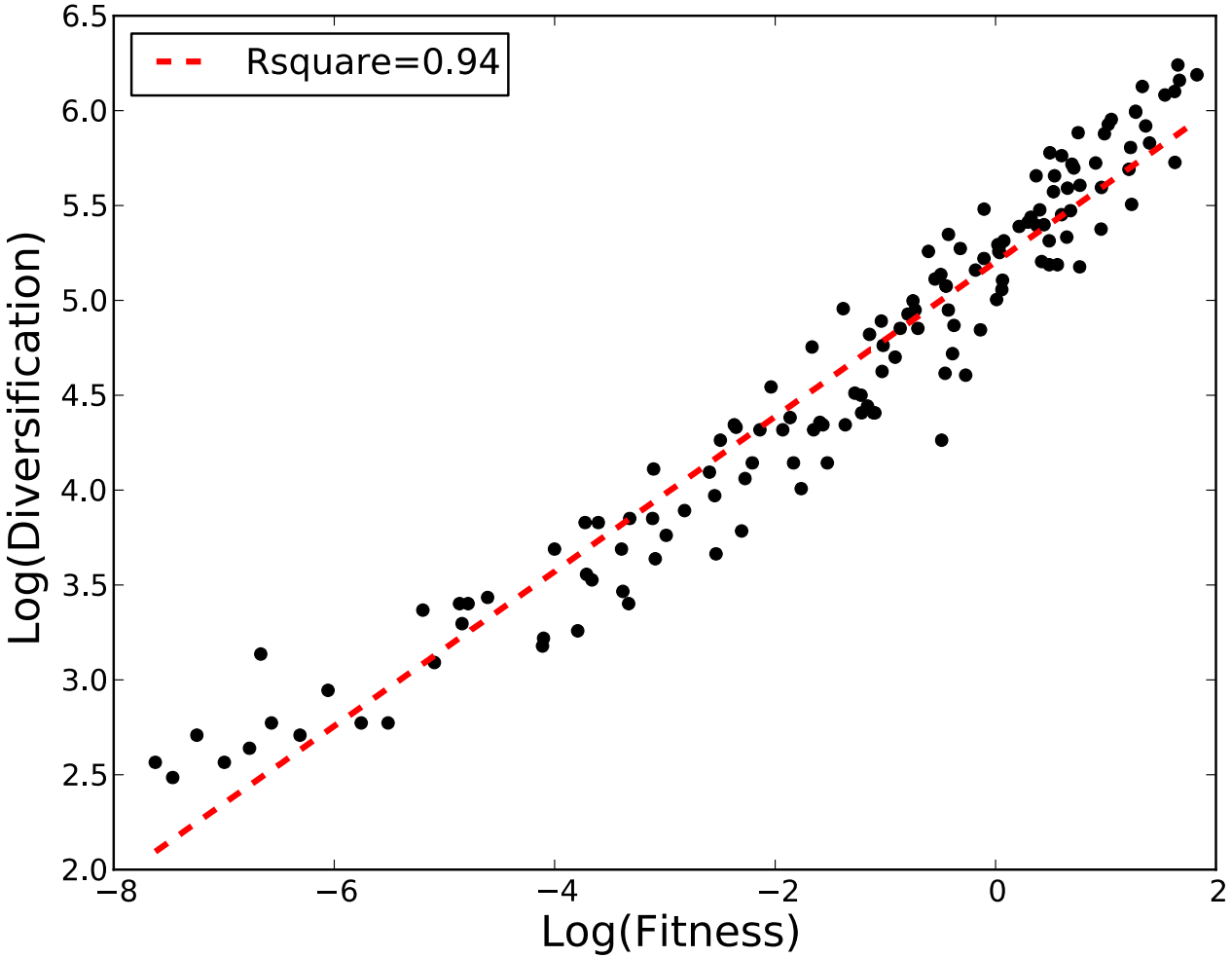
$$d = \sum_{C=1}^{K} p(C) \binom{K}{C} \sim (1+\pi)^K$$

2. The diversification *d* of a country which has *K* capabilities (*K* represents the complexity of that country) is

NB: no loss of generality assuming minimum number of capabilities =1

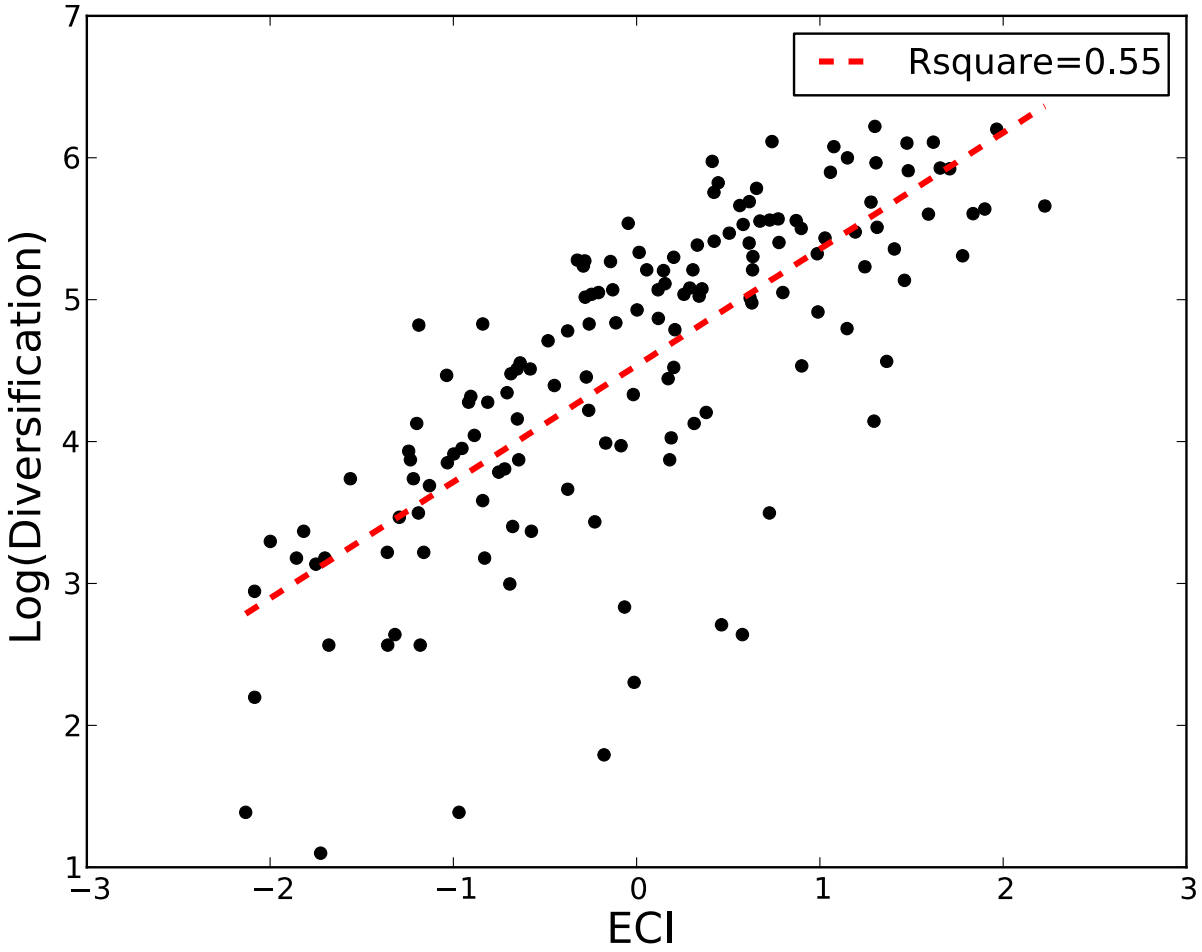
1° Prediction: let's test, as proxy for *K* , *log(Fitness)* and the *Economic Complexity Index* (ECI, C. Hidalgo et al. PNAS, 2009)

log(DIVERSIFICATION) vs log(FITNESS)



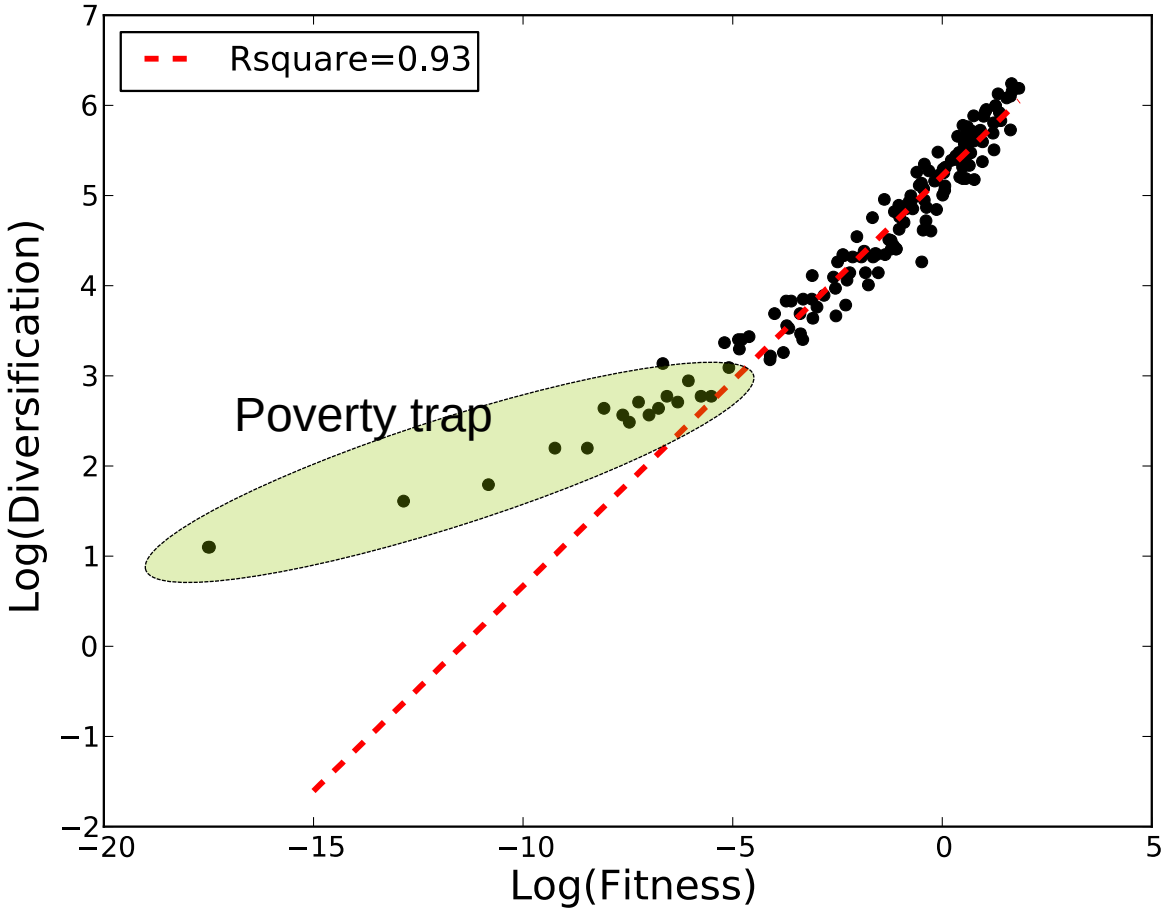
Log(Fitness) is good proxy for the *complexity K* of countries $R^2 \approx 0.92\text{-}0.94$ in the period 1995-2010

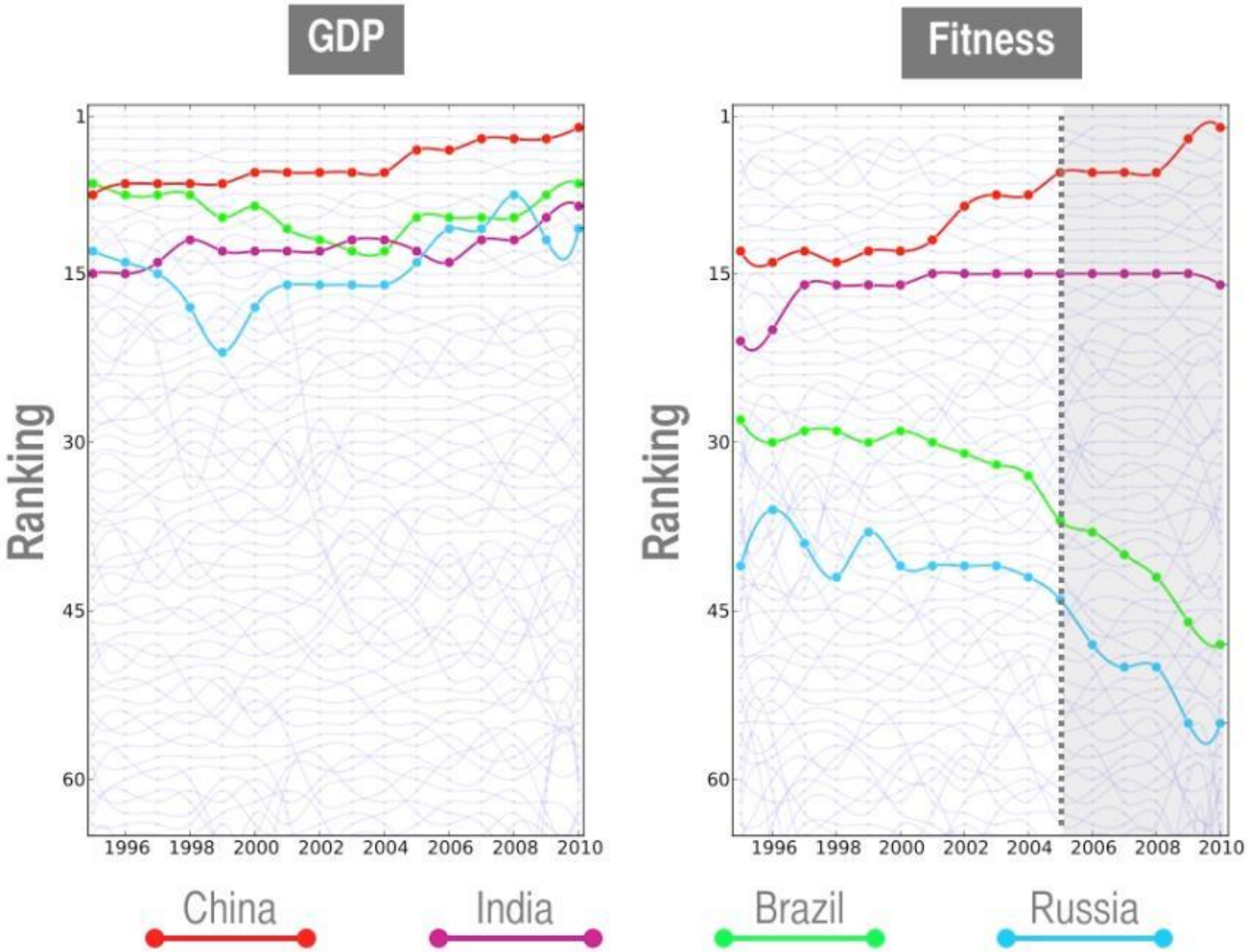
ECI is not a good proxy for *complexity K*, $R^2 \approx 0.52\text{-}0.65$ in the period 1995-2010

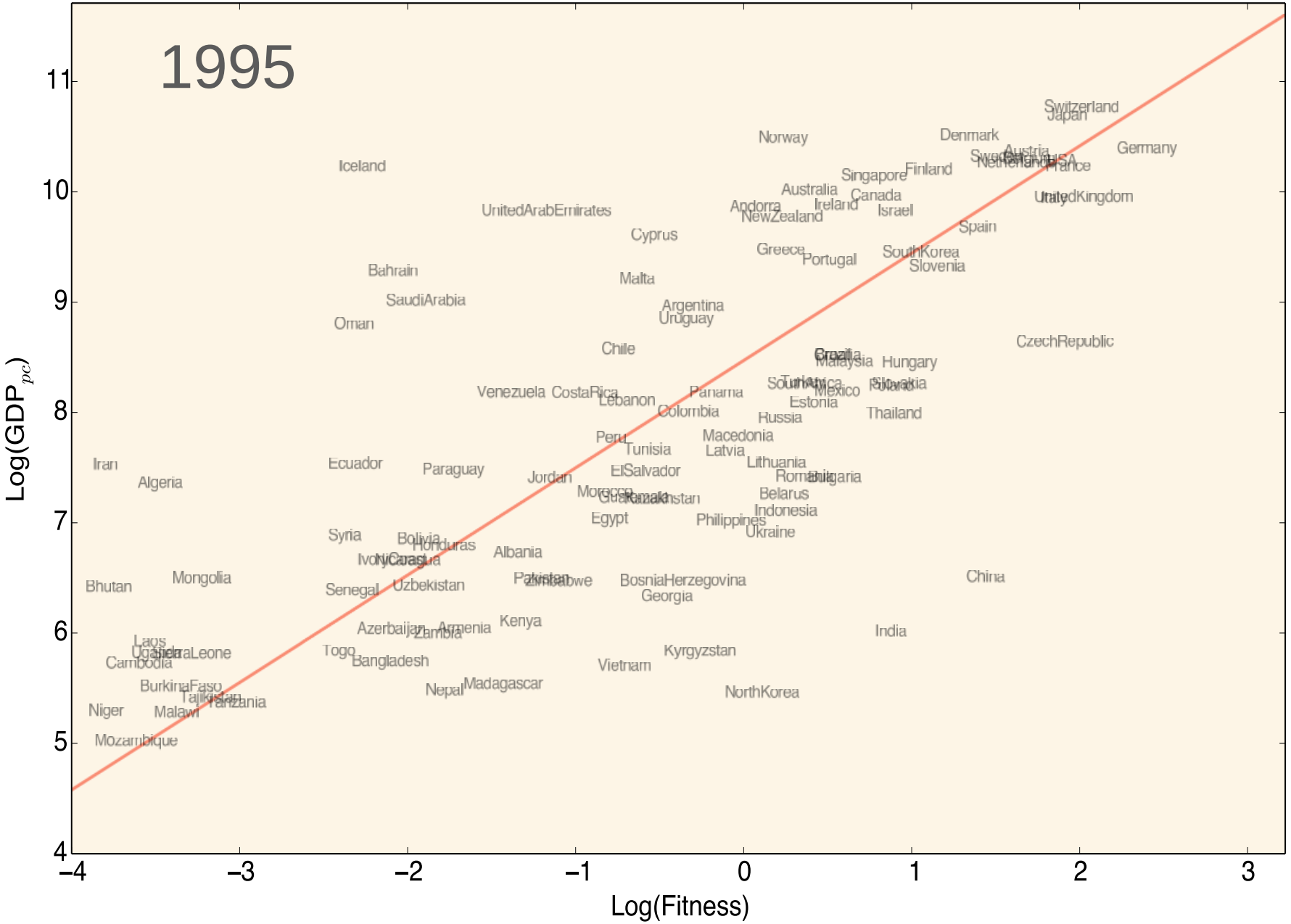


MICRO ORIGIN OF POVERTY TRAP?

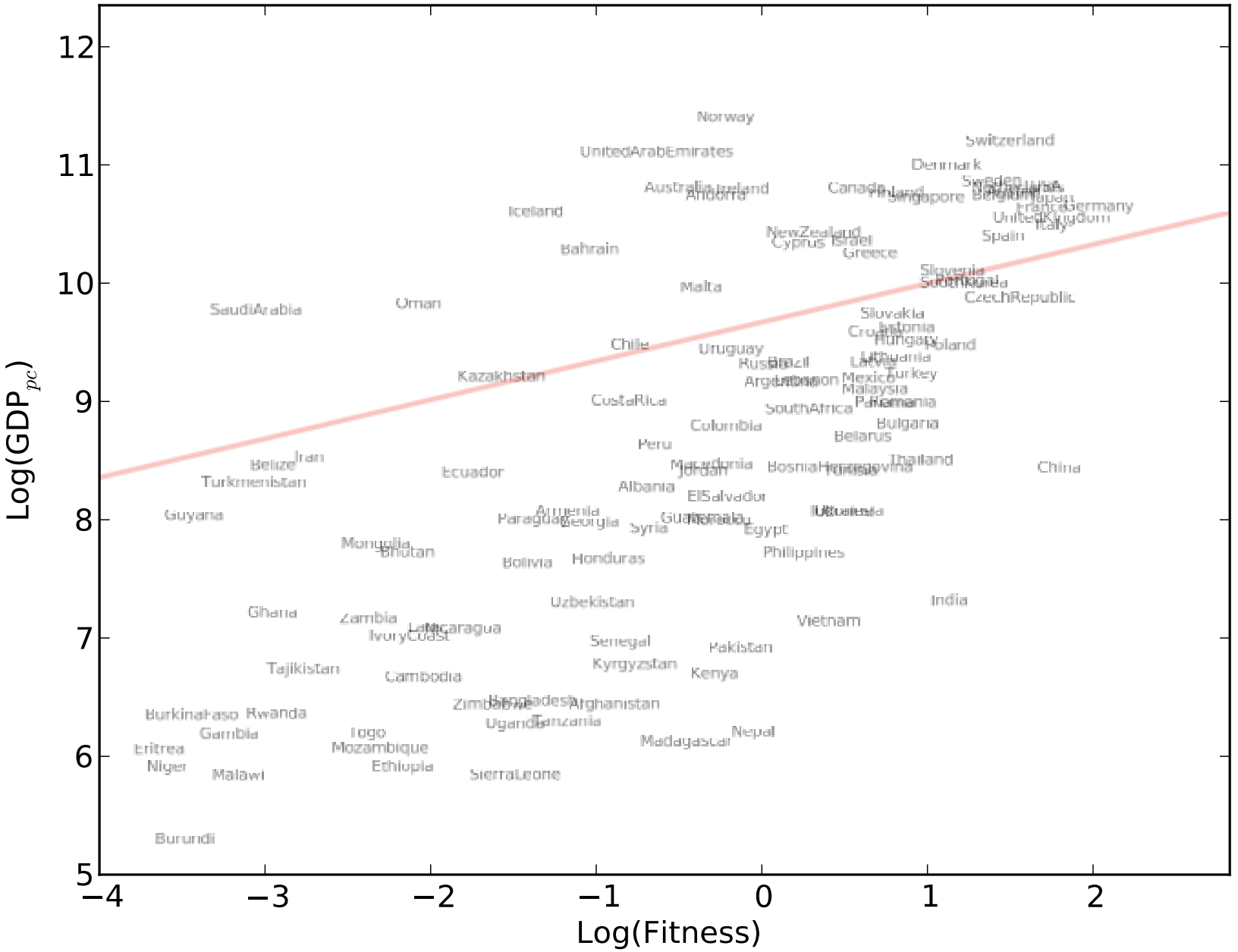
No longer exponential relationship btw *diversification* and *complexity* (i.e. *Log(Fitness)*)



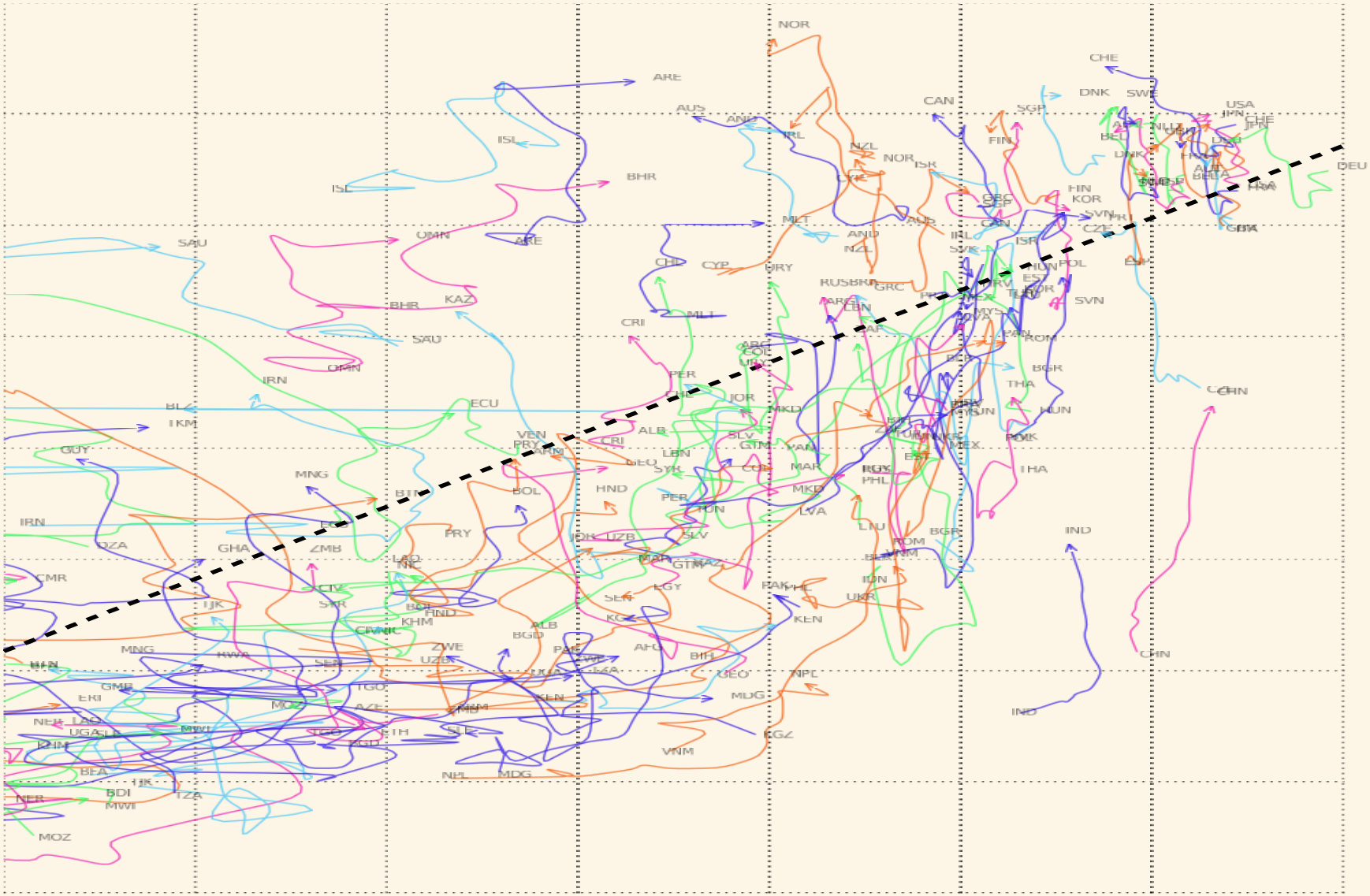

GDP
Fitness
Ranking
Ranking
1
15
30
45
60
1996
1998
2000
2002
2004
2006
2008
2010
China
India
Brazil
Russia


1995
Log(GDP$_{pc}$)
Log(Fitness)
11
10
9
8
7
6
5
4
−4
−3
−2
−1
0
1
2
3
Switzerland
Japan
Norway
Denmark
Germany
Iceland
Singapore
Finland
Australia
Canada
UnitedKingdom
UnitedArabEmirates
Ireland
Israel
NewZealand
Spain
Cyprus
Greece
Portugal
SouthKorea
Slovenia
Bahrain
Malta
SaudiArabia
Argentina
Uruguay
Oman
Chile
CzechRepublic
Malaysia
Hungary
Venezuela
CostaRica
Panama
Mexico
Estonia
Lebanon
Colombia
Russia
Thailand
Peru
Macedonia
Tunisia
Latvia
Iran
Ecuador
Paraguay
Lithuania
Algeria
Jordan
ElSalvador
Belarus
Indonesia
Egypt
Philippines
Ukraine
Syria
Bolivia
Honduras
Albania
Mongolia
China
Bhutan
Senegal
Uzbekistan
BosniaHerzegovina
Georgia
Kenya
Azerbaijan
Armenia
Zambia
India
Laos
SierraLeone
Togo
Bangladesh
Kyrgyzstan
Cambodia
Vietnam
BurkinaFaso
Madagascar
Nepal
NorthKorea
Niger
Malawi
Mozambique

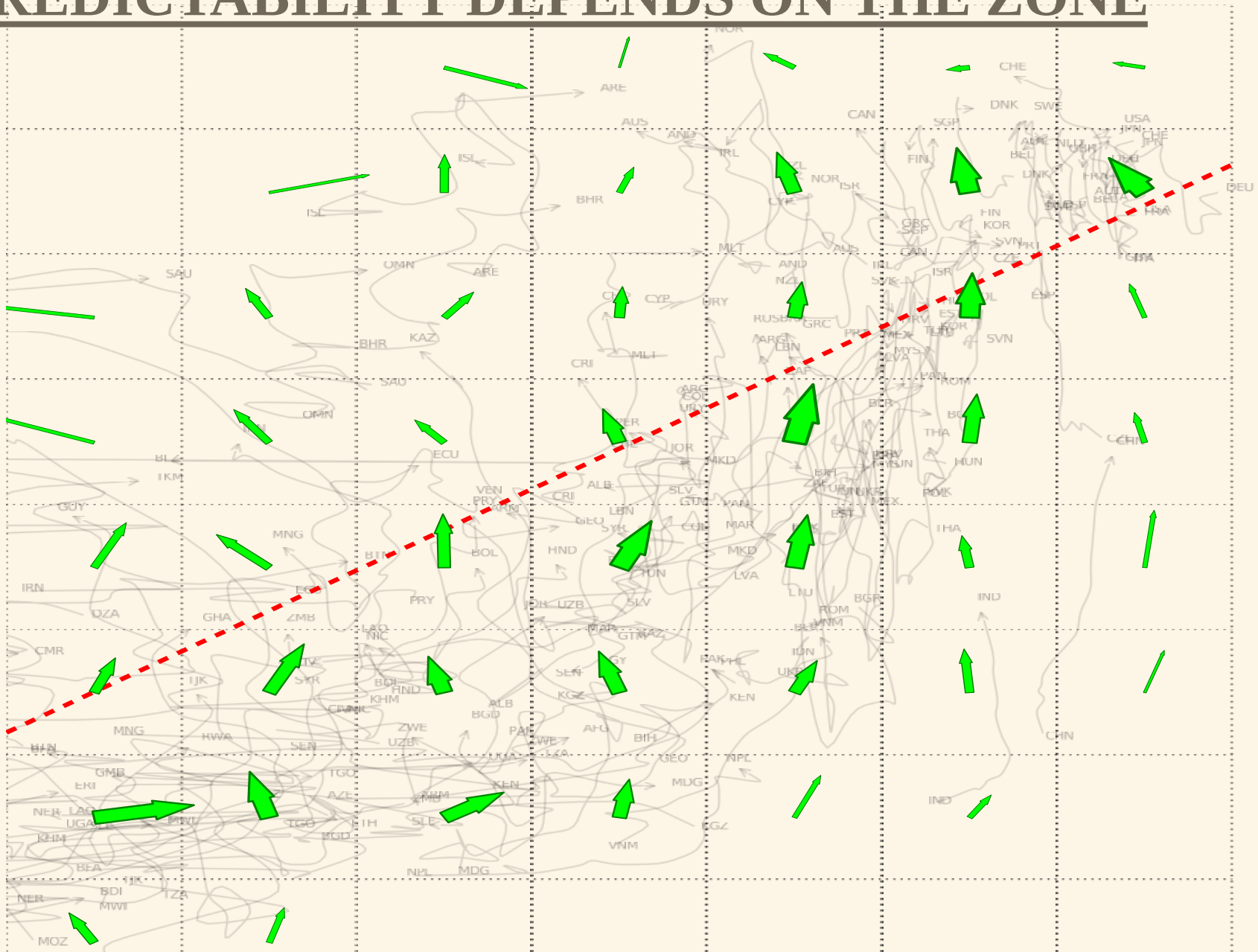
2010: Major changes are taking place



ECONOMIC DYNAMICS IS HETEROGENEOUS

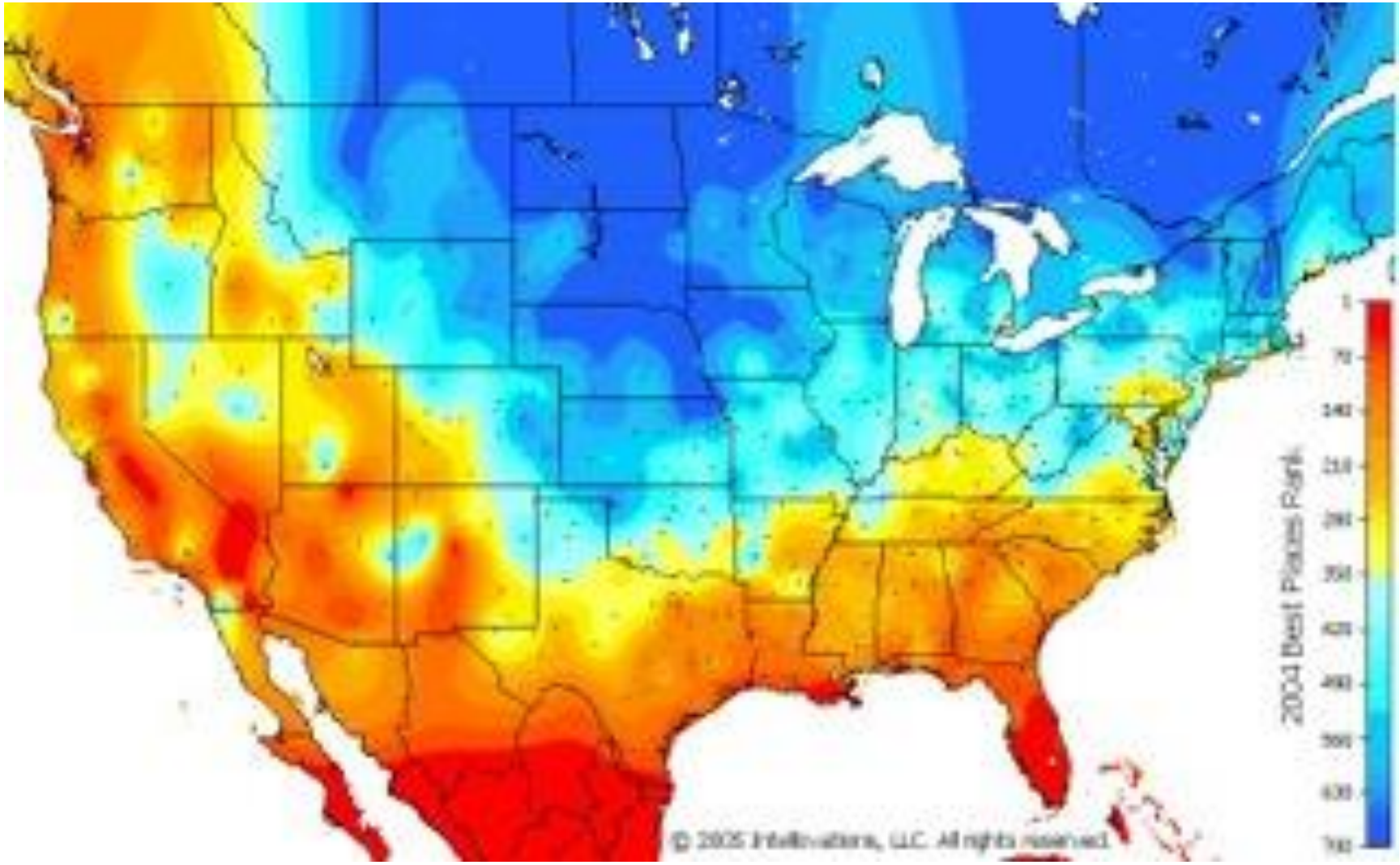


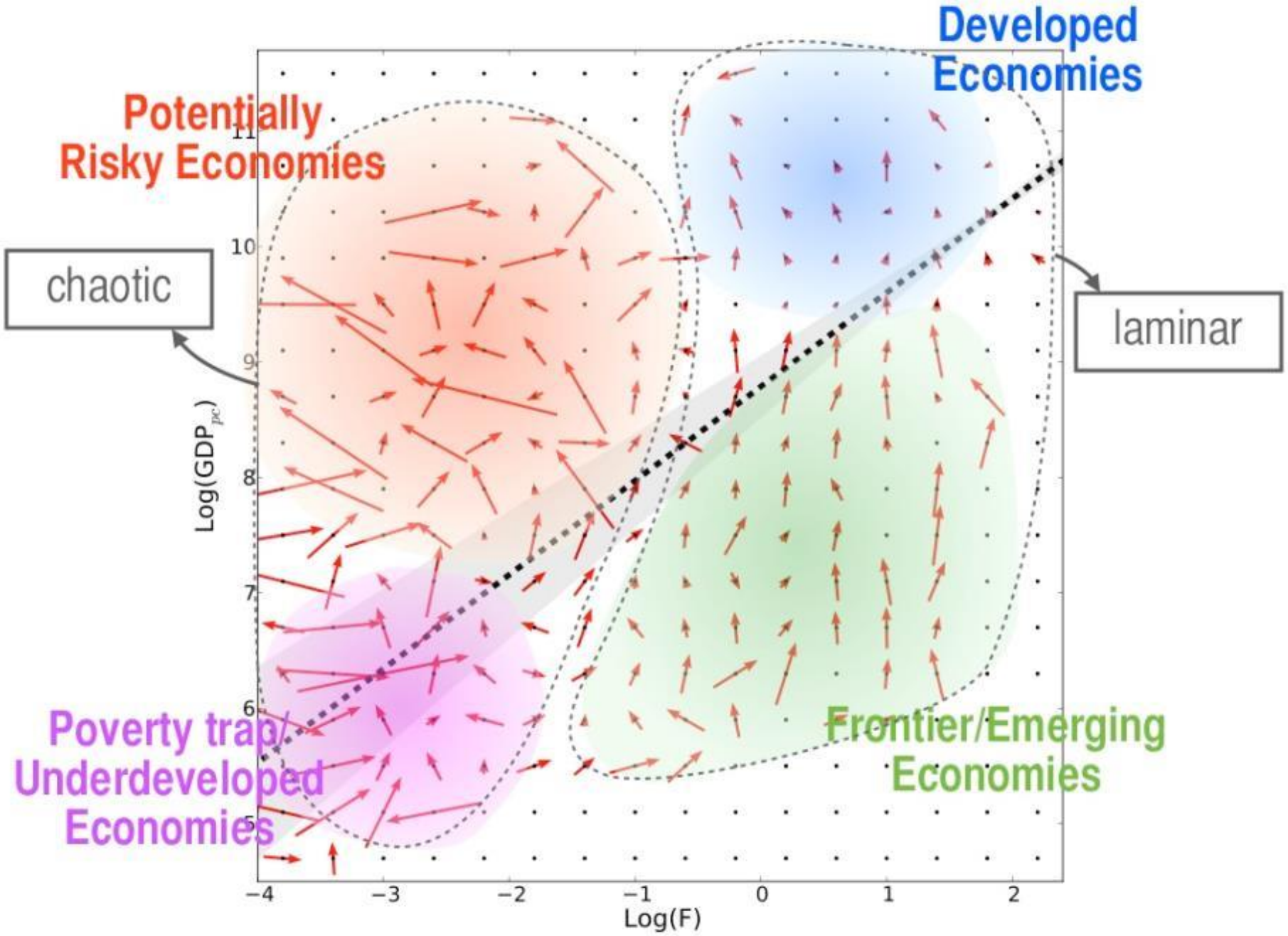
COARSE GRAINED DYNAMICS:
PREDICTABILITY DEPENDS ON THE ZONE

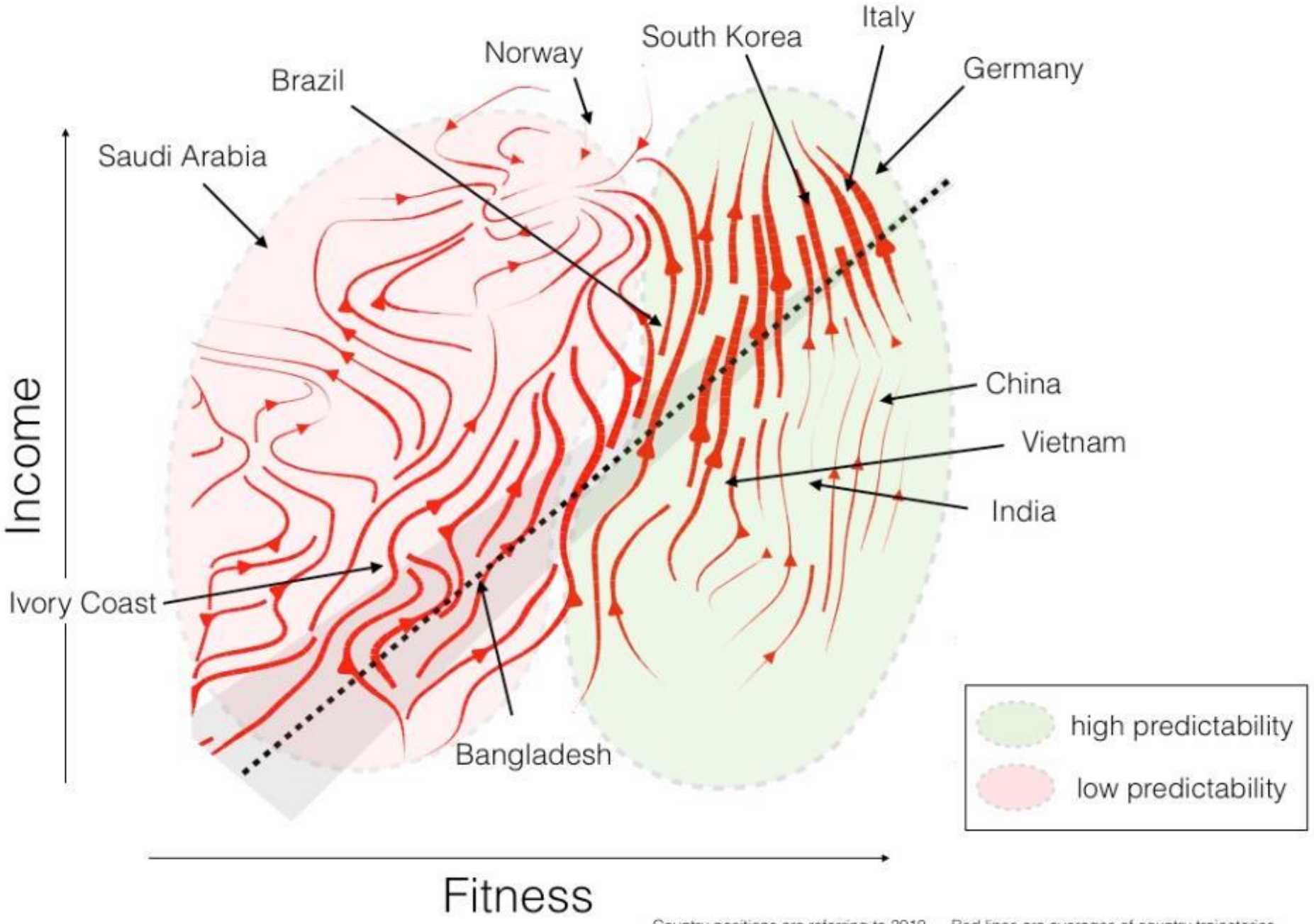


Hetreogeneous Weather Forecasting:

RED: High predictability BLUE: Low predictability




Developed Economies
Potentially Risky Economies
chaotic
laminar
Poverty trap/ Underdeveloped Economies
Frontier/Emerging Economies
Log(GDP$_{pc}$)
Log(F)
11
10
9
8
7
6
5
−4
−3
−2
−1
0
1
2



Country positions are referring to 2010 — Red lines are averages of country trajectories
Income is measured by Gross Domestic Product *per capita*, PPP (current international $)

Predictability – Forecasting (Beyond Regressions)

Heterogeneous Growth Dynamics: Selective Predictability

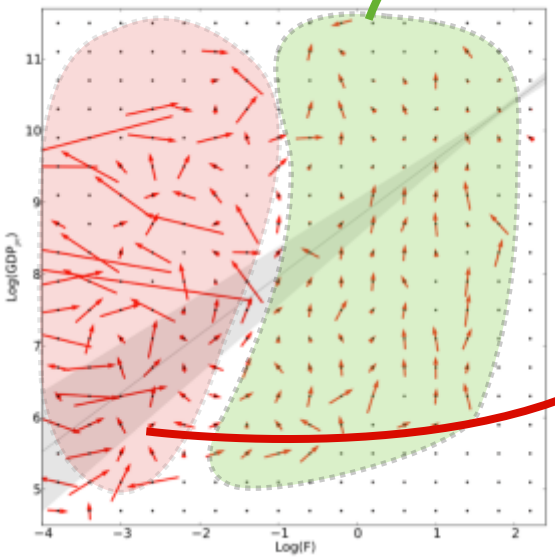
Overview of scienfic predictions:

- If one KNOWS the equation of motion:
  - Linear dynamics: full predictability. Sun raises tomorrow at 06:22
    Halley comet will come back in 121y, 237days, 13h, 45 min, 12 sec
  - Nonlinear chaotic dynamics: Lyapunov exponents
    Weather forecasts, limit of 3 – 7 days
    BUT: don't buy a calendar for more than 5 million years

- If one DOES NOT KNOW the equation of motion:
  Method of Analogous: dynamical system approach; effective dimension of phase space. New in economics; concretely data-driven

- Method of Regressions: cause-effect relation; homogeneity of response etc.
  Not suitable for heterogeneous dynamics

Borrowing concepts from dynamical systems



Laminar regime

Low effective dimension ($d_e \approx 2$)

Fitness is the relevant and driving variable for the economic dynamics in this regime

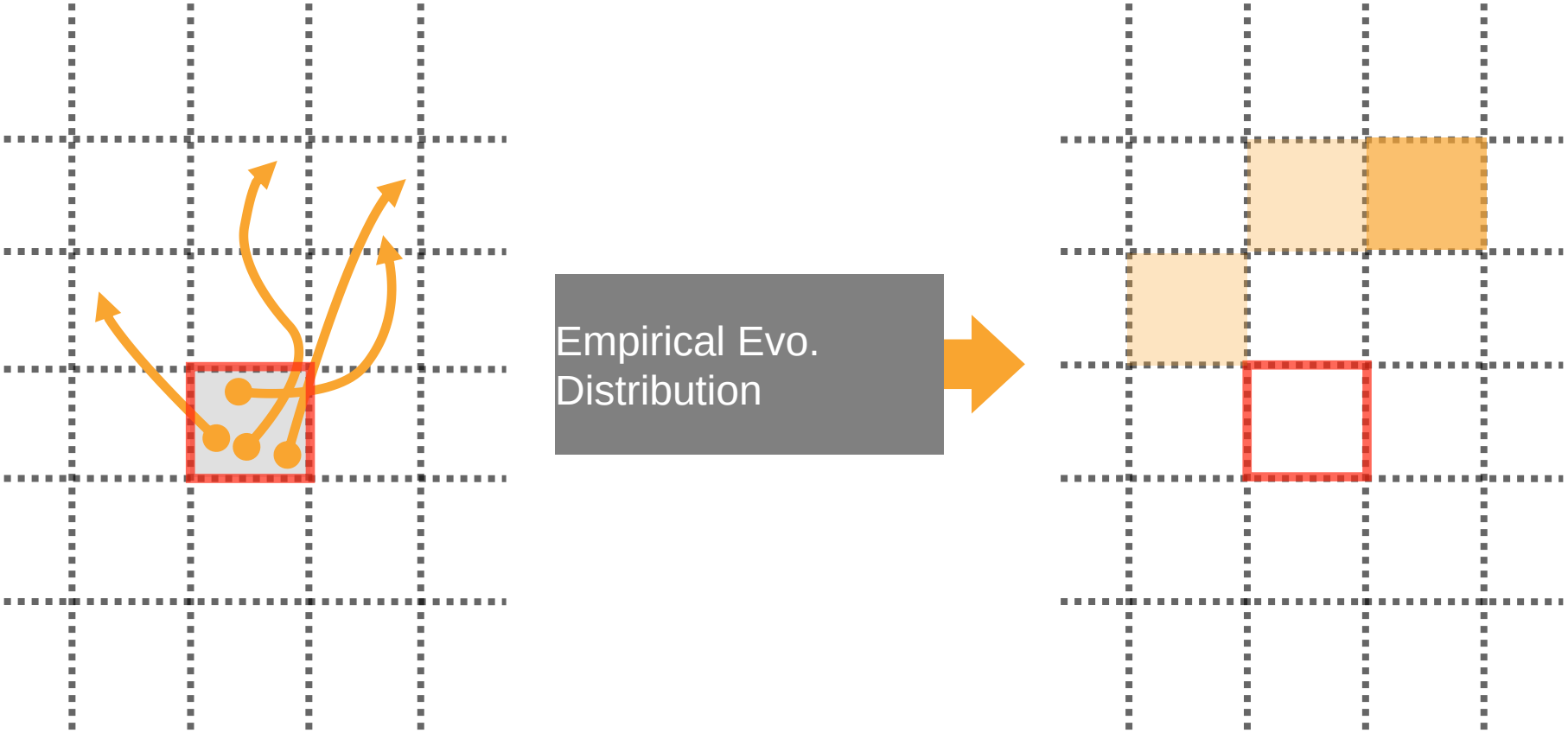
Chaotic regime

Chaotic dynamics OR $d_e \gg 2$

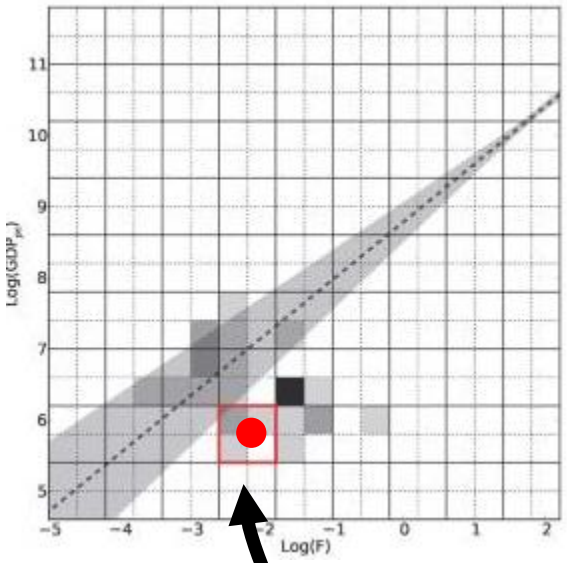
Dynamics is ruled by several other exogenous factors competing with Fitness

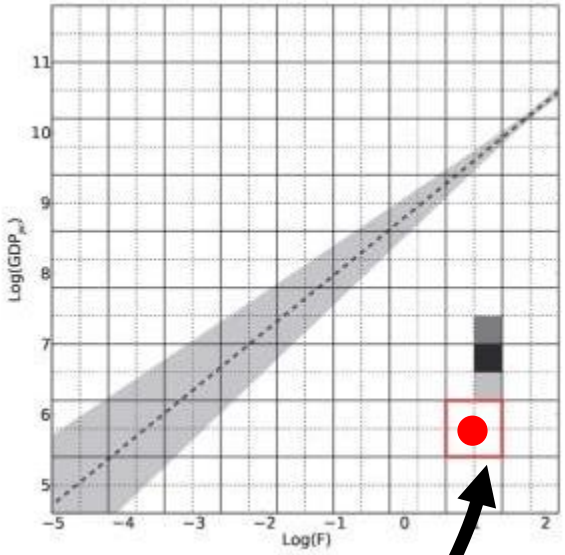
SELECTIVE PREDICTABILITY

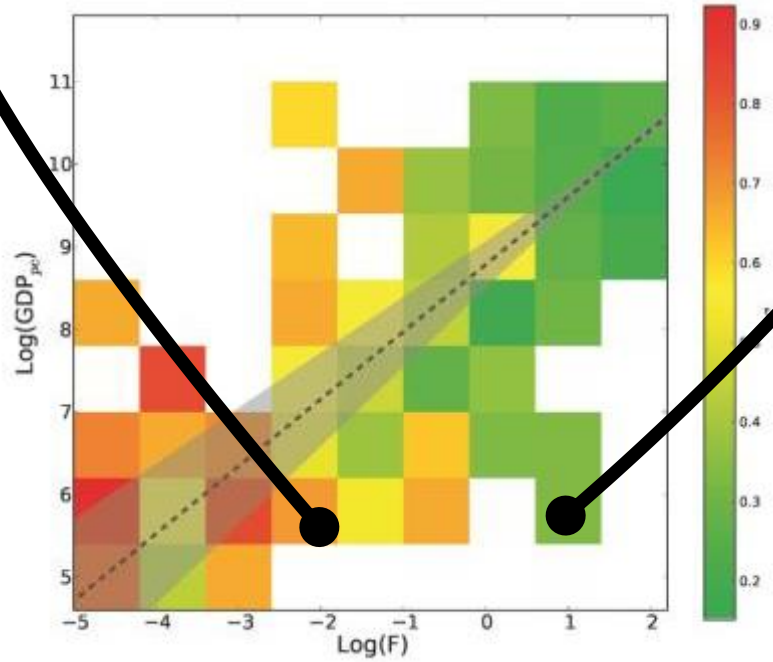
Method of Analogs: forecasting the future by the knowledge of the past



the *Selective Predictability* Scheme







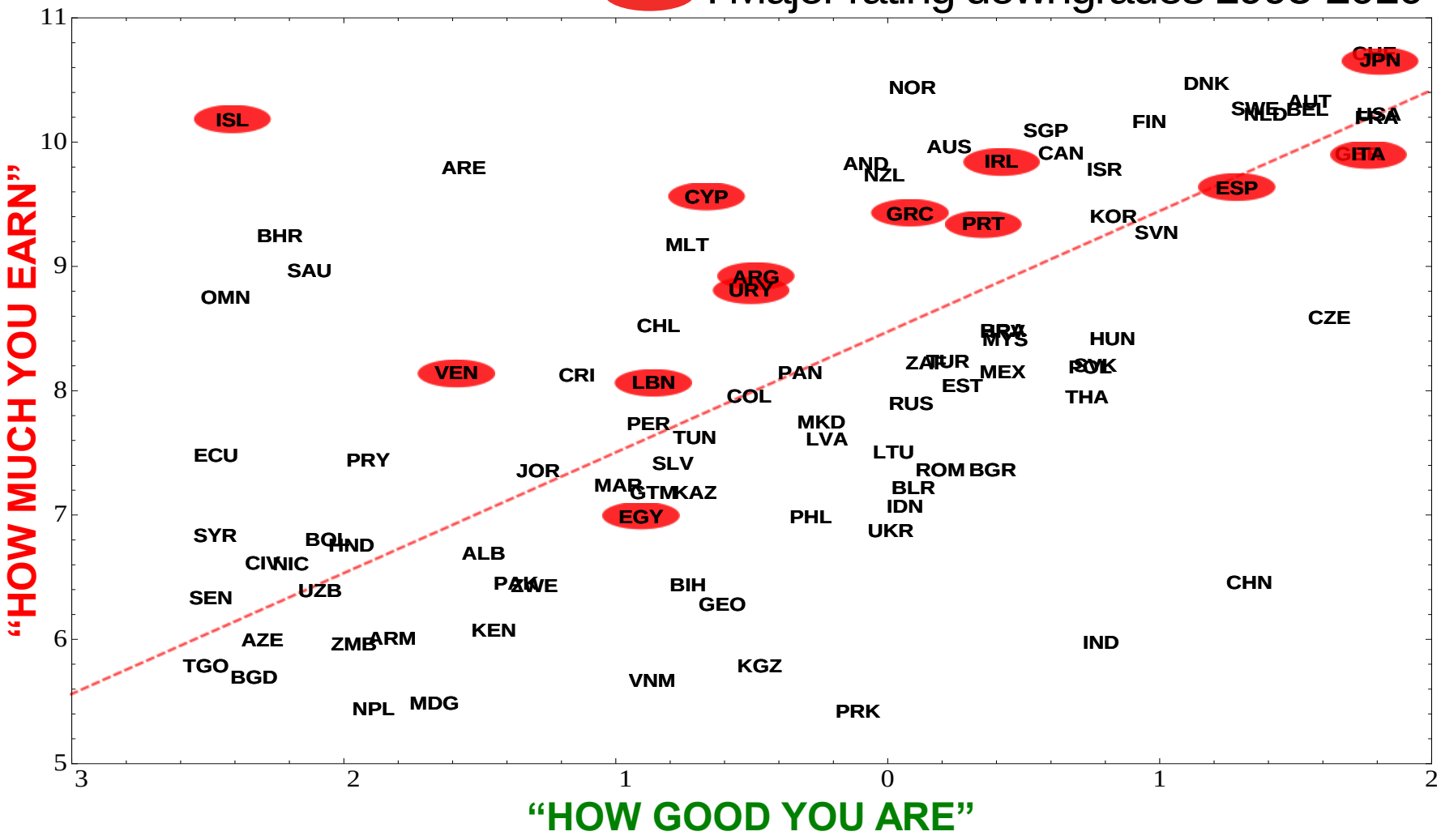
$$\mathcal{C} = \frac{n_{\text{boxes}}^{(i)}}{N^{(i)}} - \frac{1}{N^{(i)}}$$

NB: $N^{(i)} \geq 10$

Range:
1 – 5 years

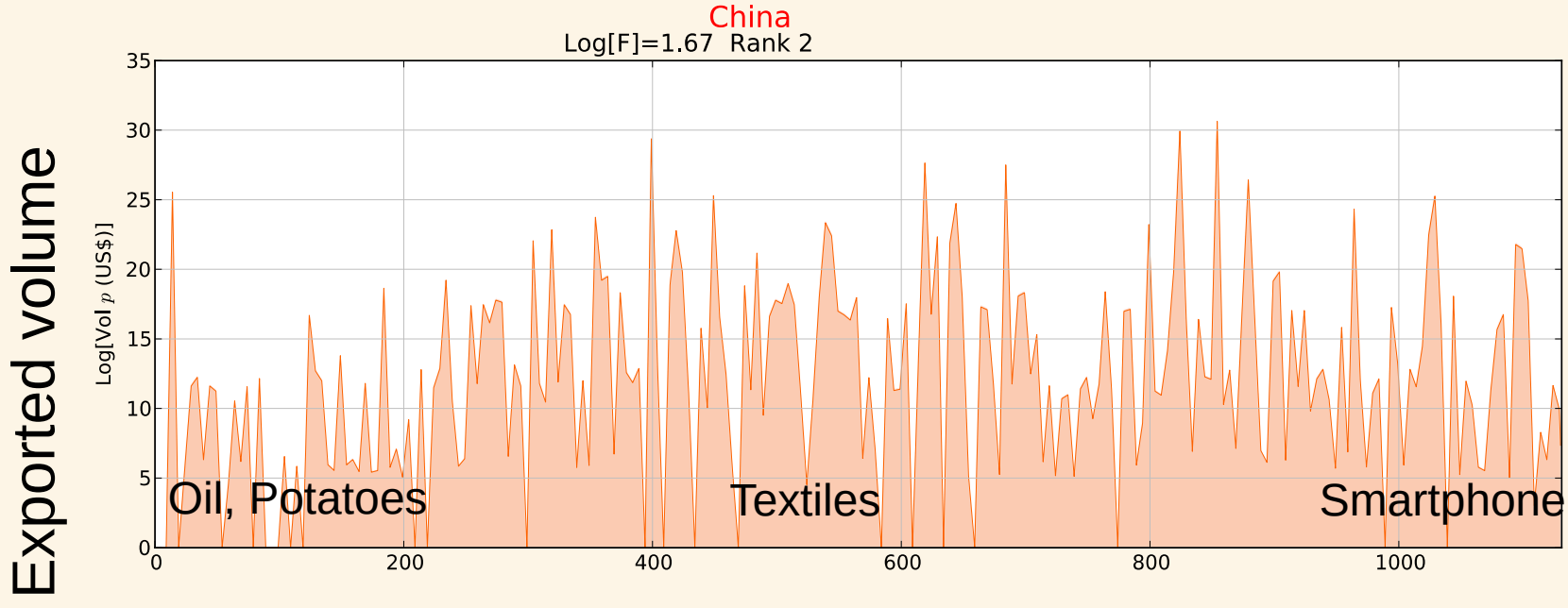
FITNESS vs. GDP_{pc}

: Major rating downgrades 1995-2010

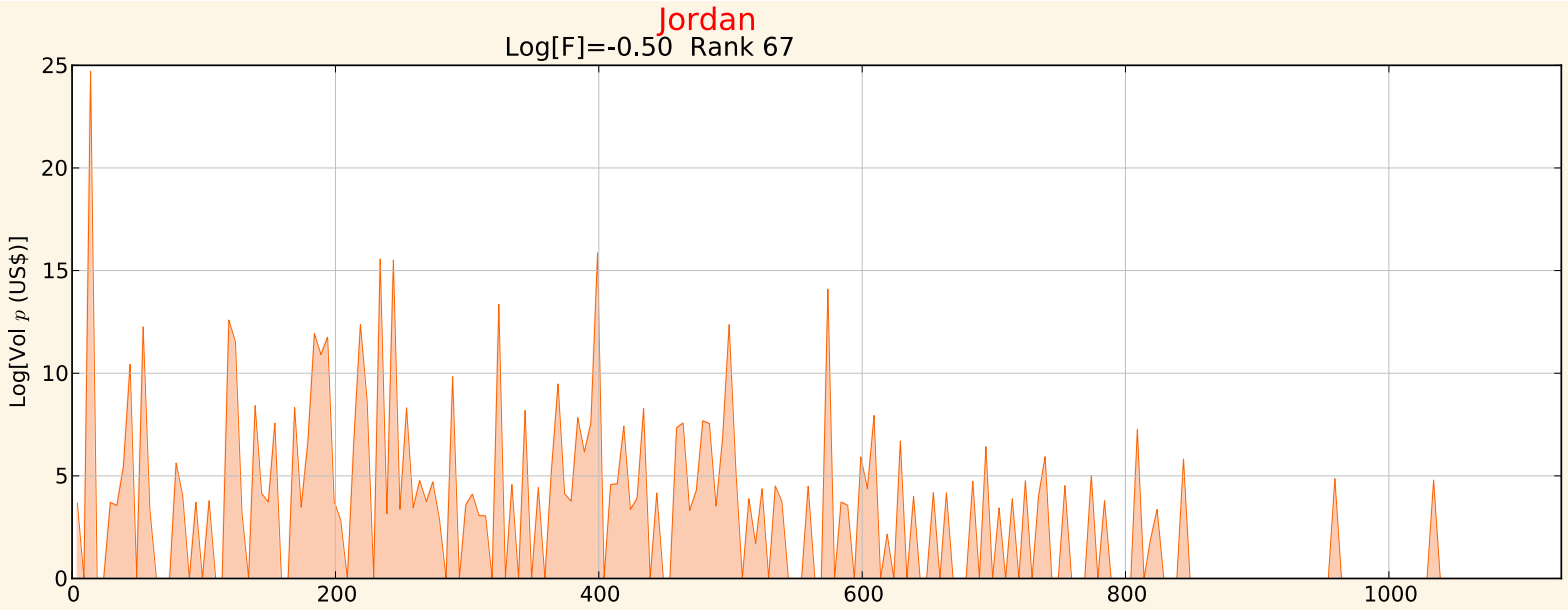


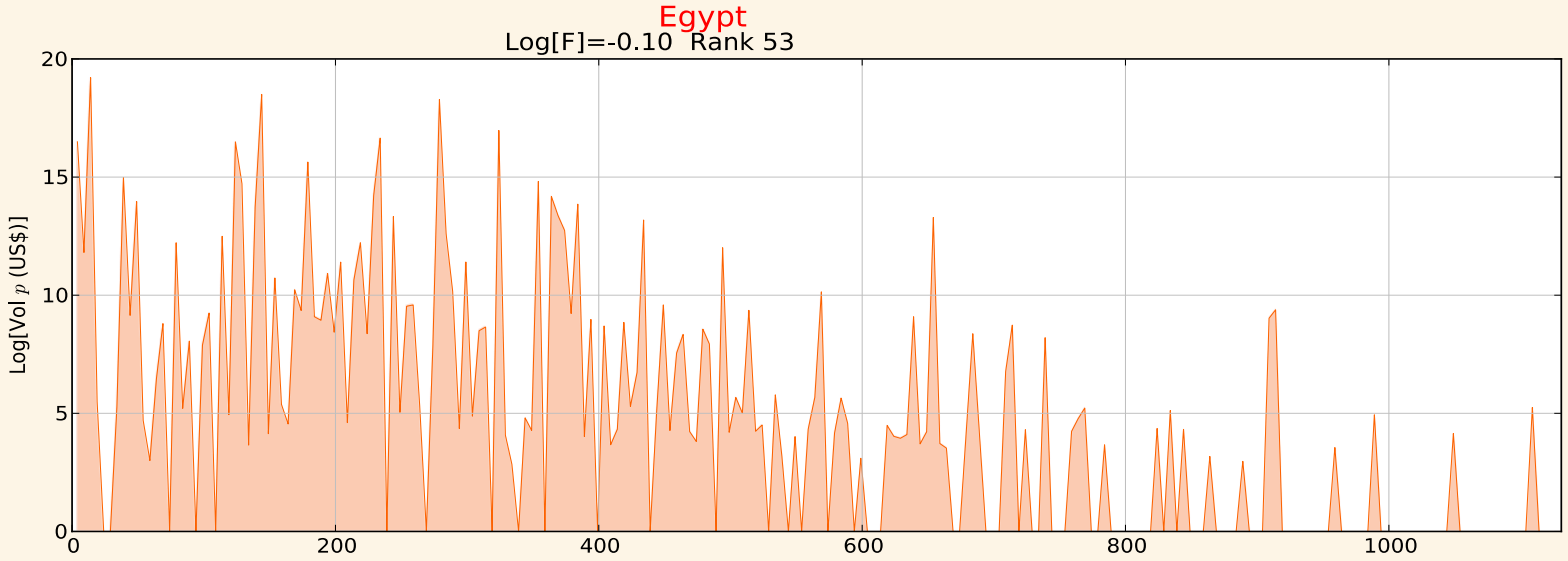
COUNTRY SPECTROSCOPY

- Products appear clustered in Quality Space
- The revanche of specialization – Industrial sectors and individual companies tend to be reasonably specialized

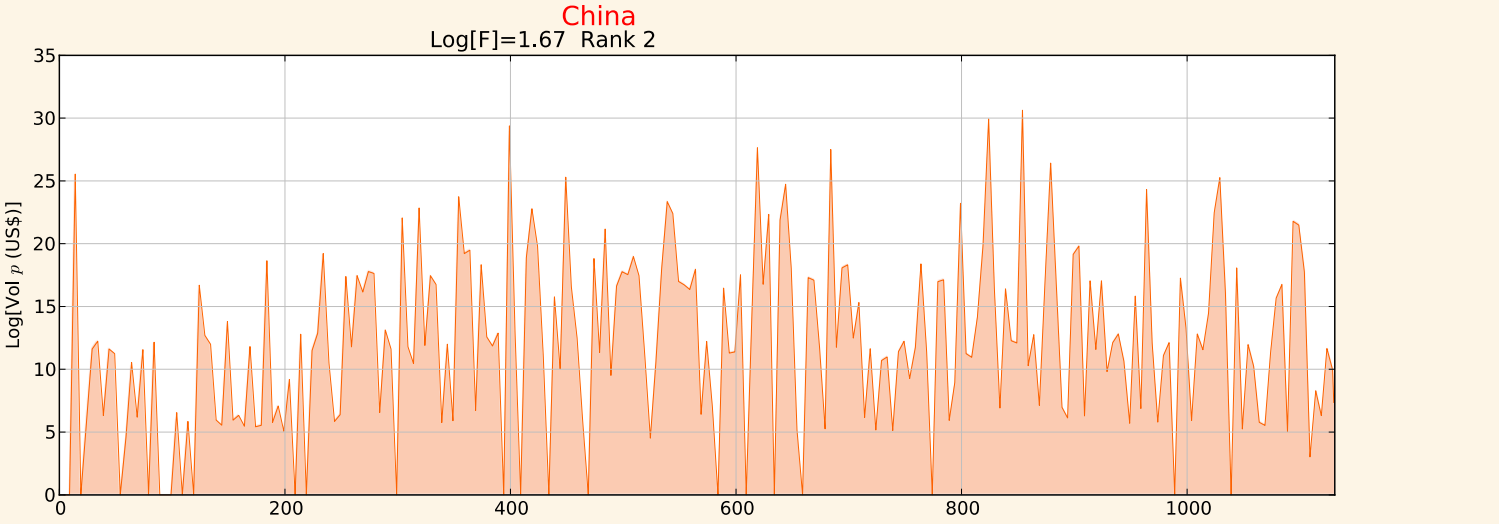


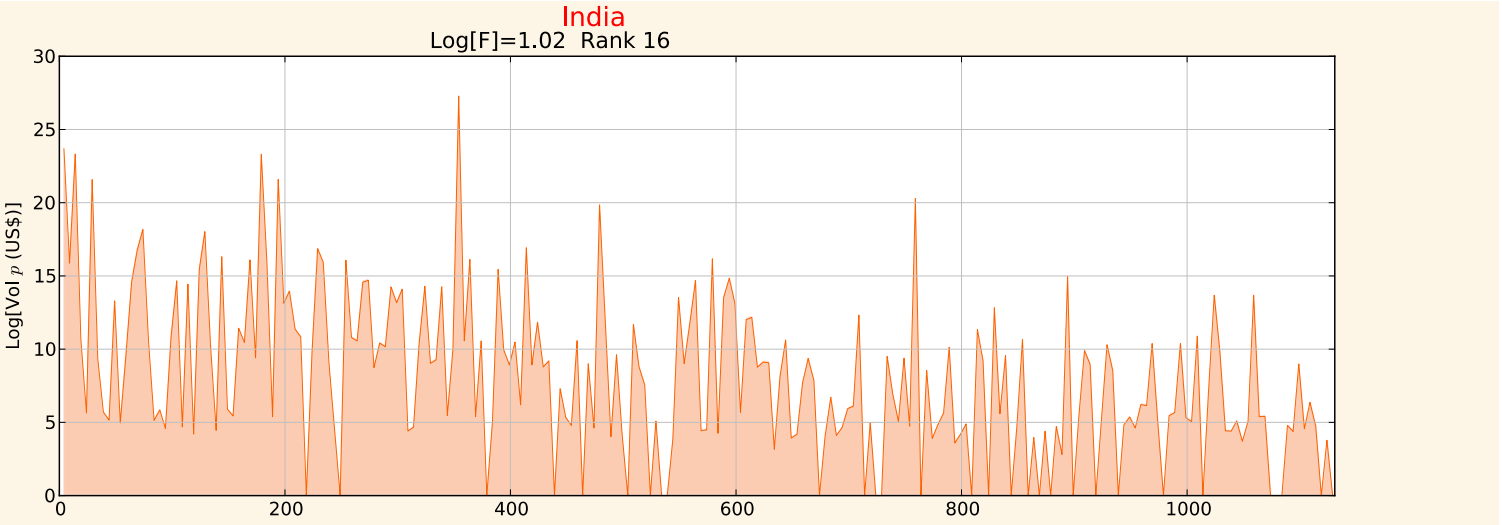
COUNTRY SPECTROSCOPY



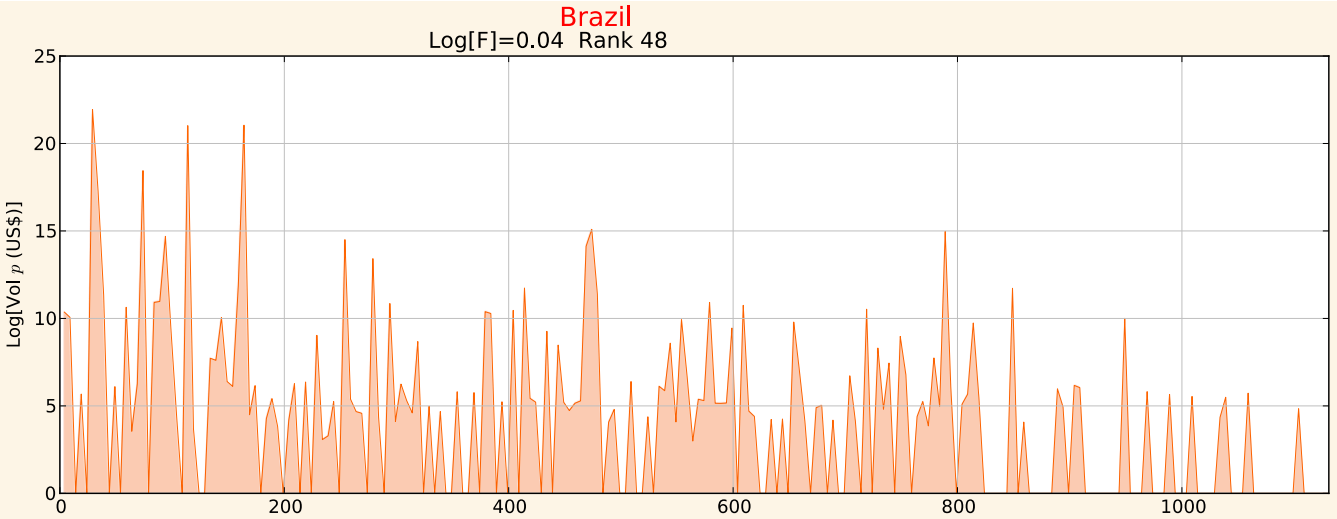


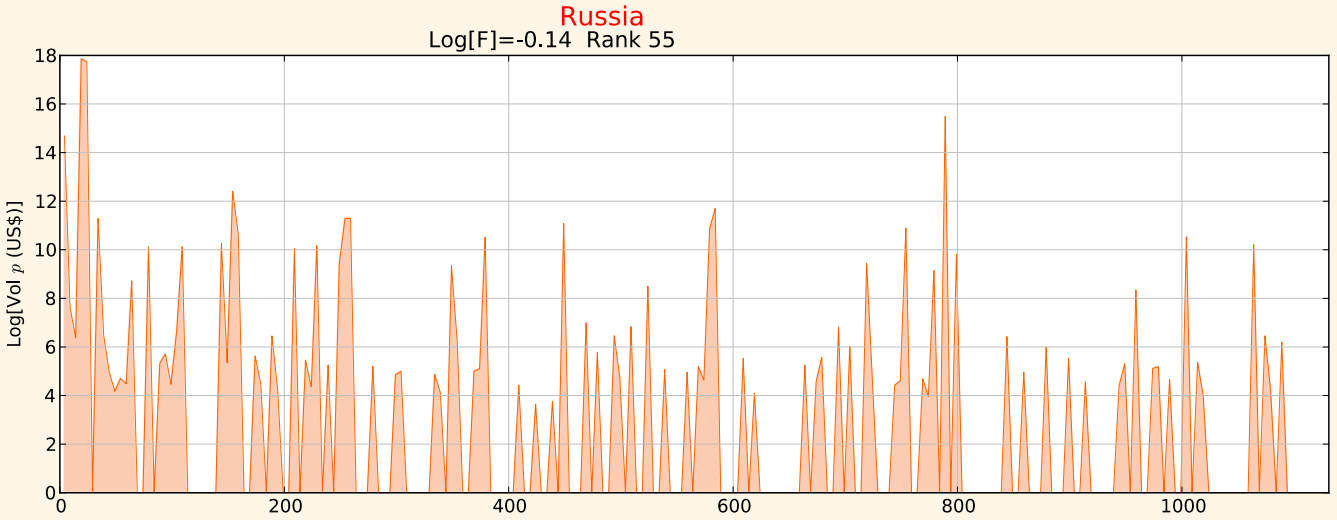
COUNTRY SPECTROSCOPY





COUNTRY SPECTROSCOPY





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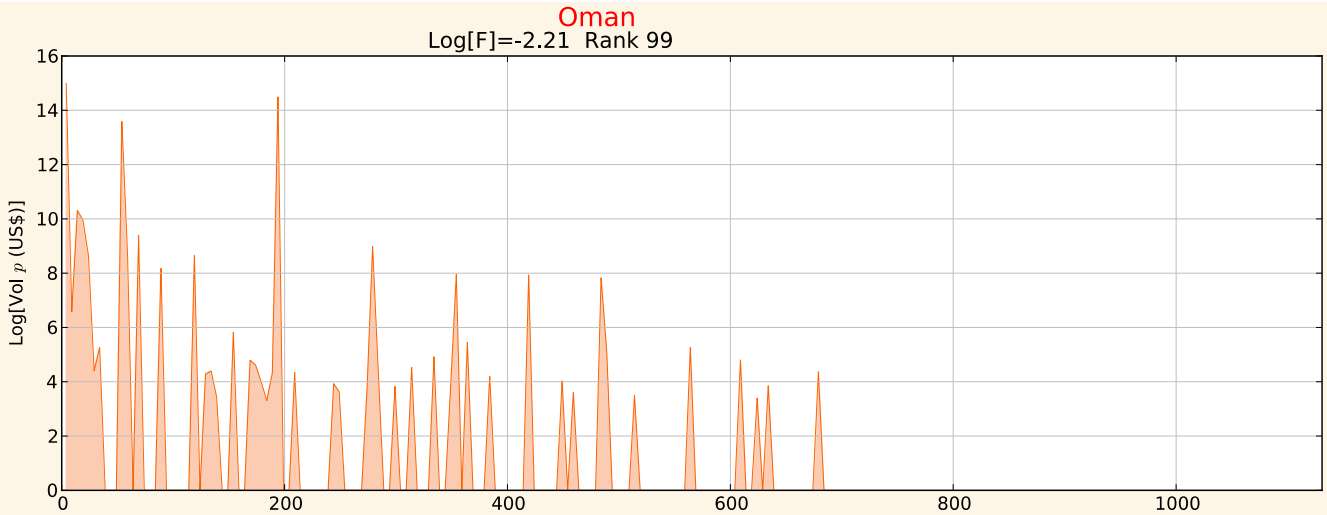
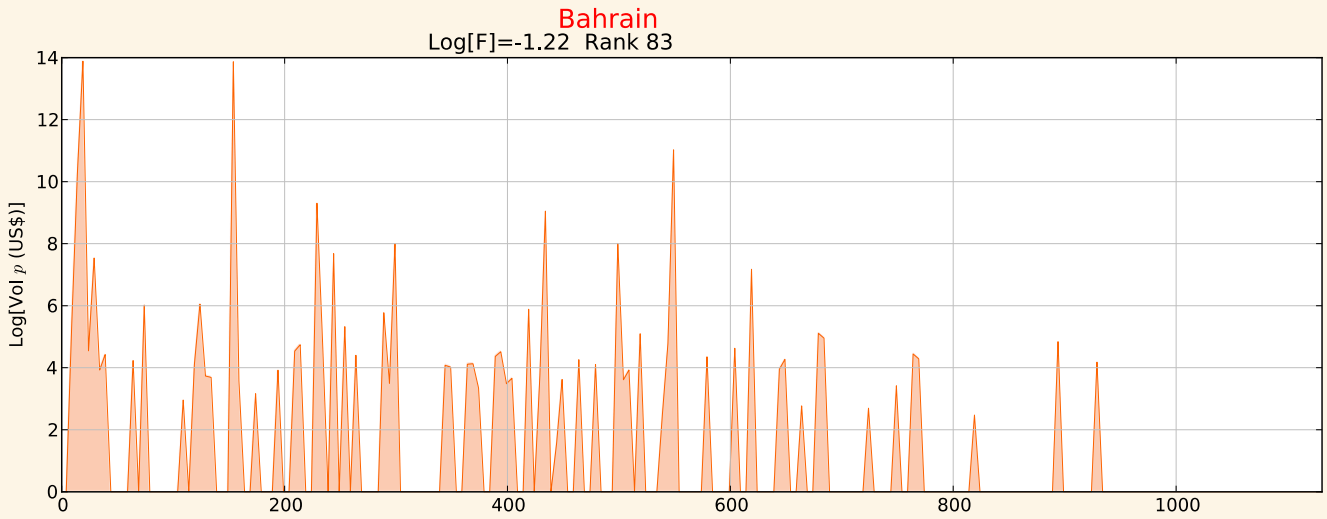
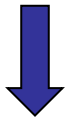
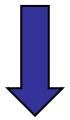




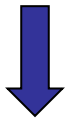
The PRODUCT SPACE:Bipartite C-P network



Contraction: P-P network



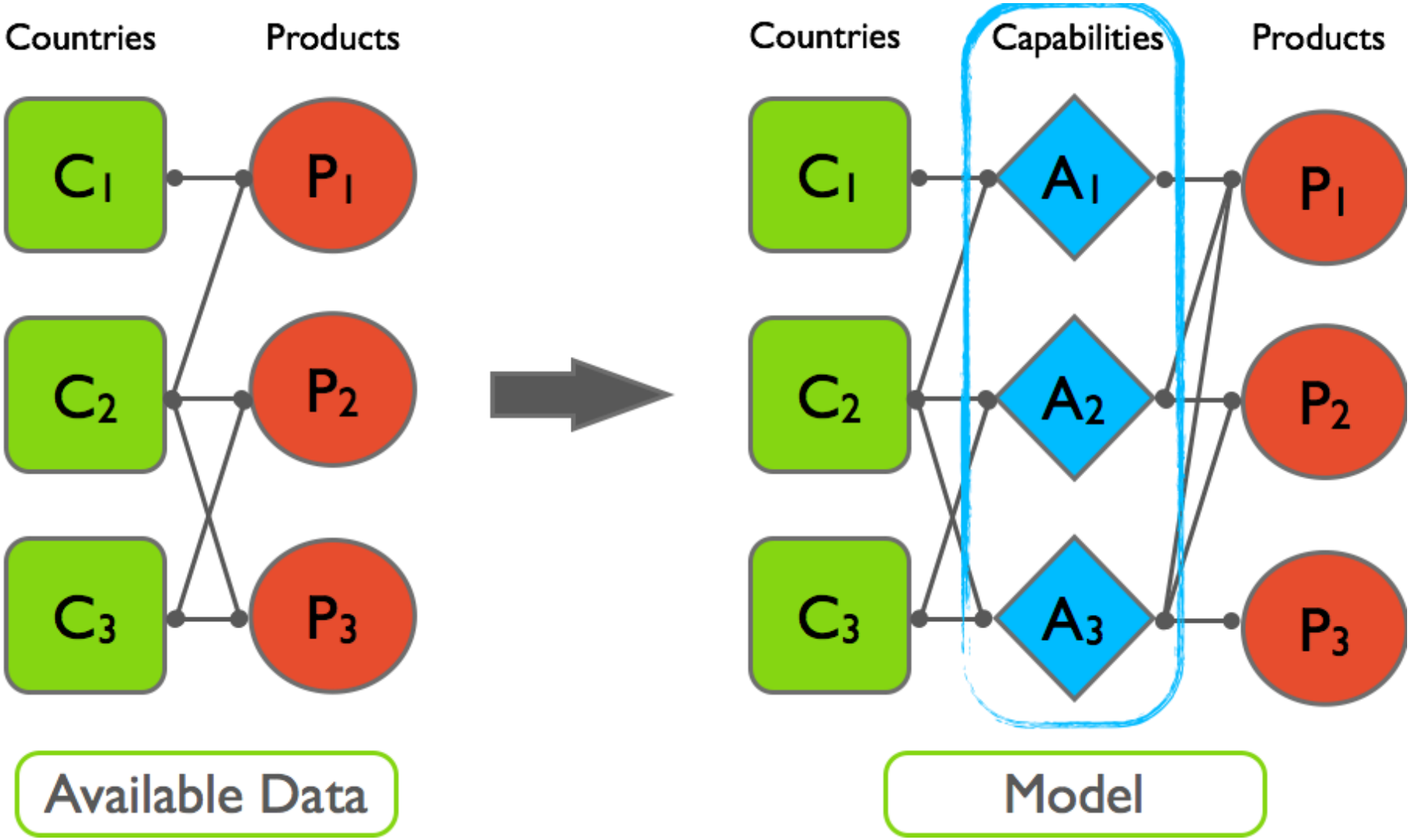
Filtering Procedure: selecting “dependency” links



The “Product Space”

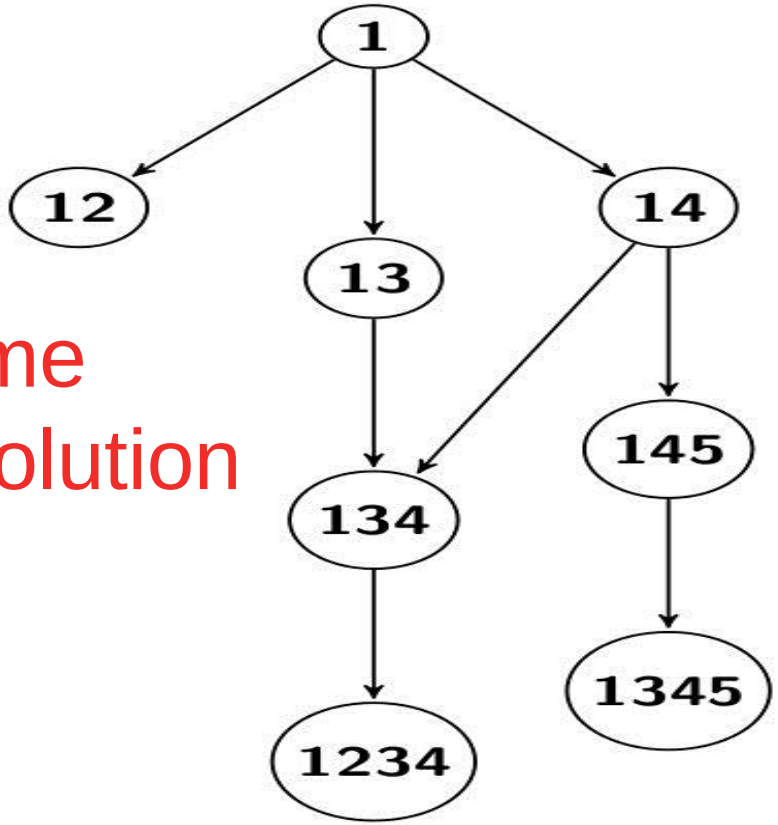
The Building Blocks of Economic Complexity

C. Hidalgo (MIT), R. Hausmann (Harvard)

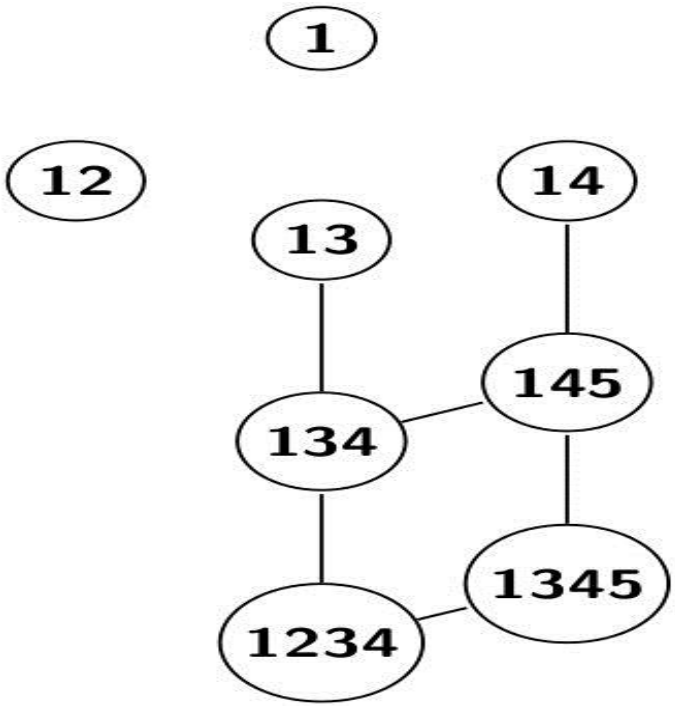


The Complex Taxonomy of Products

Time evolution

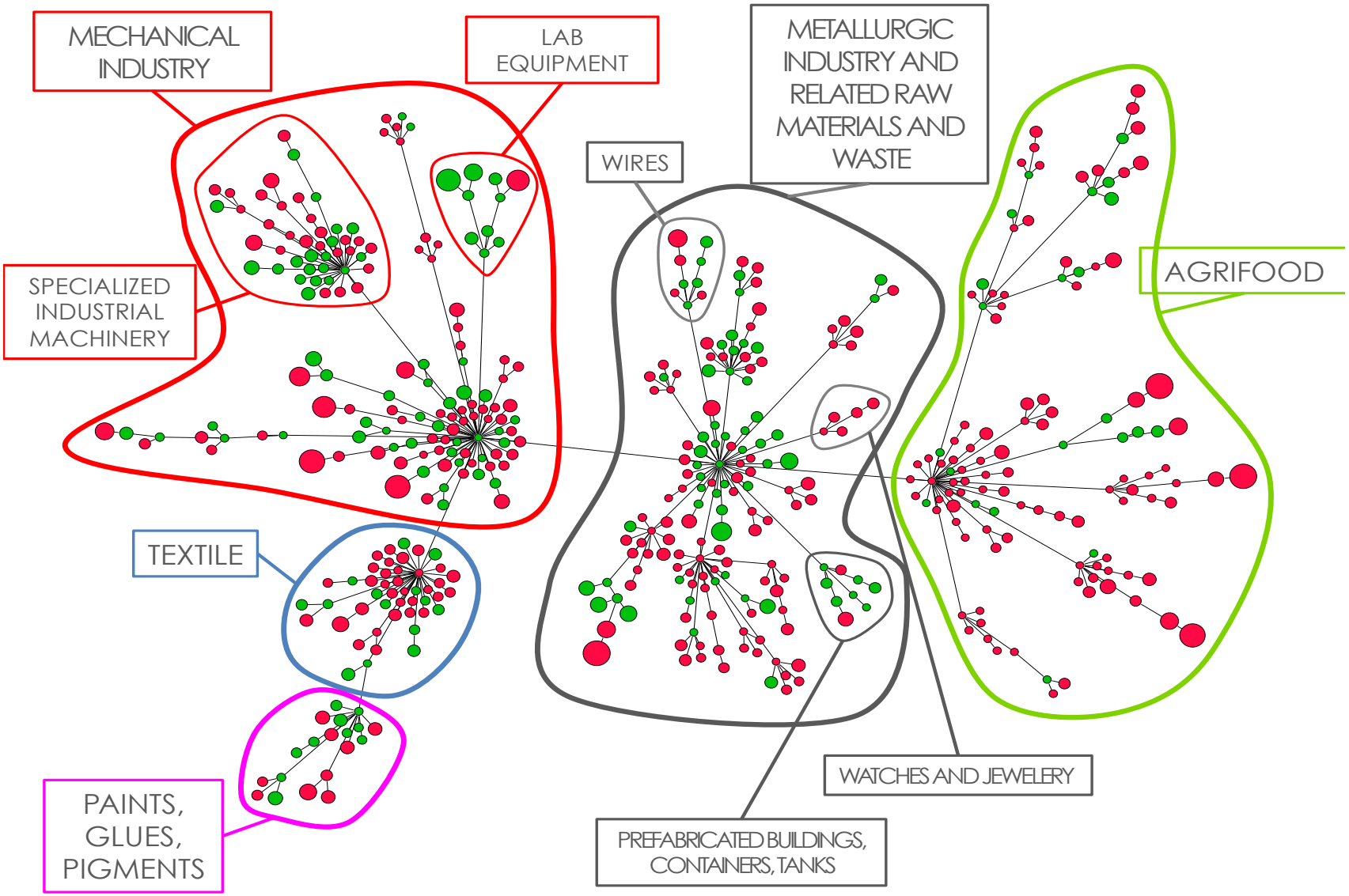


Vicinity

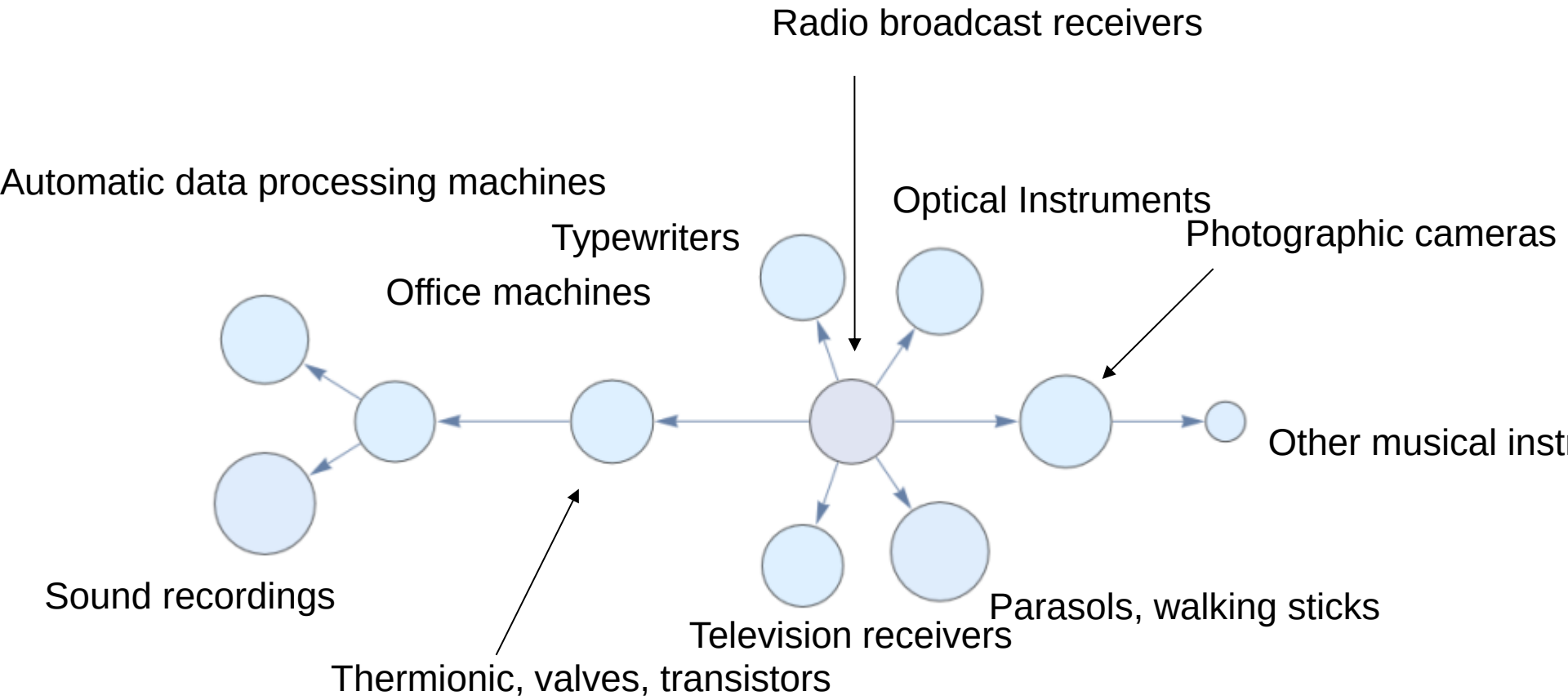


- Definition of products in terms of the needed capabilities
- Hierarchical, tree-like structure
- Directed vs undirected edges (time evolution)
- Possibility to understand and forecast development

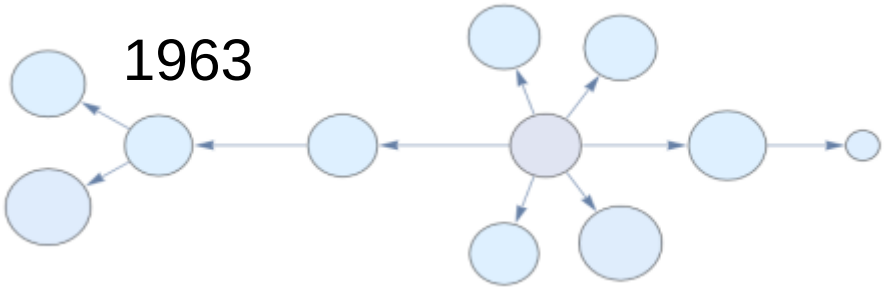
SWEDEN: PORTION OF THE PRODUCT SPACE



Example: SK 81 detailed products



Diffusion of South Korea 1963-2000



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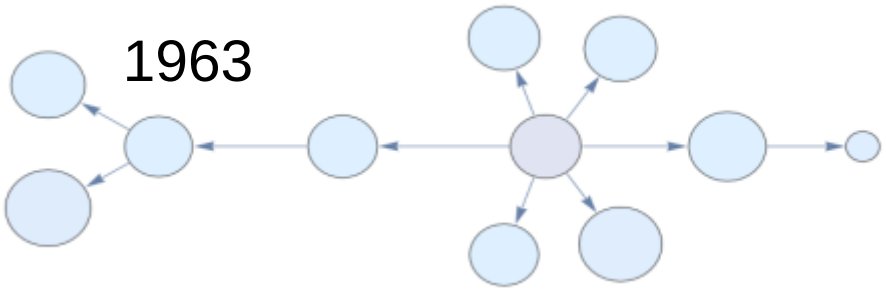

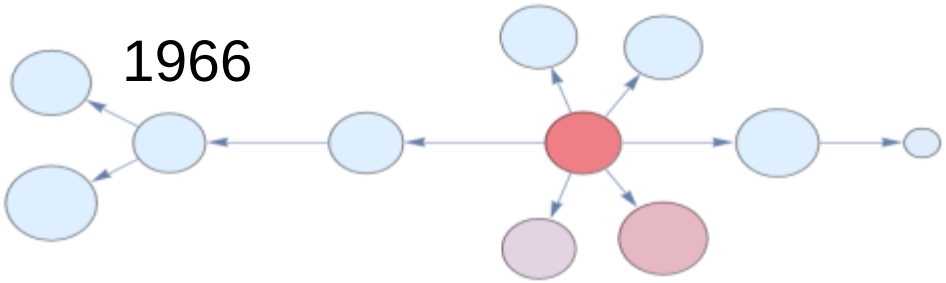

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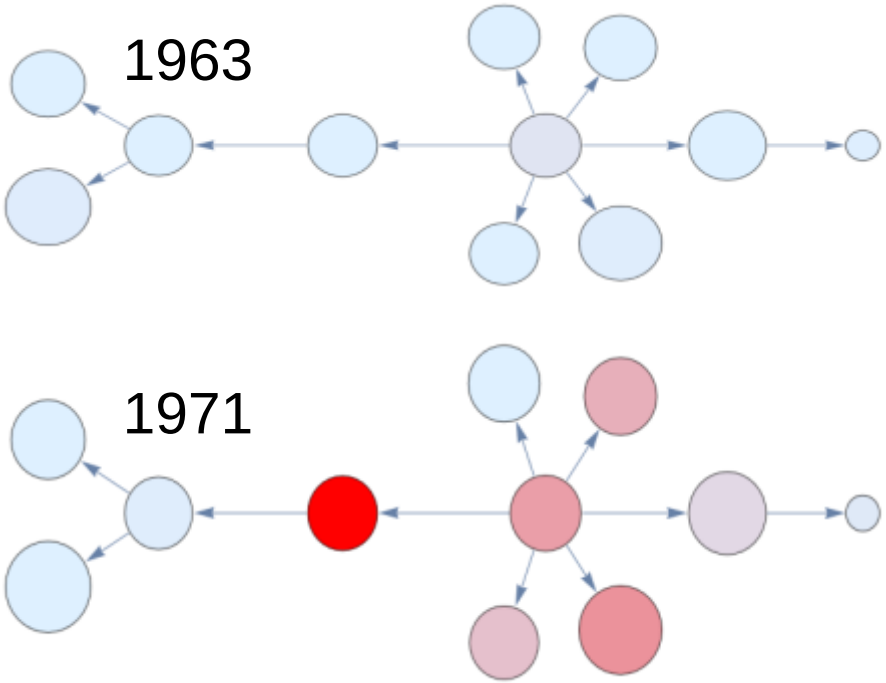

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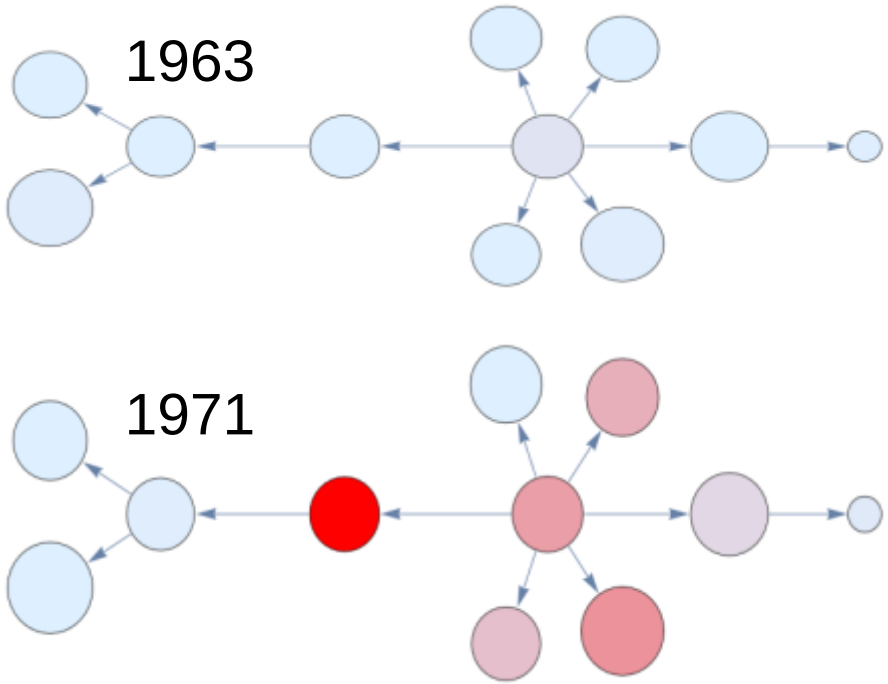
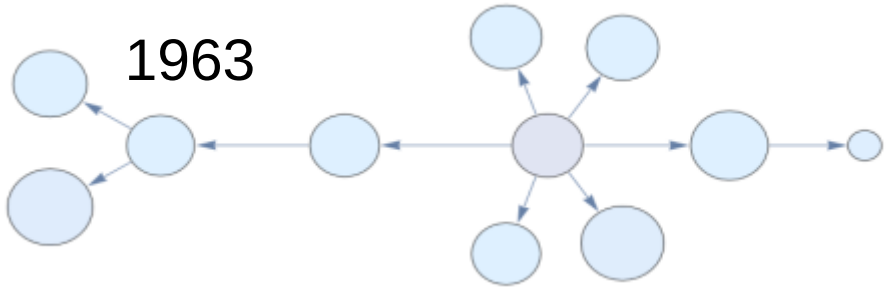
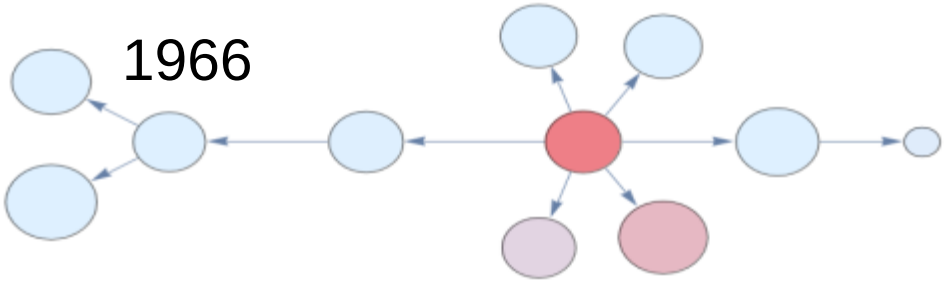
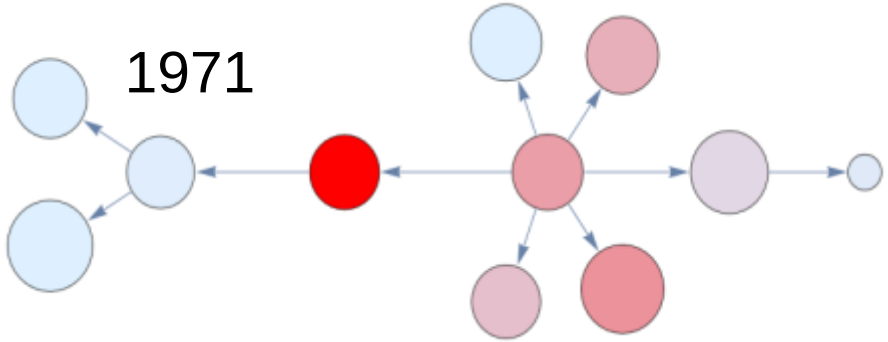
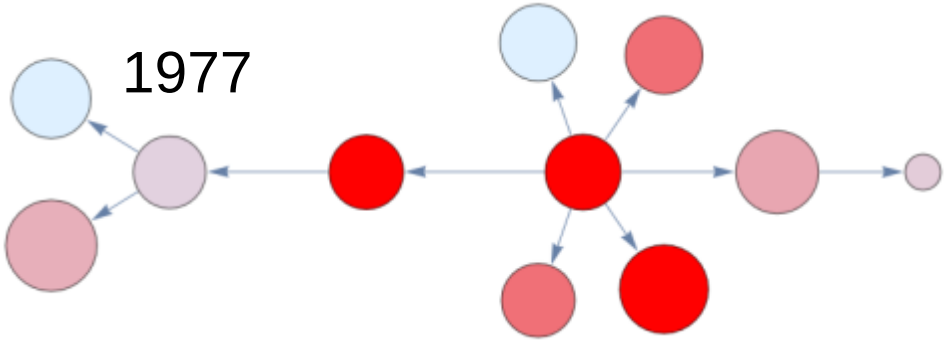


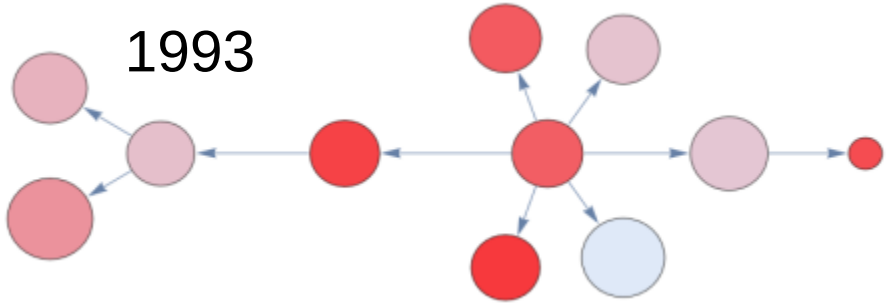
Example: Diffusion of SK 1963-2000



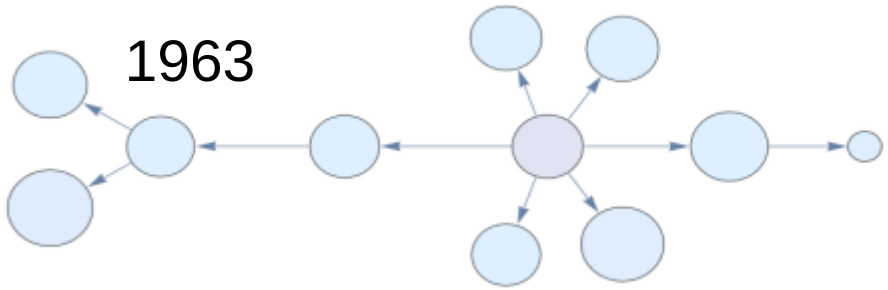


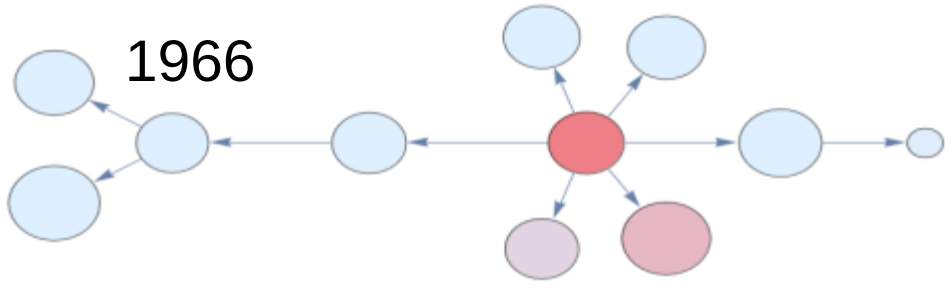


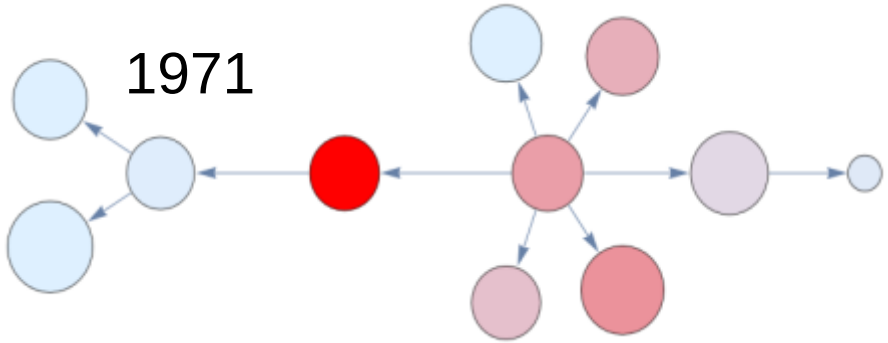


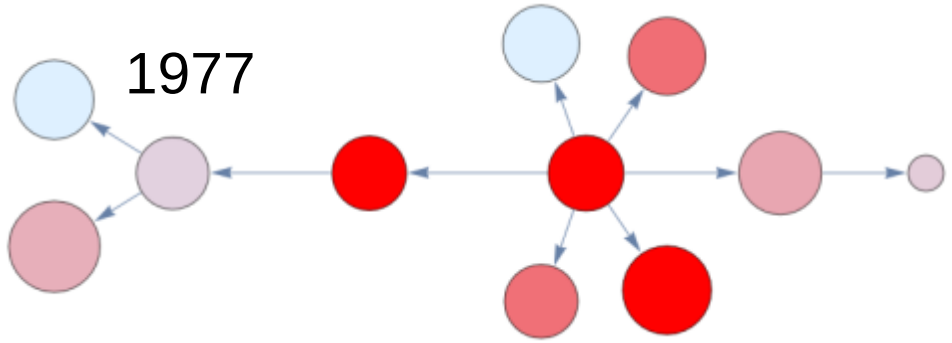


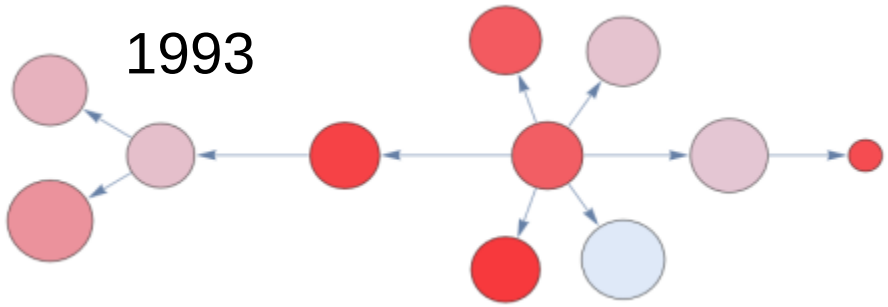
Example: Diffusion of SK 1963-2000

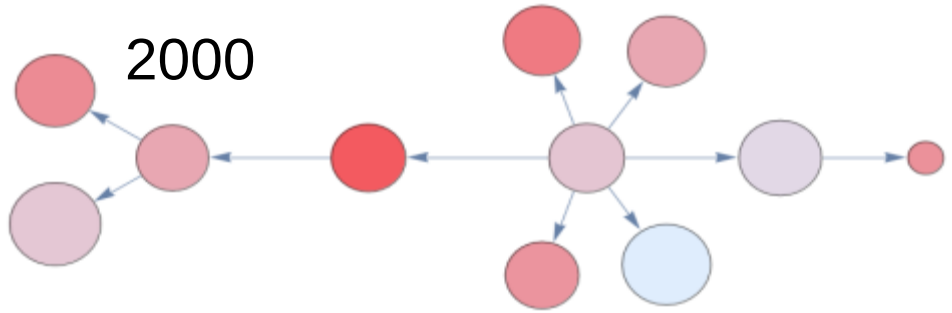




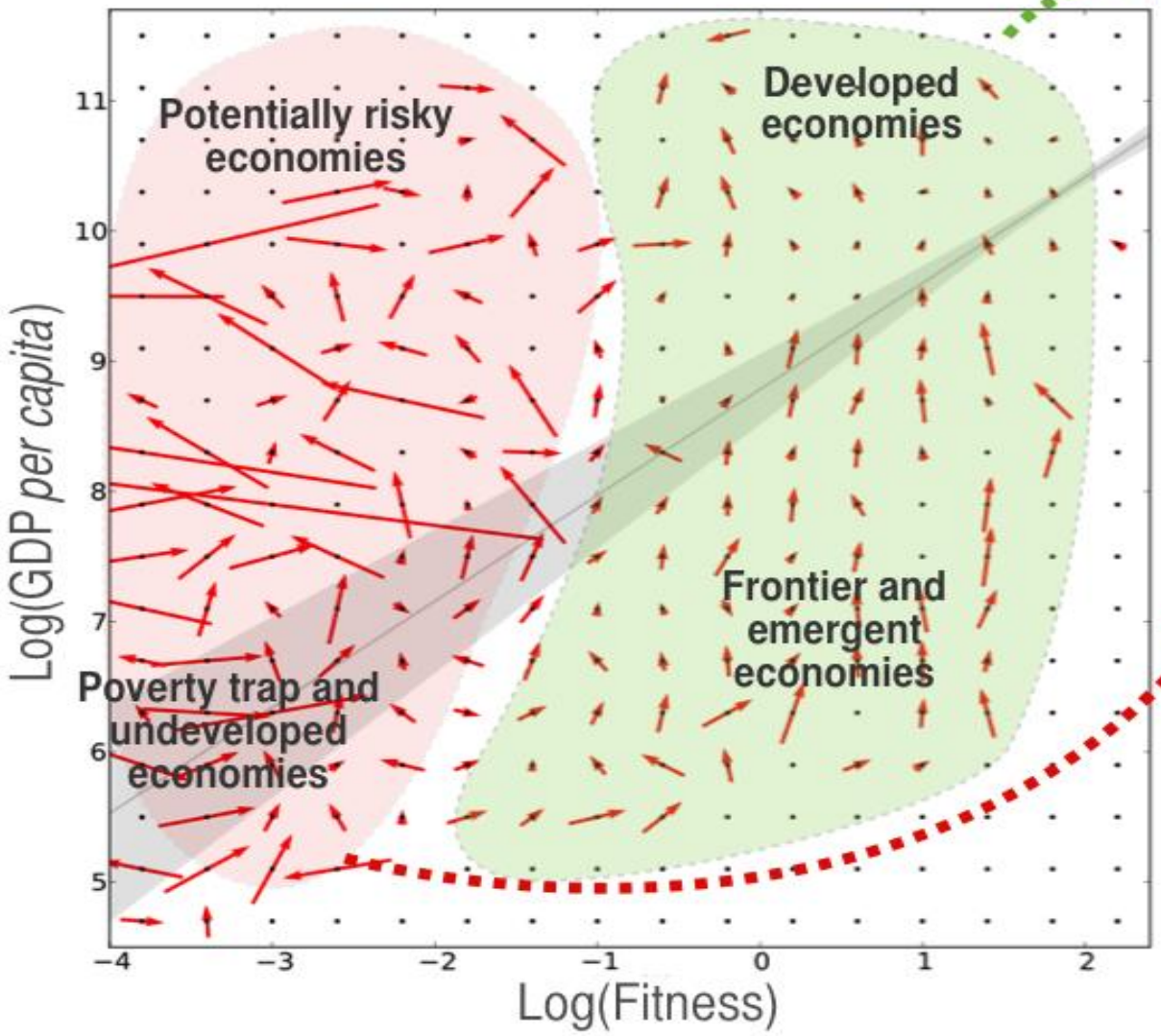








New Fundamental Economic Theory - New information - Finance



Laminar regime

Fitness is the relevant and driving variable for the economic dynamics in this regime

high predictability

Chaotic regime

Dynamics is ruled by several other exogenous factors competing with Fitness

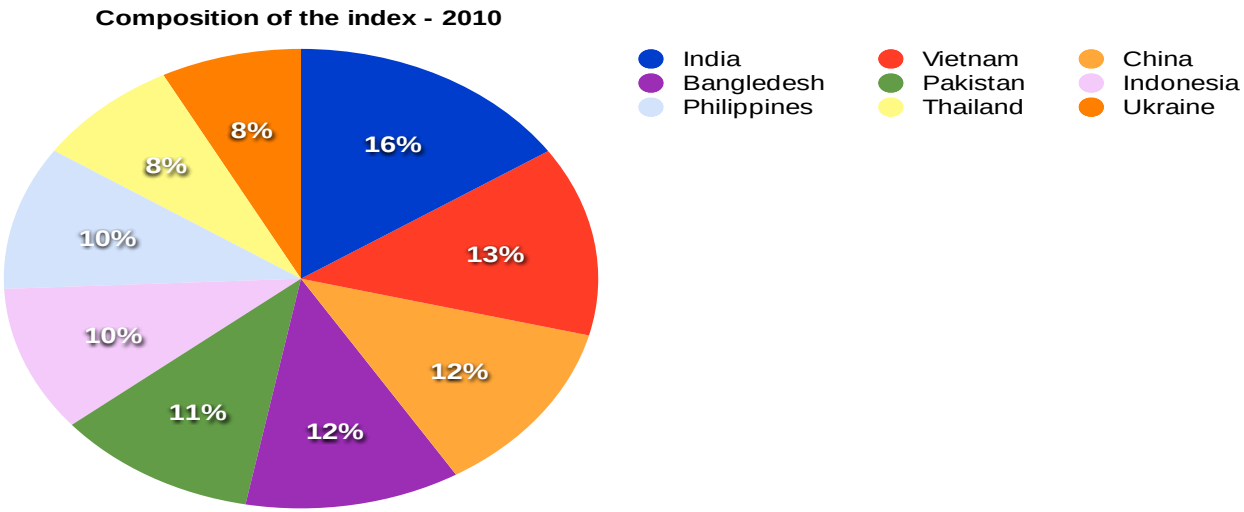
low predictability

OPTIMAL PORTFOLIO FOR GROWTH: GDP, STOCK INDEX, DEBT …

A fundamentally based Index: COMPLEXITY INDEX

(NB: Non market Cap)

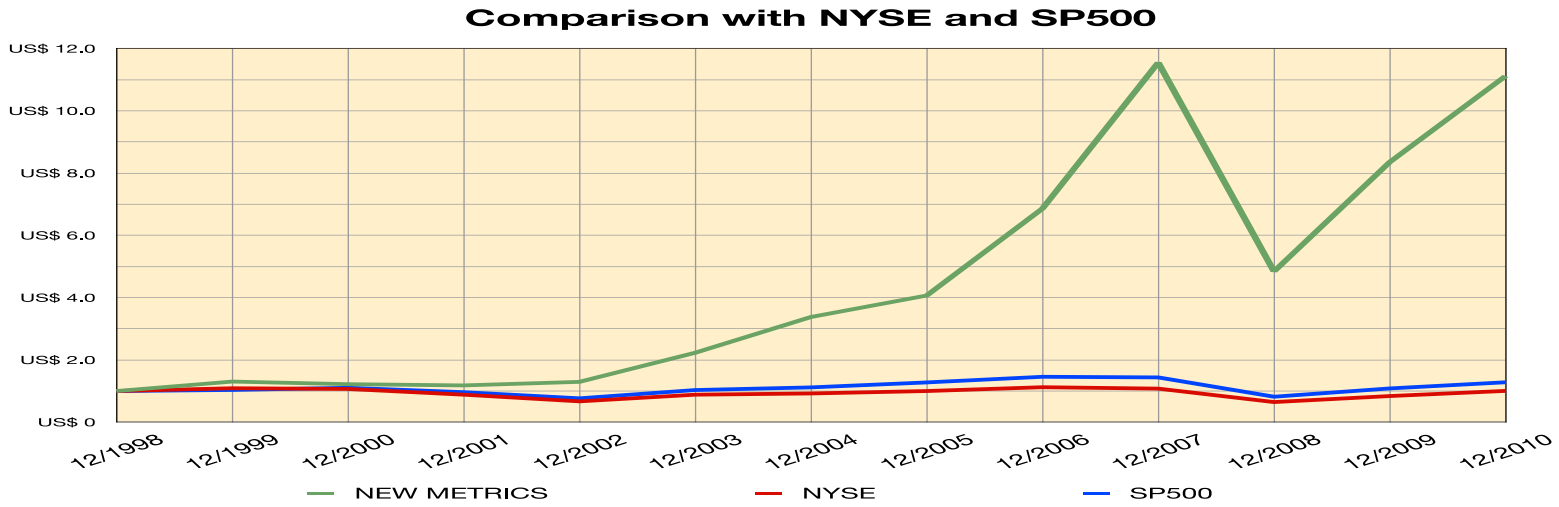
Composition of the Index	31-12-09 to 31-12-10
Country	Percentage
India	15.63
Vietnam	13.34
China	12.29
Bangledesh	11.73
Pakistan	11.03
Indonesia	10.27
Philippines	10.11
Thailand	7.93
Ukraine	7.67

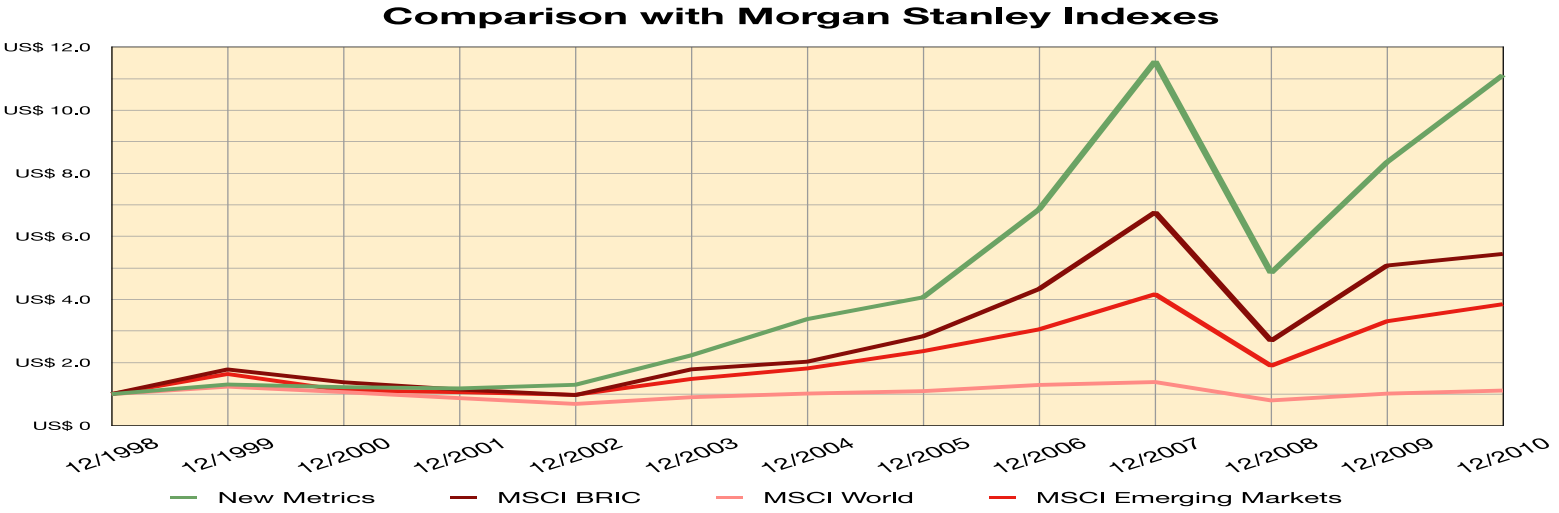


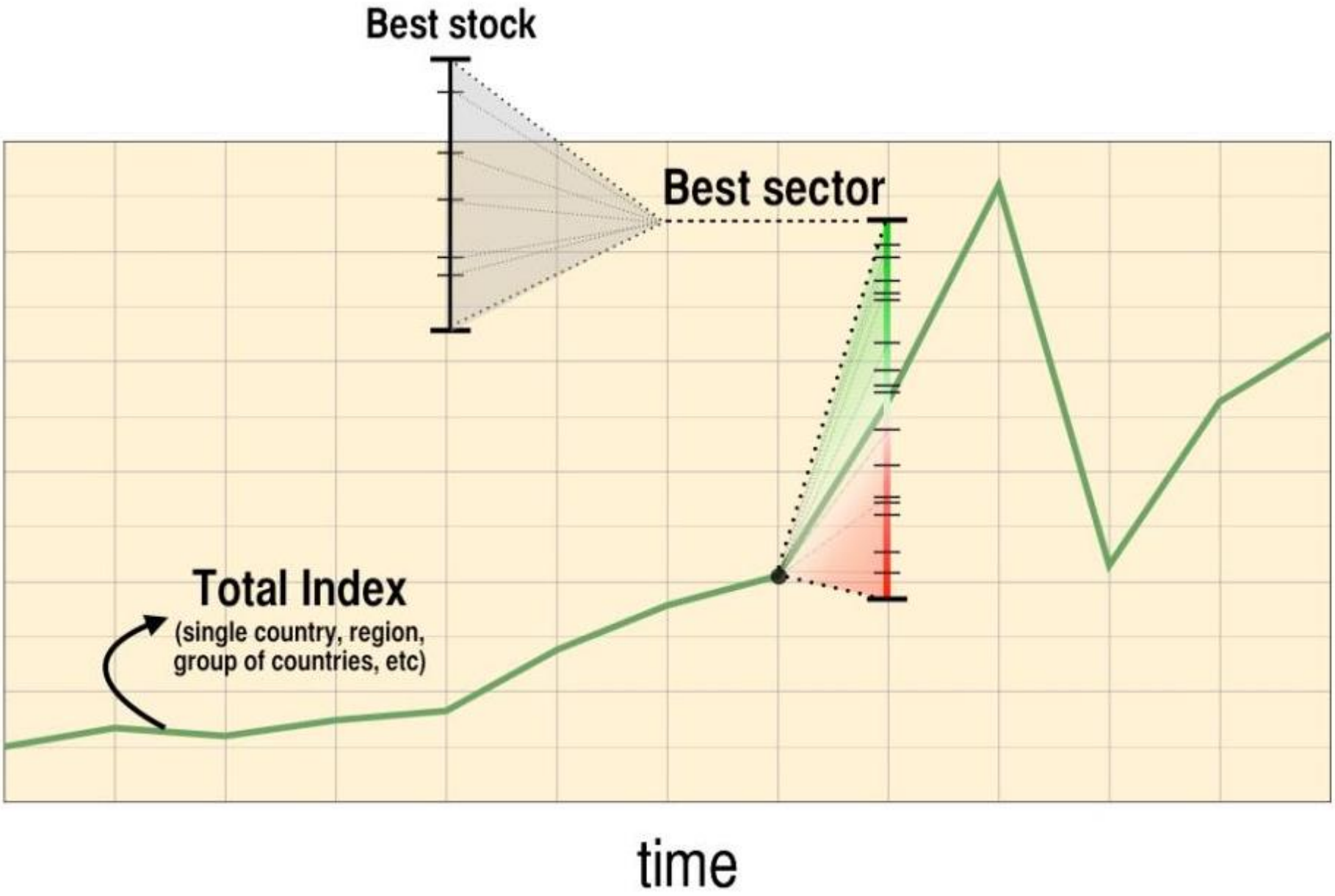
OPTIMAL PORTFOLIO FOR GROWTH: GDP, STOCK INDEX, DEBT …

A fundamentally based Index: **COMPLEXITY INDEX**

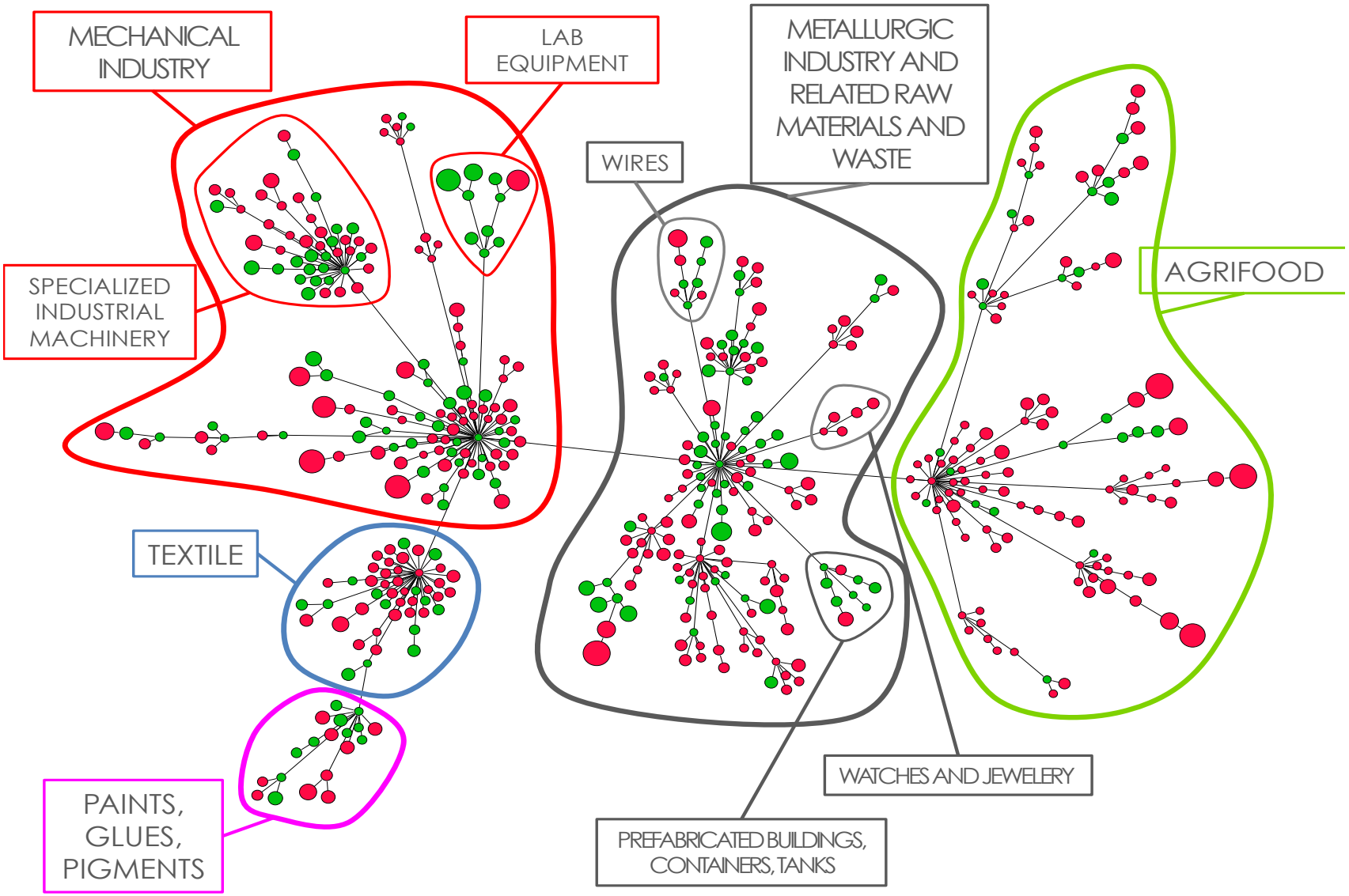
(NB: Non market Cap)






Best stock
Best sector
Total Index
(single country, region,
group of countries, etc)
time

SWEDEN: PORTION OF THE PRODUCT SPACE

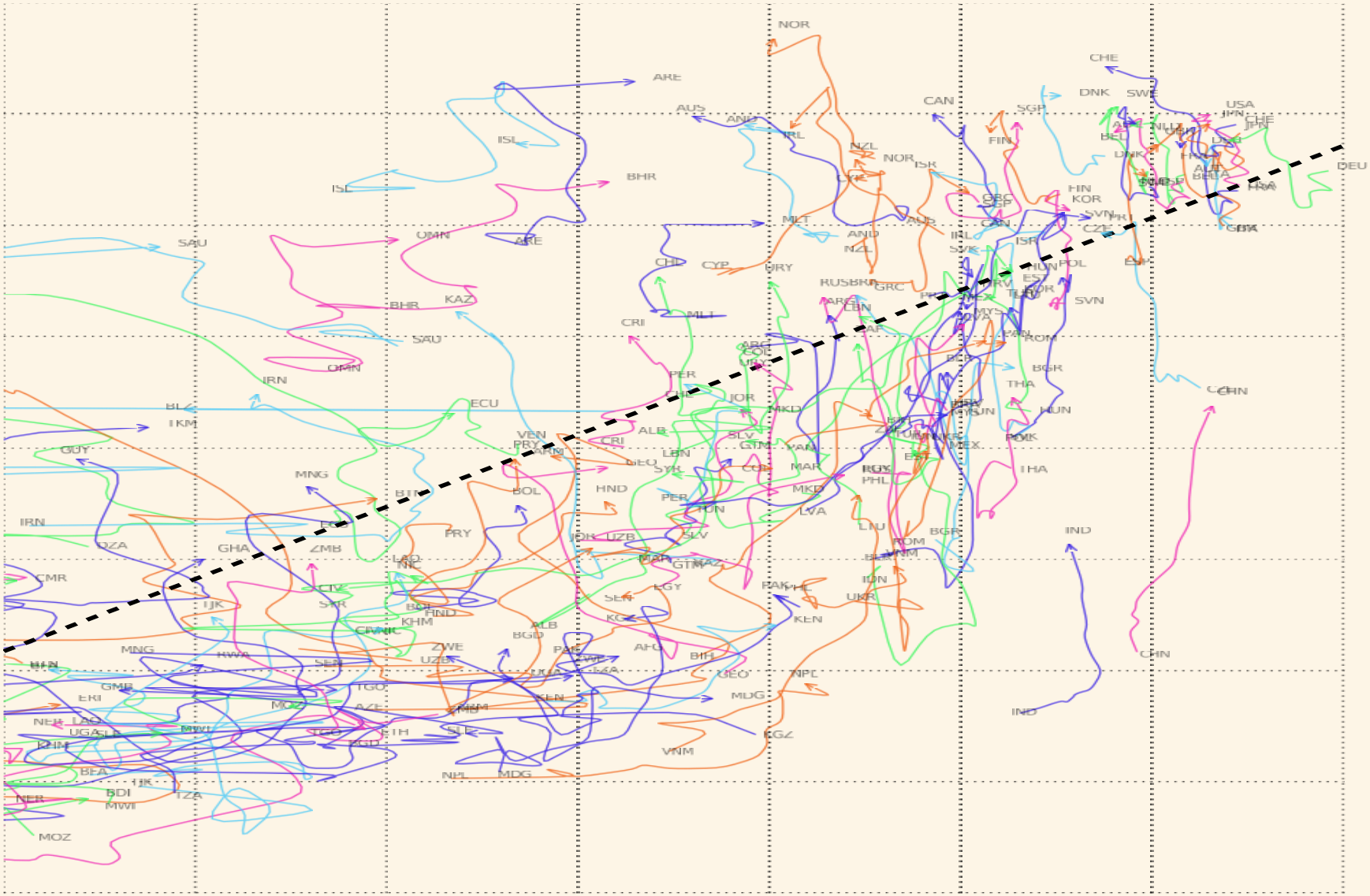


New directions 2014

- Extended database from 1963: 60 years instead of 15.
- Analysis of Dynamics and predictability test much improved
- How to get out of the poverty trap
- Evolution of Products Complexity
- Economic Cycles etc

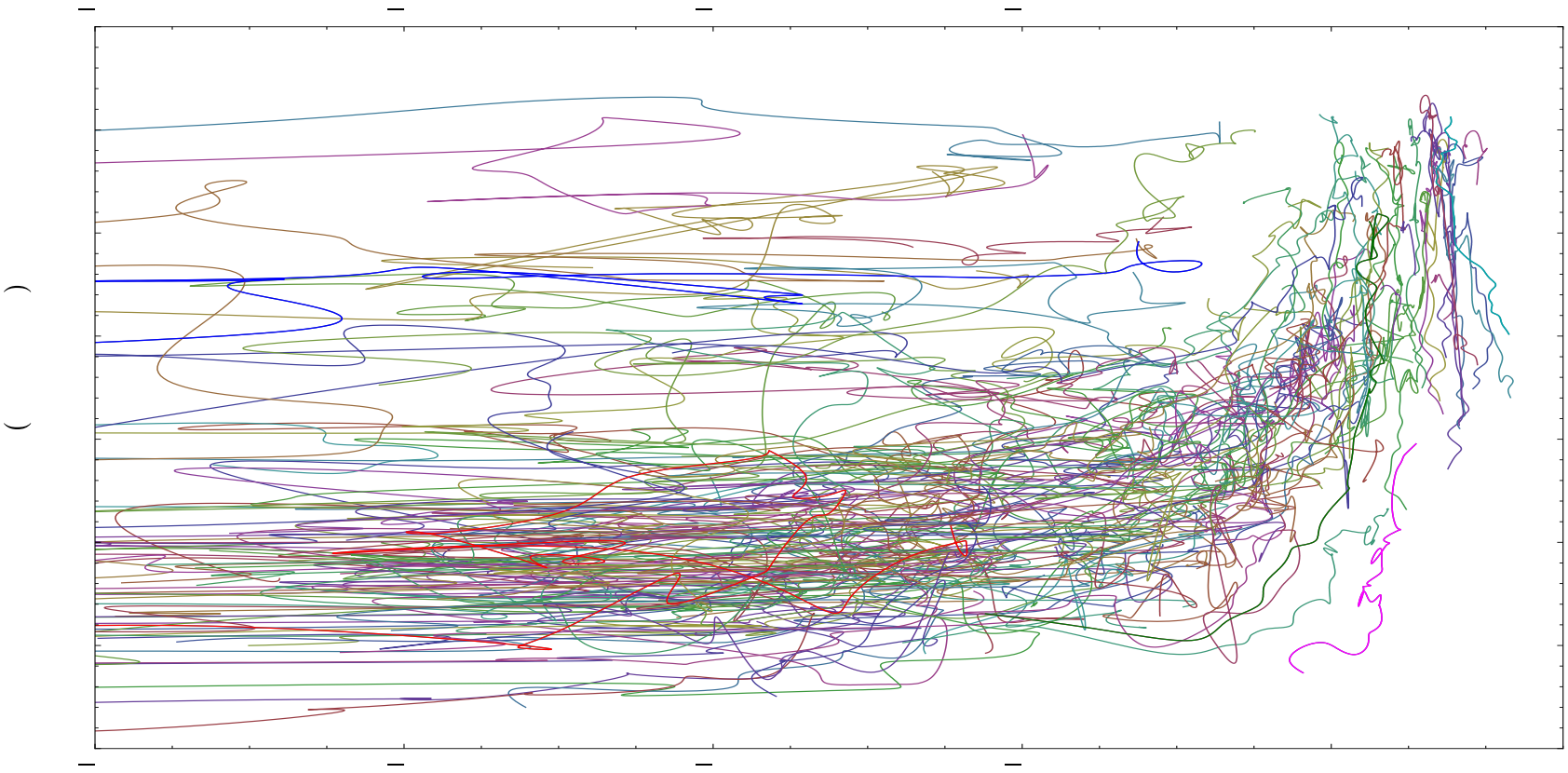
- Systematic construction of the Product Space
- Analysis of Sectors. Focus on countries with an appreciable hidden potential, look at emerging sectors (before RCA) and look at their position in Product Space
- Invasion of the Product Space in succesful cases of industrialization

ECONOMIC DYNAMICS IS HETEROGENEOUS



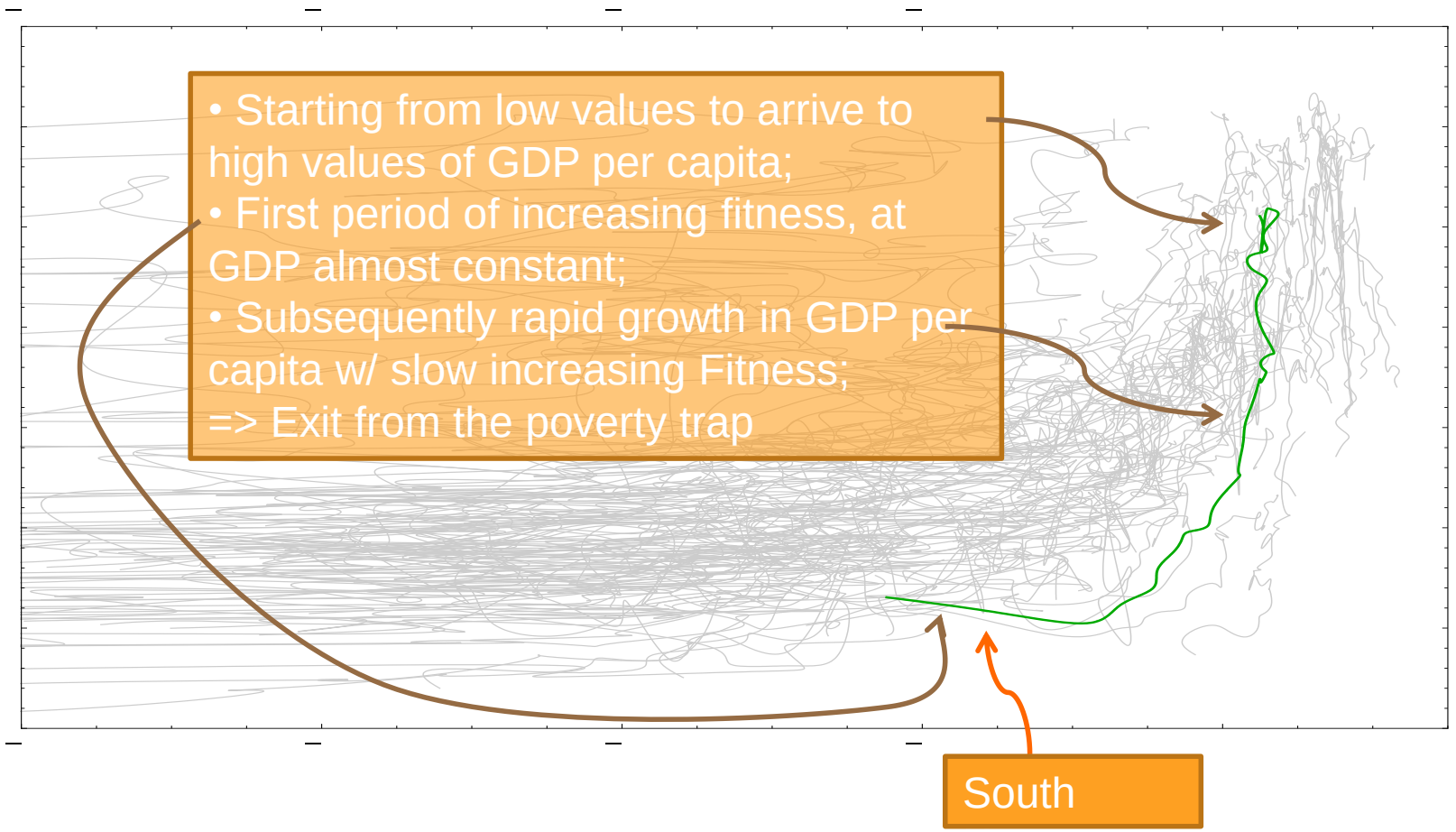
Poverty Trap 1 1963 - 2000

Comparing Fitness and GDP per capita permits to obtain more



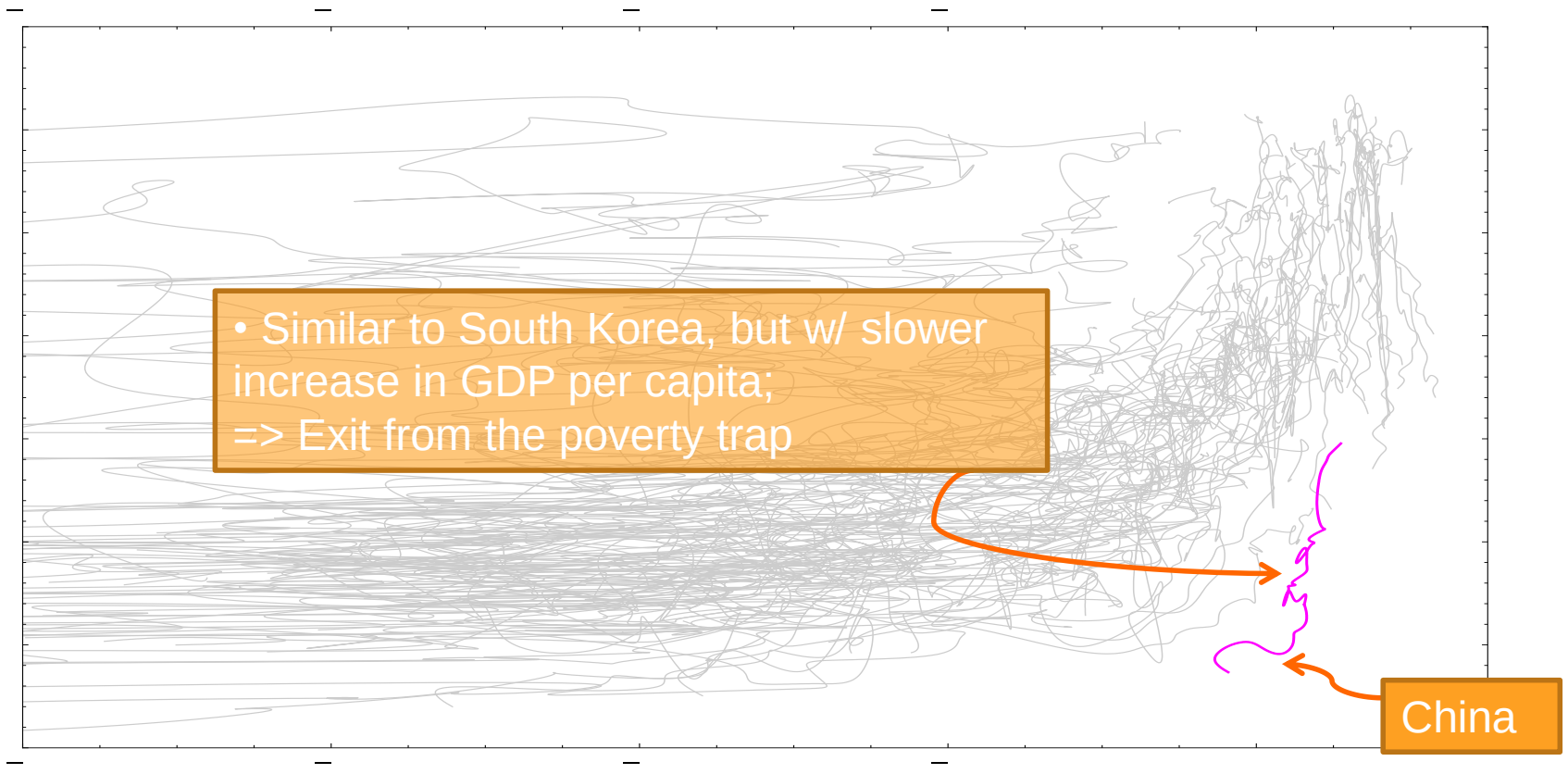
South Korea Evolution

Some examples of different regimes… 1963 - 2000



China Evolution

Some examples of different regimes… 1963 - 2000



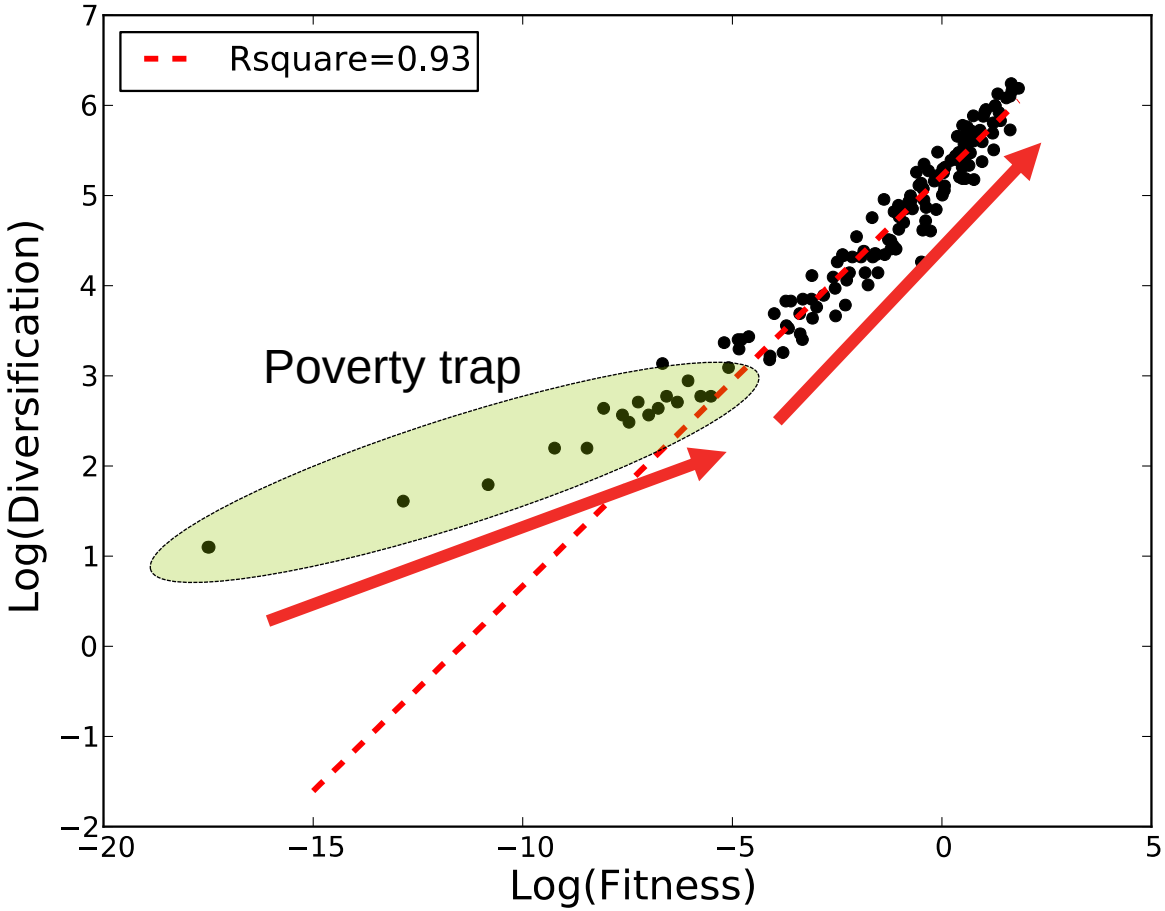
MICRO ORIGIN OF POVERTY TRAP?

No longer exponential relationship btw *diversification* and *complexity* (i.e. *Log(Fitness)*)

2010

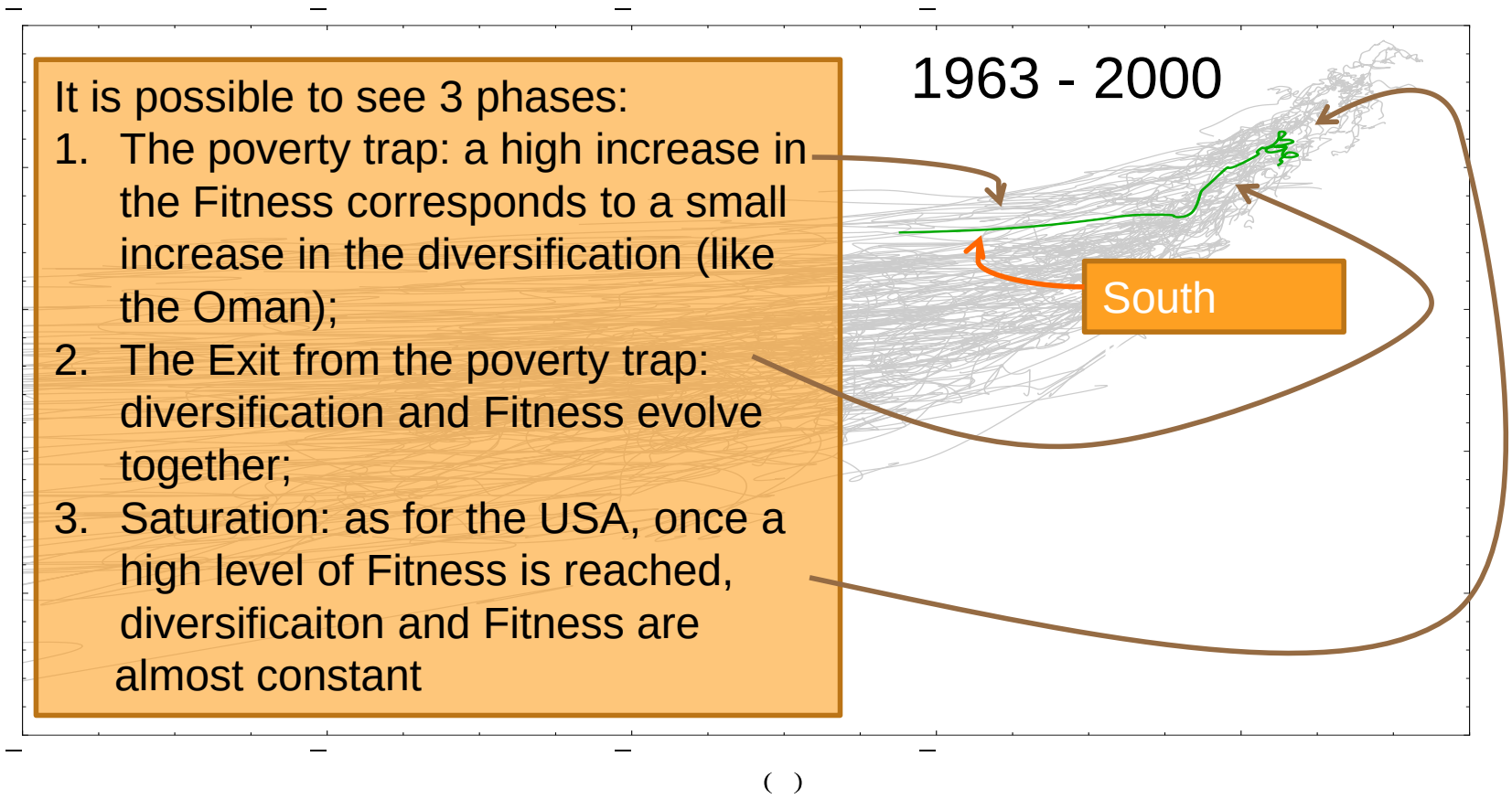
Here we see the static picture of 2010 and the points correspond to different countries.

Next we are going to see the time evolution of a single country:
red arrows



South Korea Evolution 2

Time evolution of South Korea in the diversification-fitness diagram



It is possible to see 3 phases:

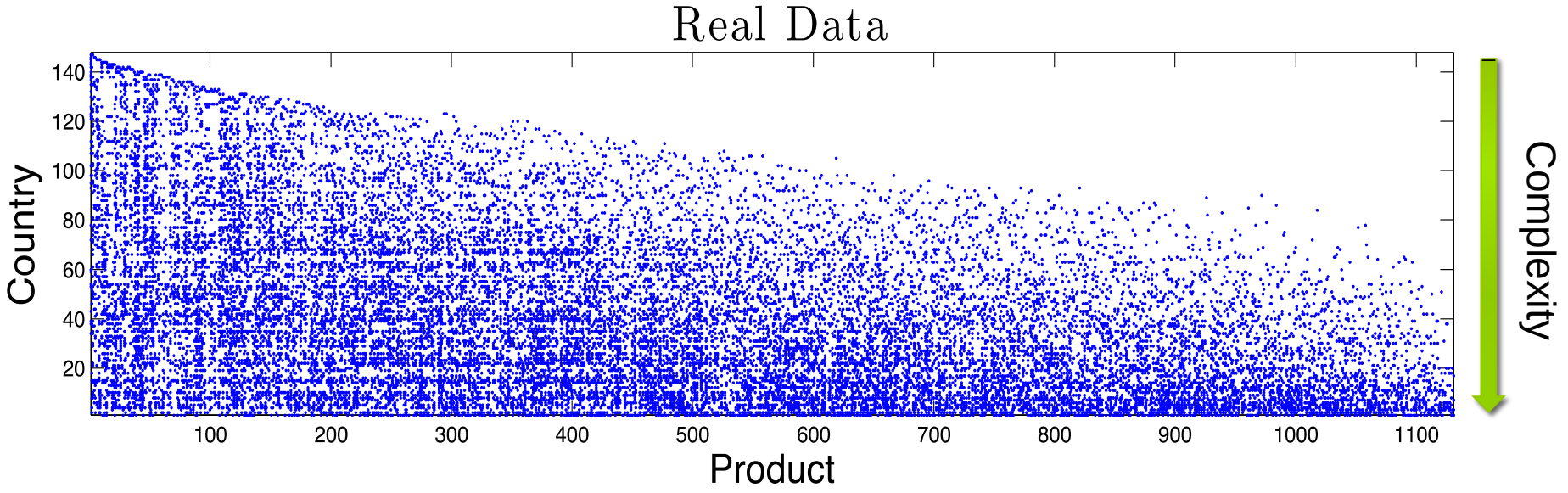
1. The poverty trap: a high increase in the Fitness corresponds to a small increase in the diversification (like the Oman);
2. The Exit from the poverty trap: diversification and Fitness evolve together;
3. Saturation: as for the USA, once a high level of Fitness is reached, diversificaiton and Fitness are almost constant

Mcp Triangularity

Real World

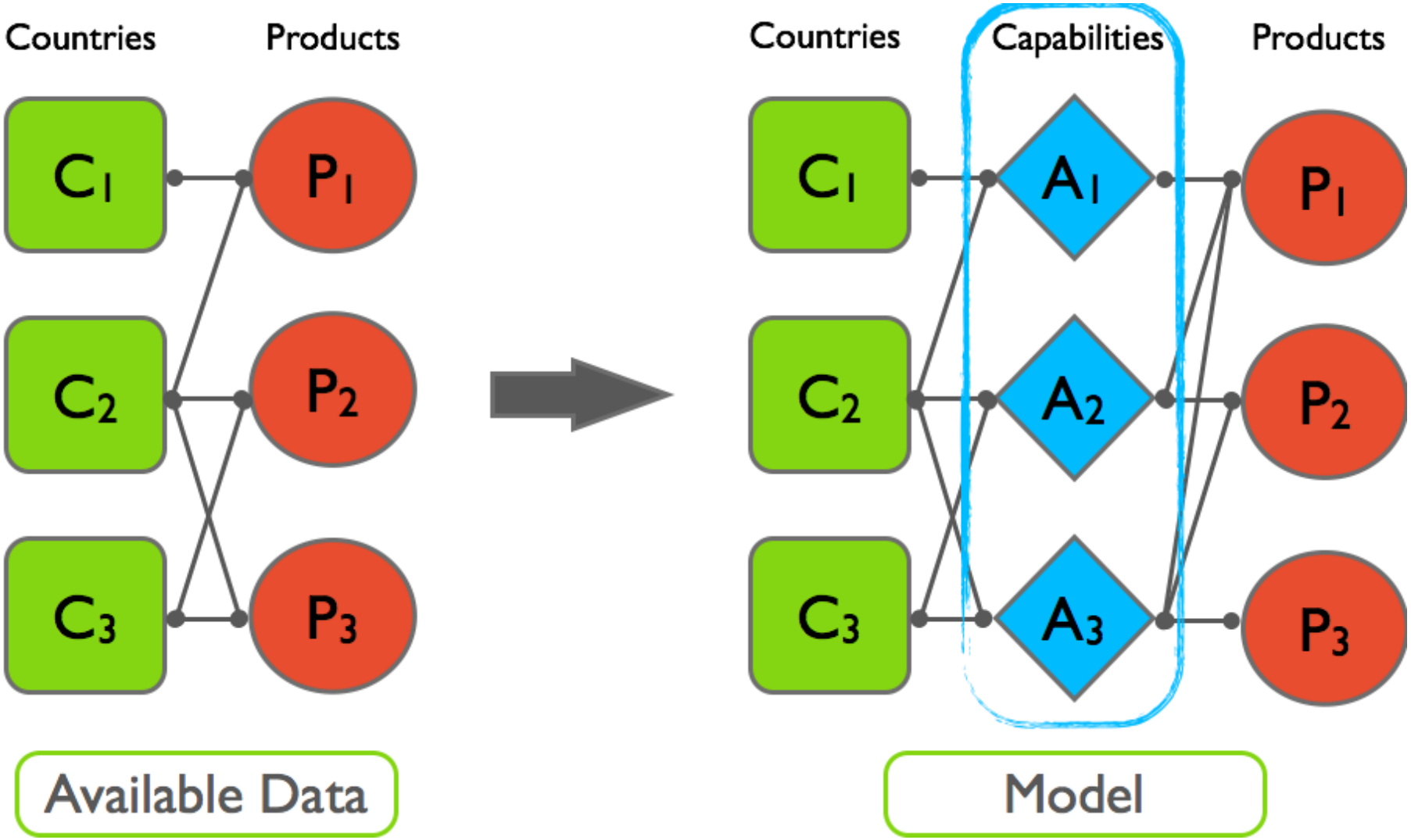
Binary matrix of exports

Triangular shape



The Building Blocks of Economic Complexity

C. Hidalgo (MIT), R. Hausmann (Harvard)



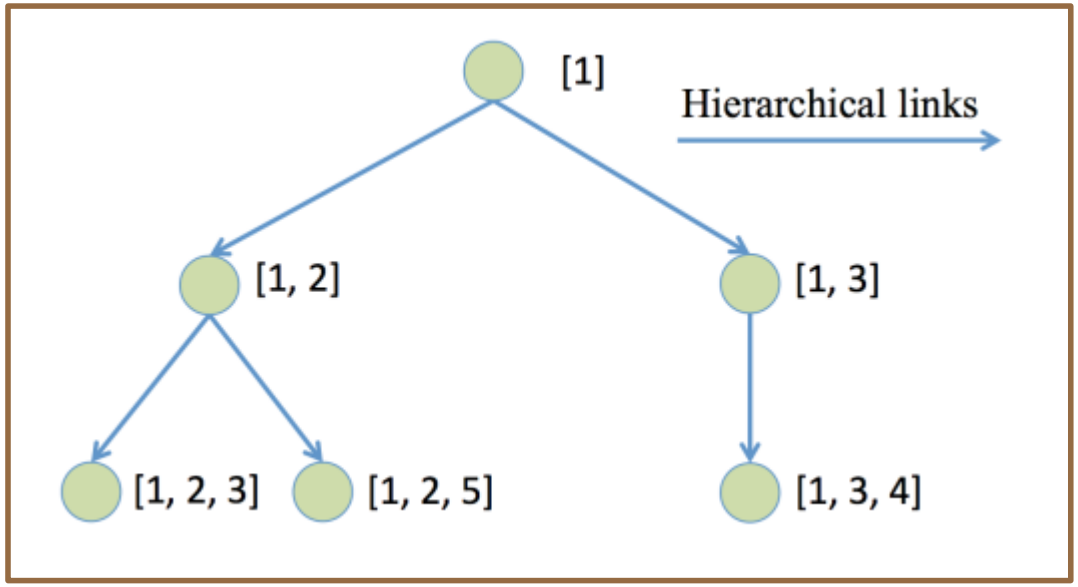
Introducing: A Probabilistic Model

1) Capabilites → randomly assigned → each country owns each capability with probability **α**

2) The probability of a capability to be needed by a certain product follows a Power Law (some capabilities are necessary for many products)

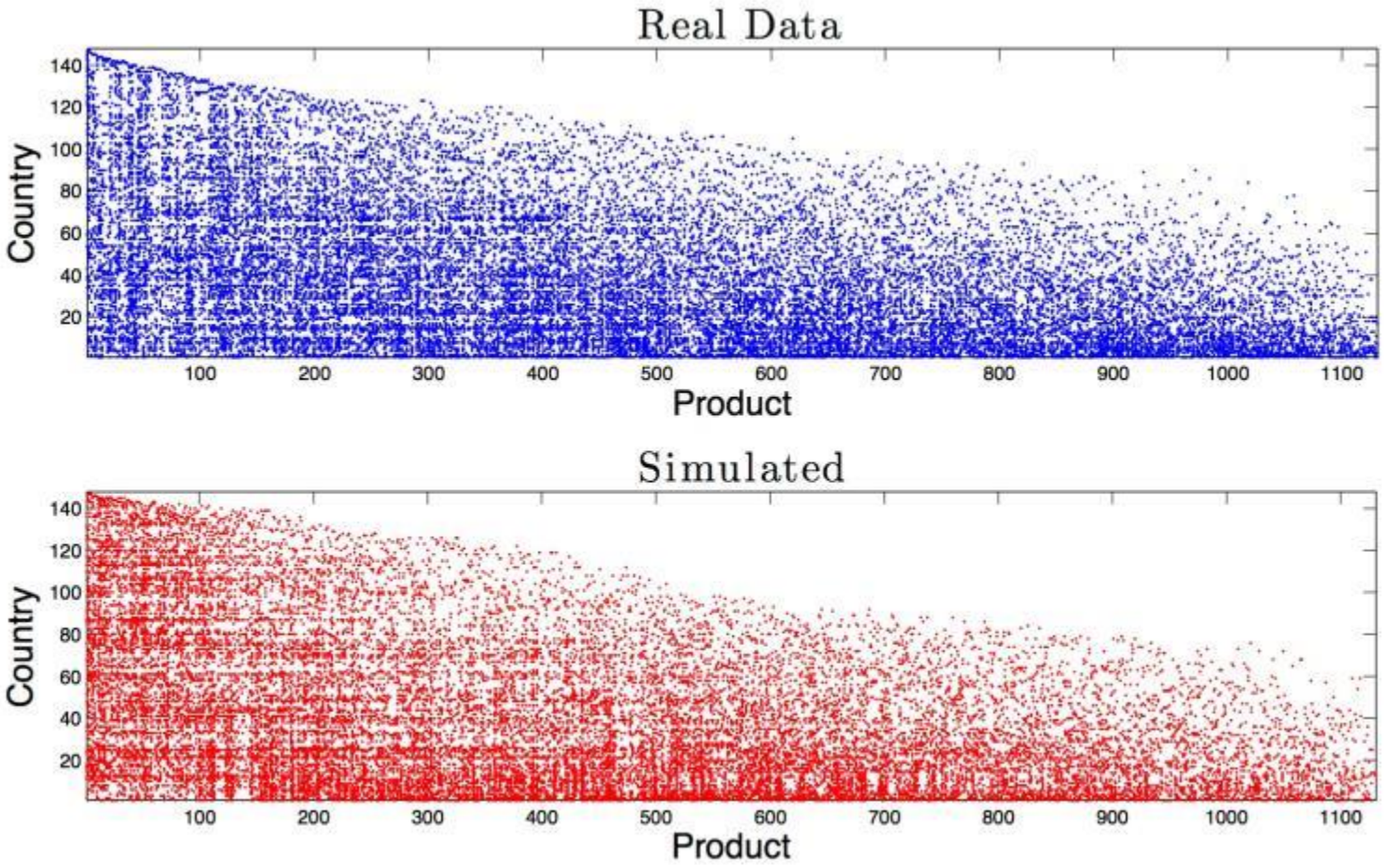
3) The number of capabilities needed to build a product is drawn by a uniform distribution.

Network Interpretation

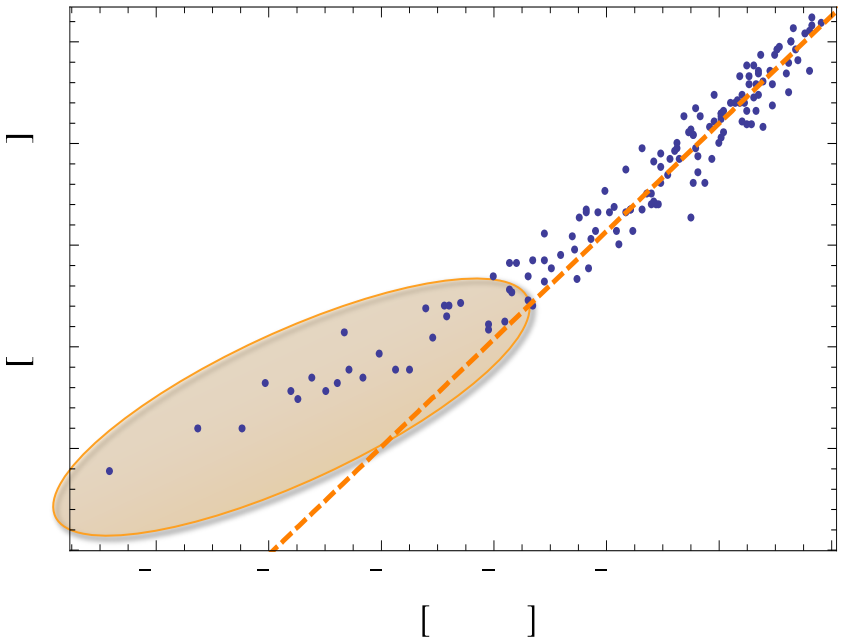


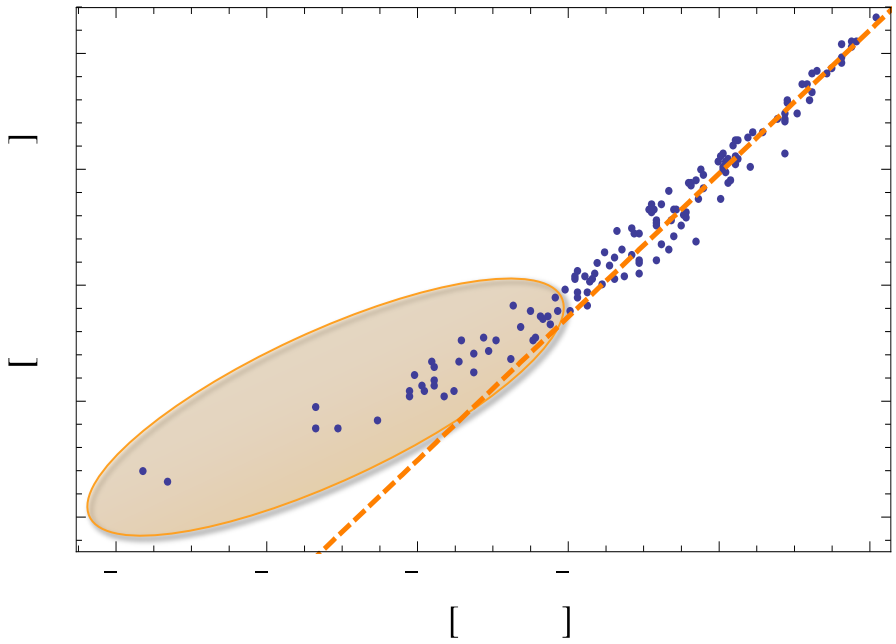
1. At each time step a new capability is introduced
2. The new capability defines a new product
3. A directed link is inserted from new product and

Main results



Poverty Trap

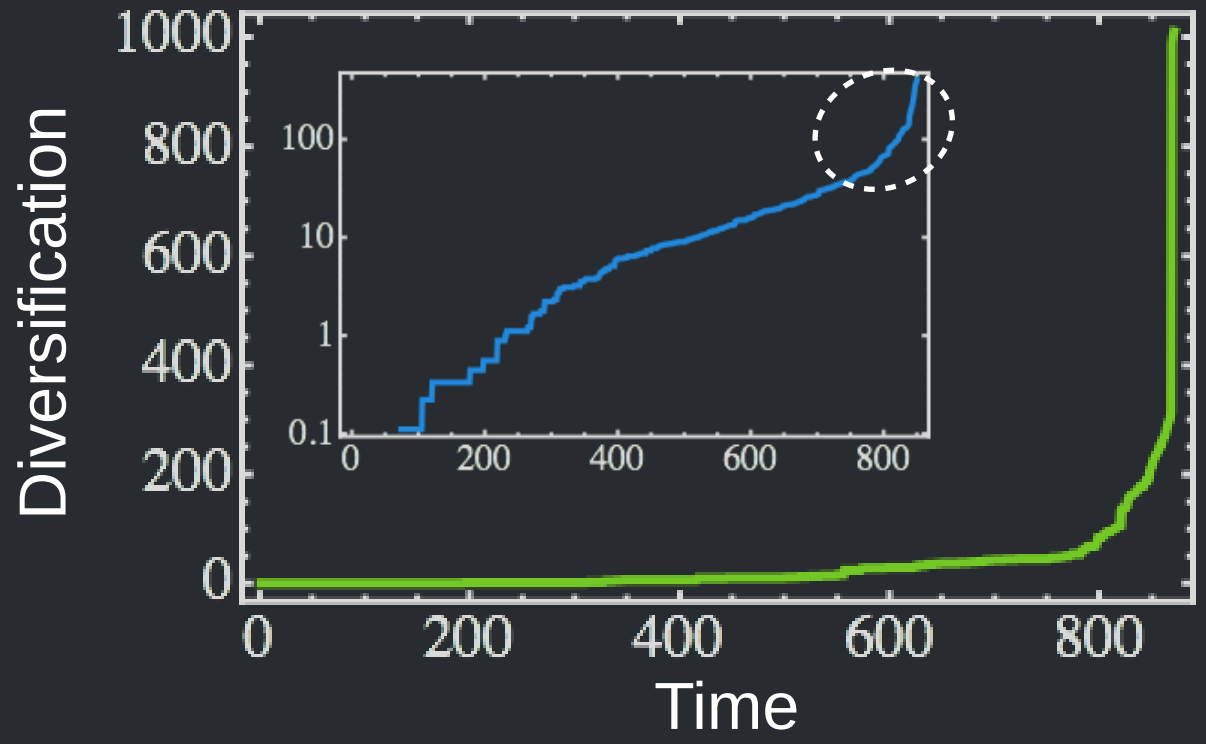




COUNTRY

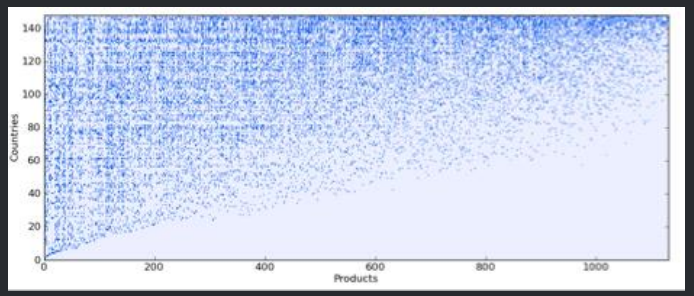
AT EACH TIME STEP WE ADD RANDOM CAPABILITIES PROPORTIONALLY TO REACHED DIVERSIFICATION AND COMPUTE THE NEW DIVERSIFICATION

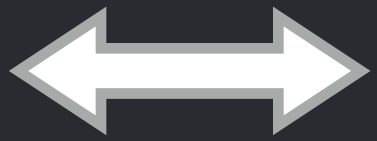
Superexponential growth



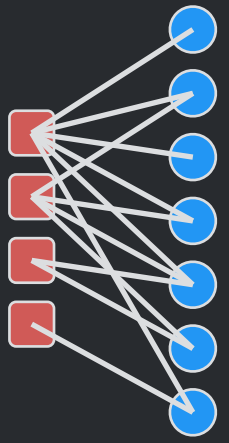
These concepts are general exist in ecology too

Economics

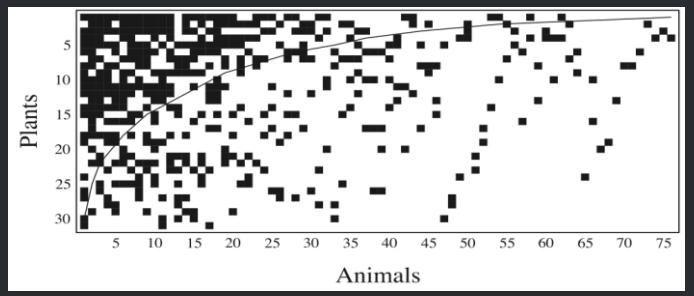




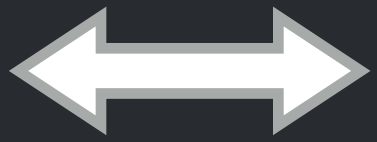
Countries Products



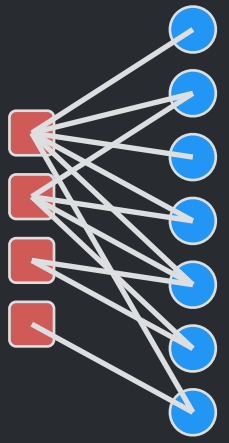
Ecology



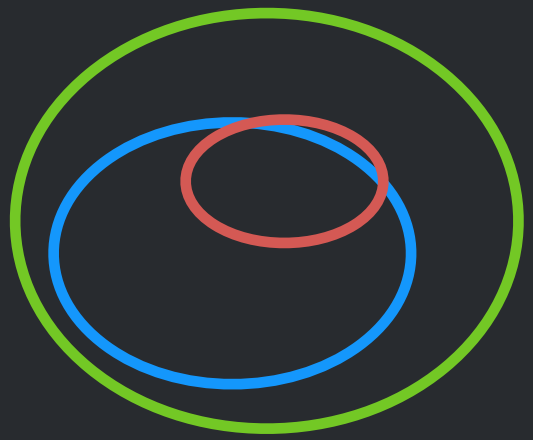
J. Bascompte et al. PNAS (2003)



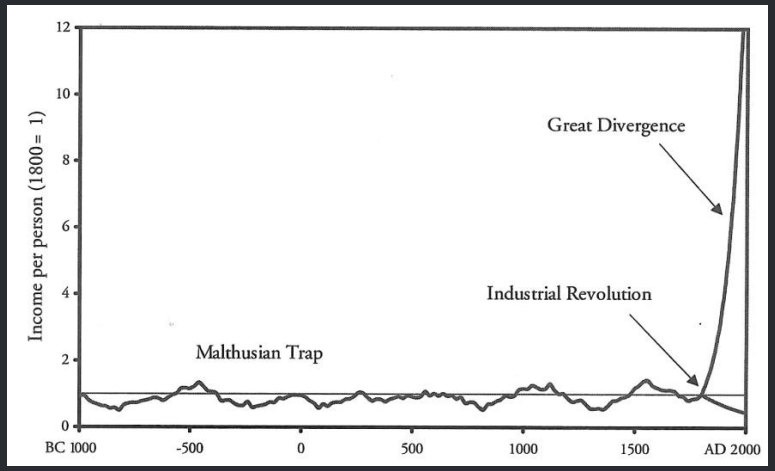
Plants Pollinators



1. Nestedness

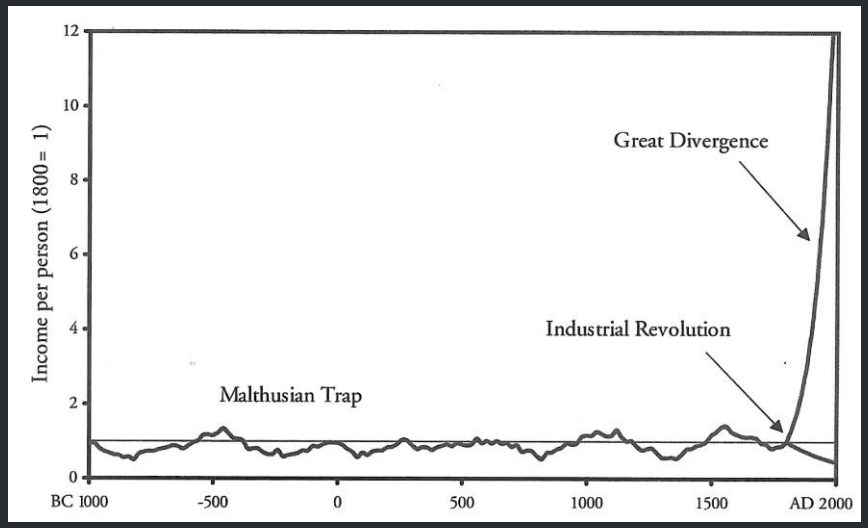


2. Poverty Traps



ECONOMIC COMPLEXITY MODEL

Economics

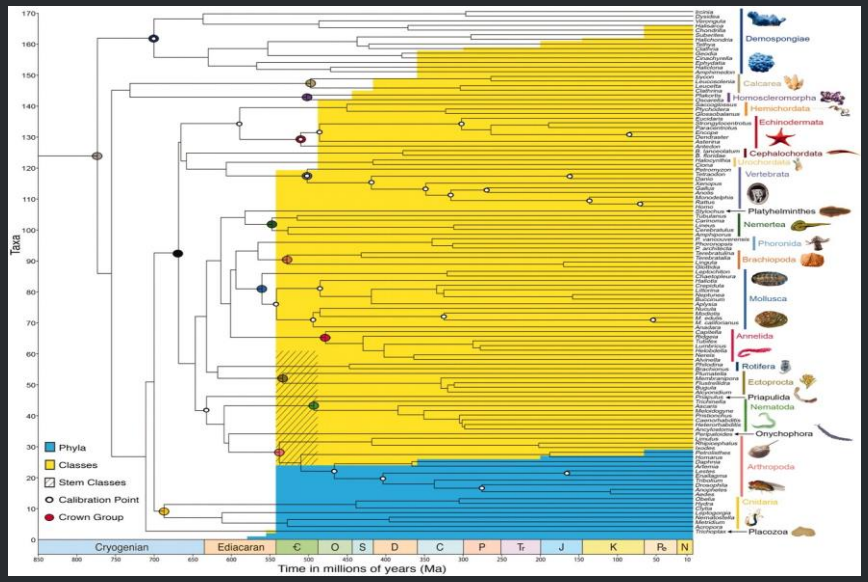


Great divergence
sudden increase in income

but also in

PRODUCTS' DIVERSITY

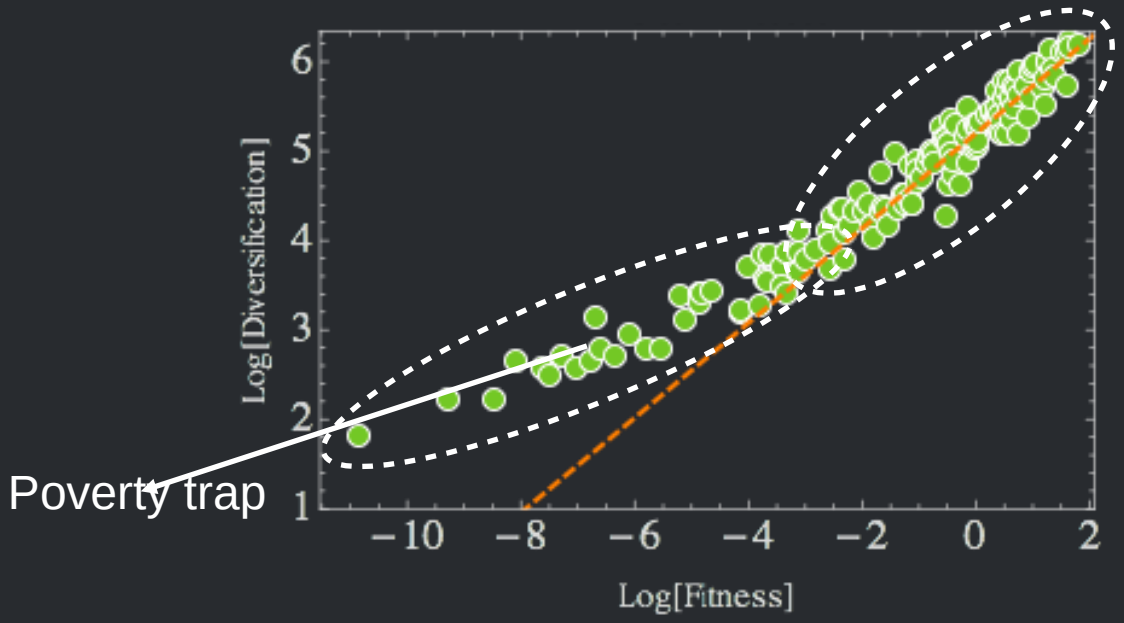
Ecology



Cambrian Explosion
"sudden" increase in

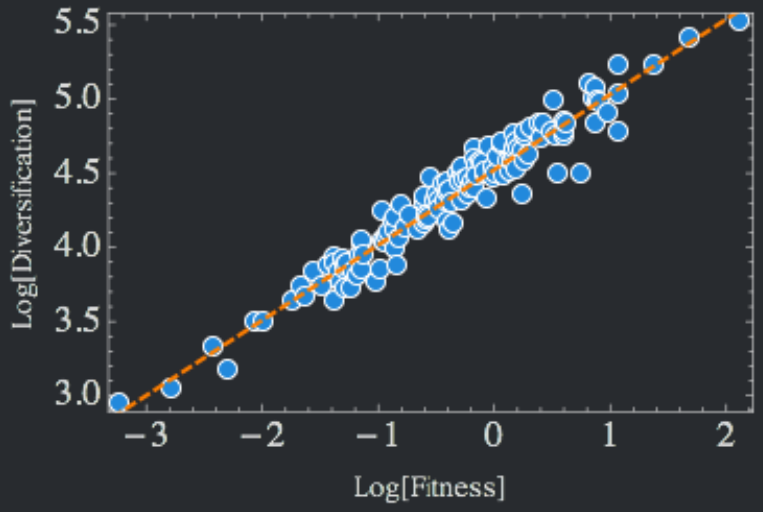
BIODIVERSITY

Results: Poverty Traps

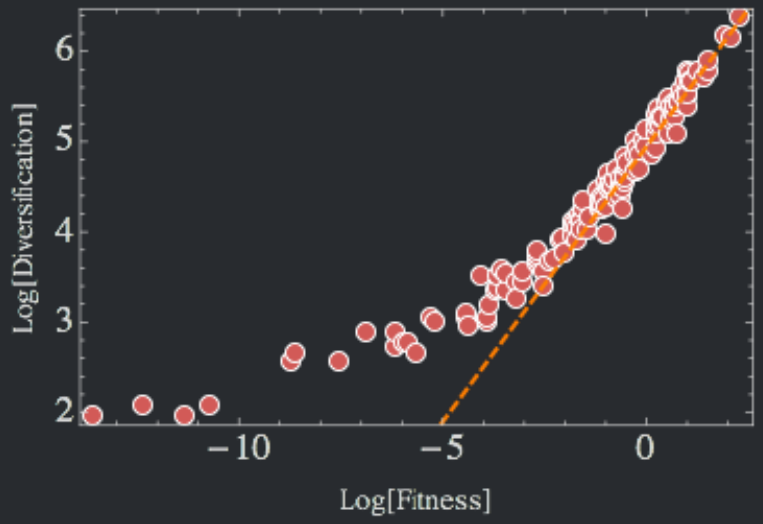


Real Data

Exponential usefulness



Power Law usefulness



Growth Decomposition

.

Is Growth of Countries an Endogeneous or Exogeneous Process?

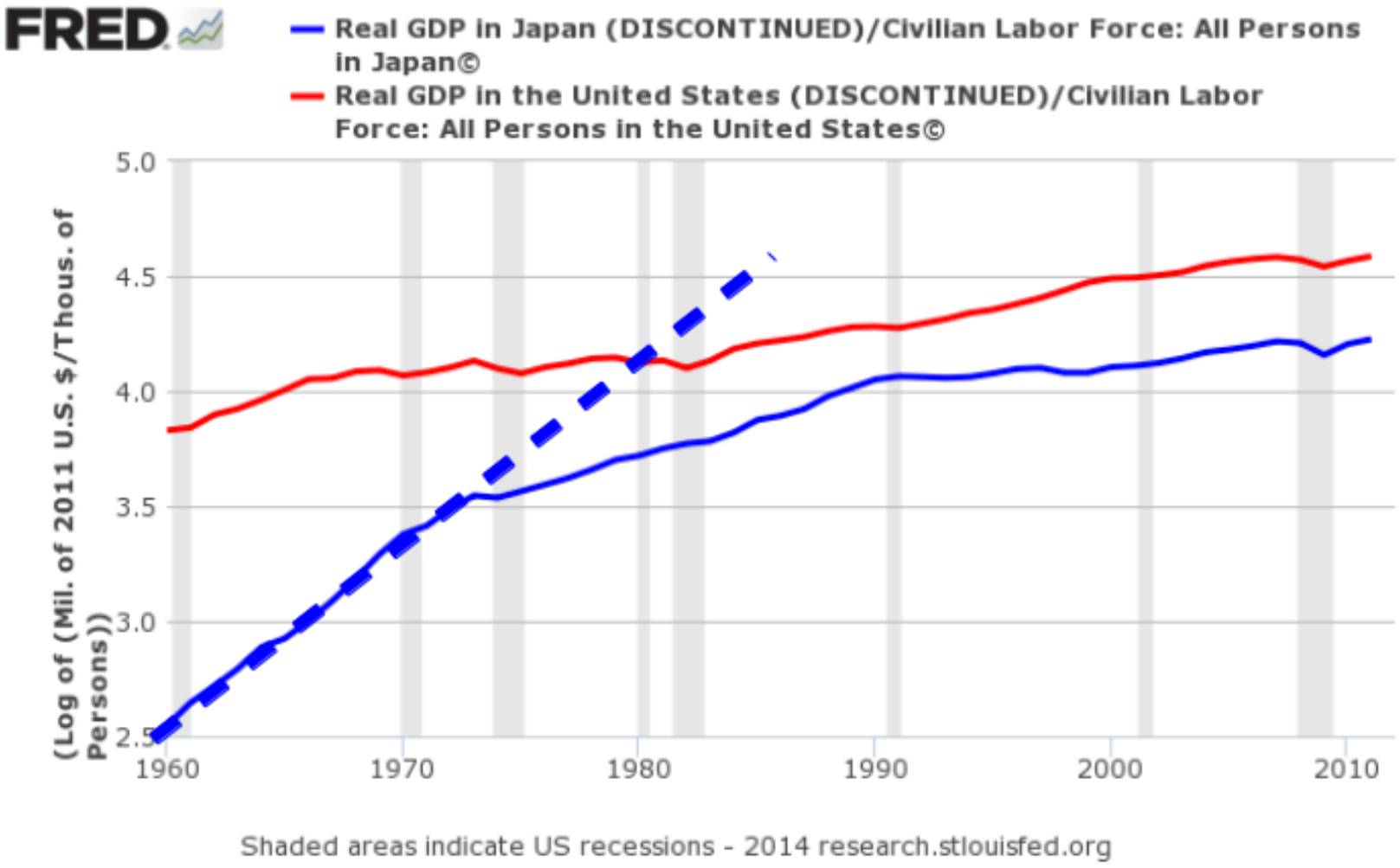
$$Y = AK^{\alpha}L^{1-\alpha}$$

Solow (1956): Exogenous, Technology

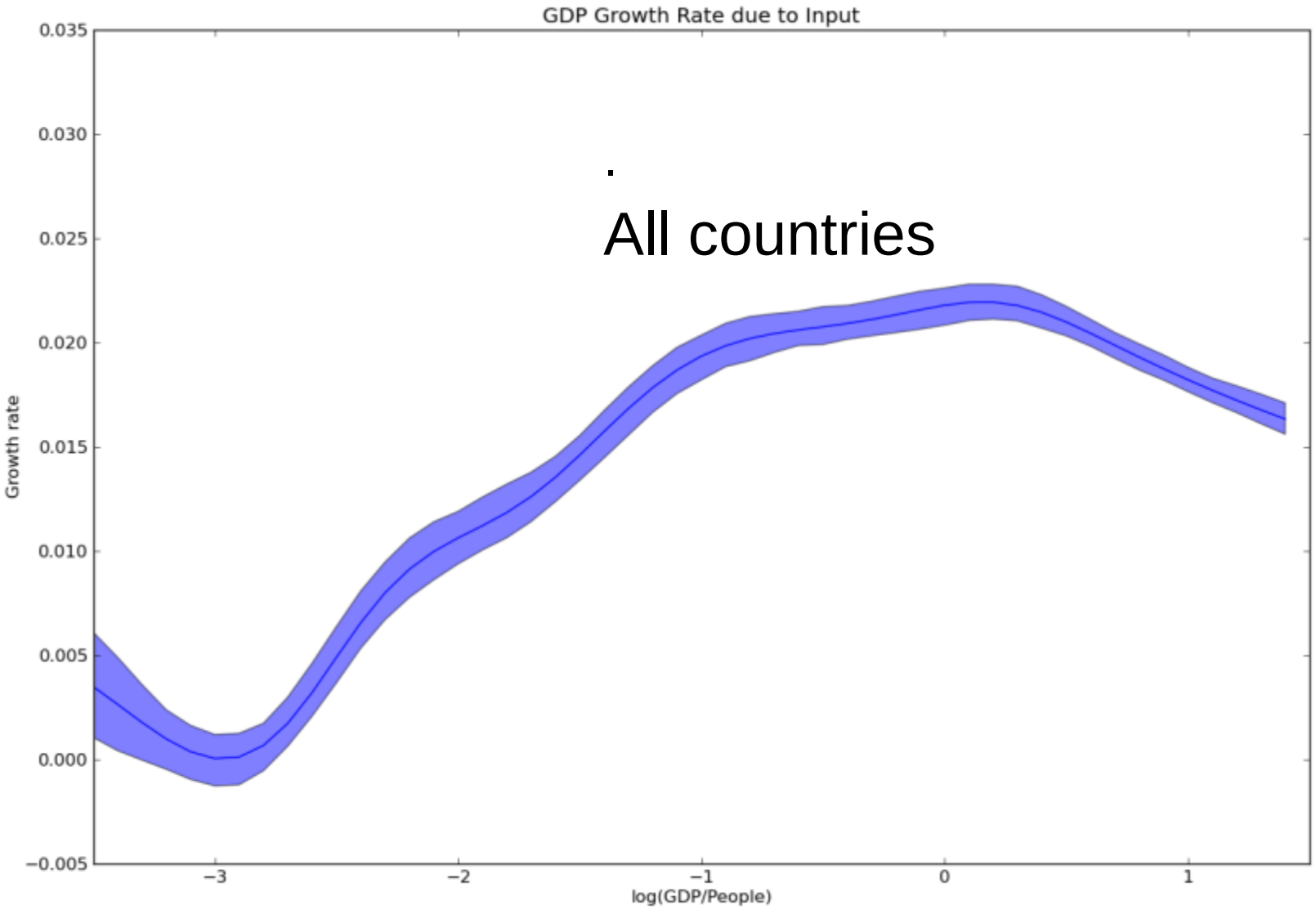
Rodeinstein-Roden (1943): Endogeneous, Input

Murphy, Shleifer, Vichny (1989), Krugman (1993): The Big Push (Short Period of Endogeneous Growth)

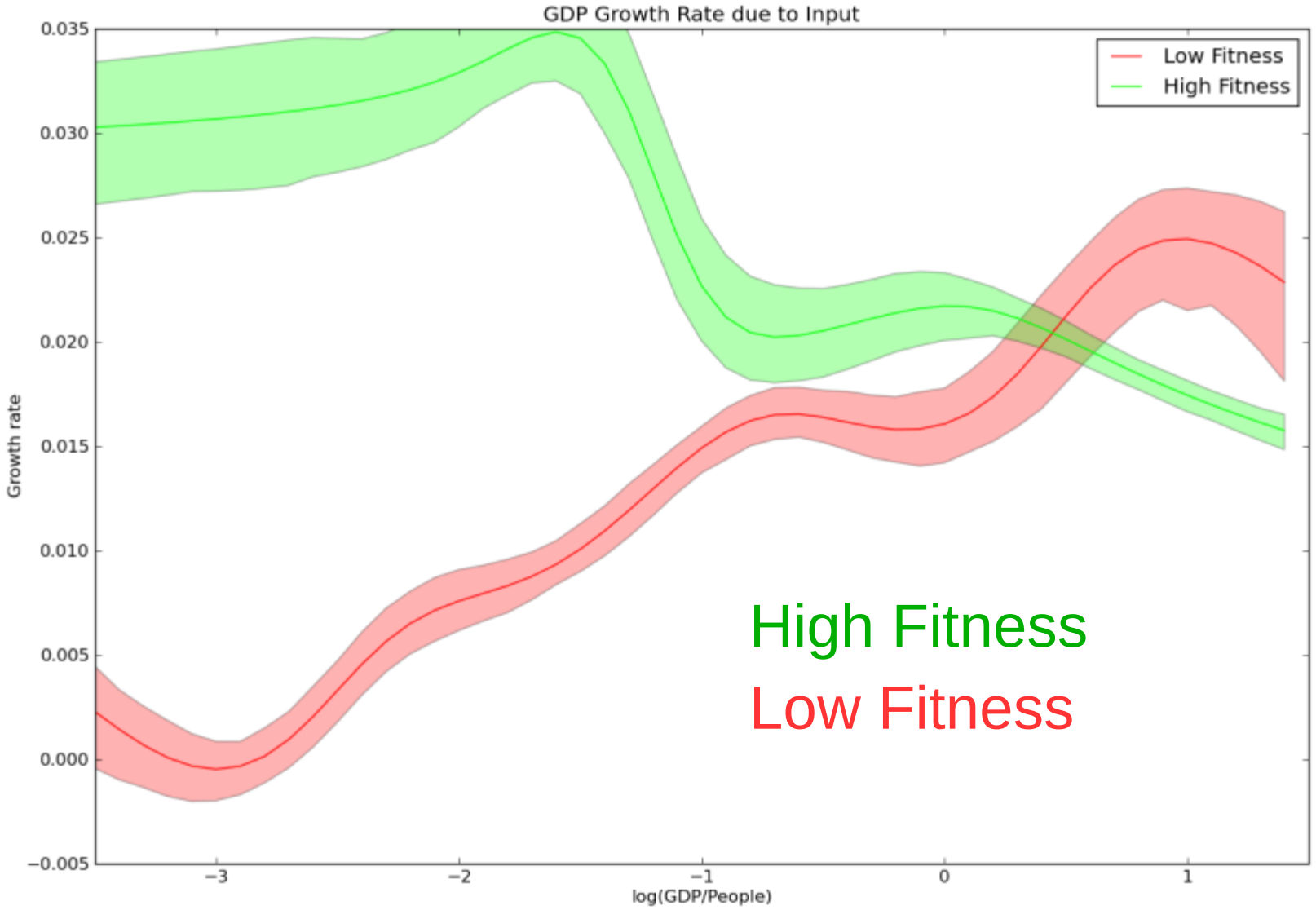
USA vs Japan
Catching up

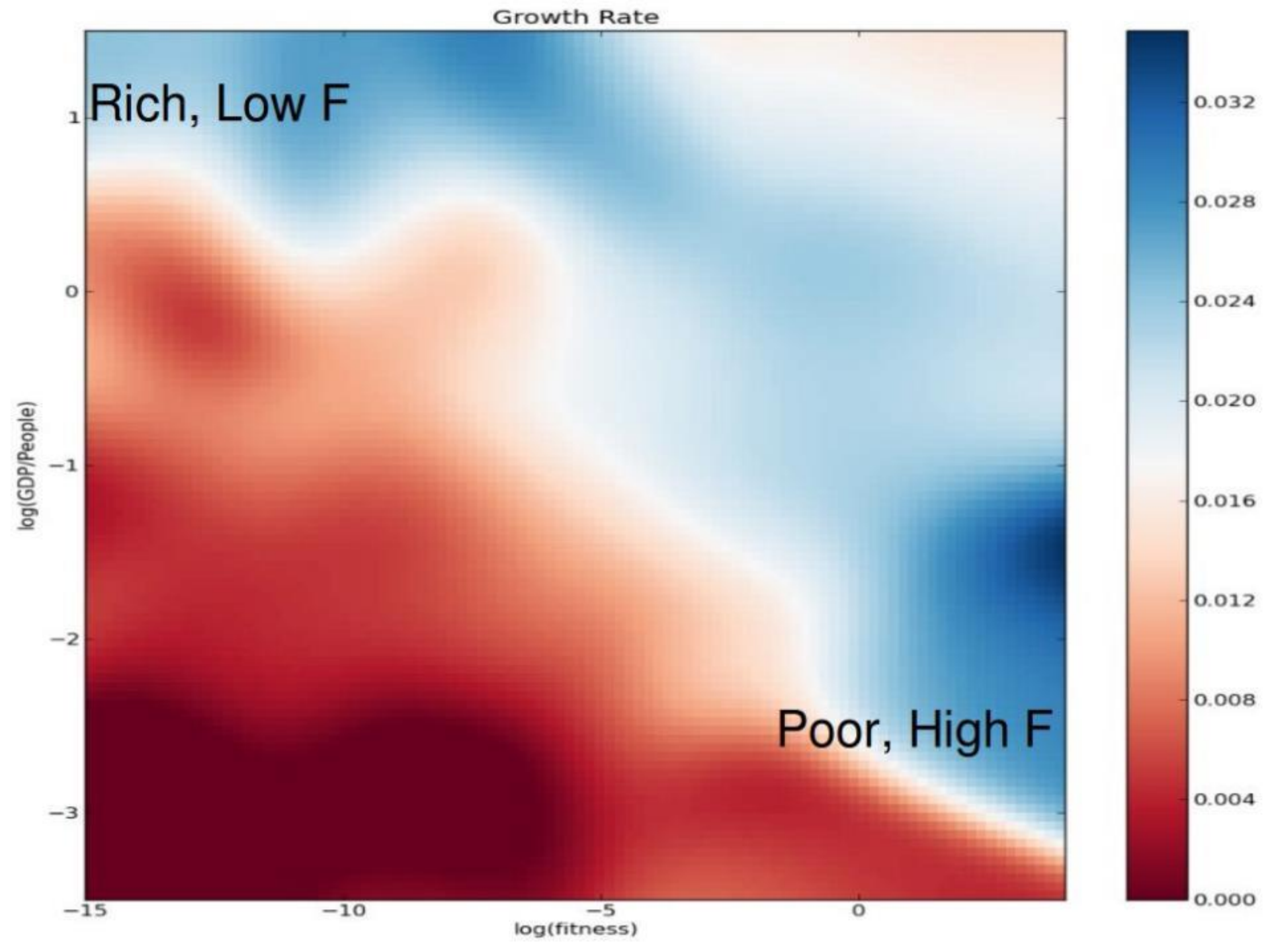


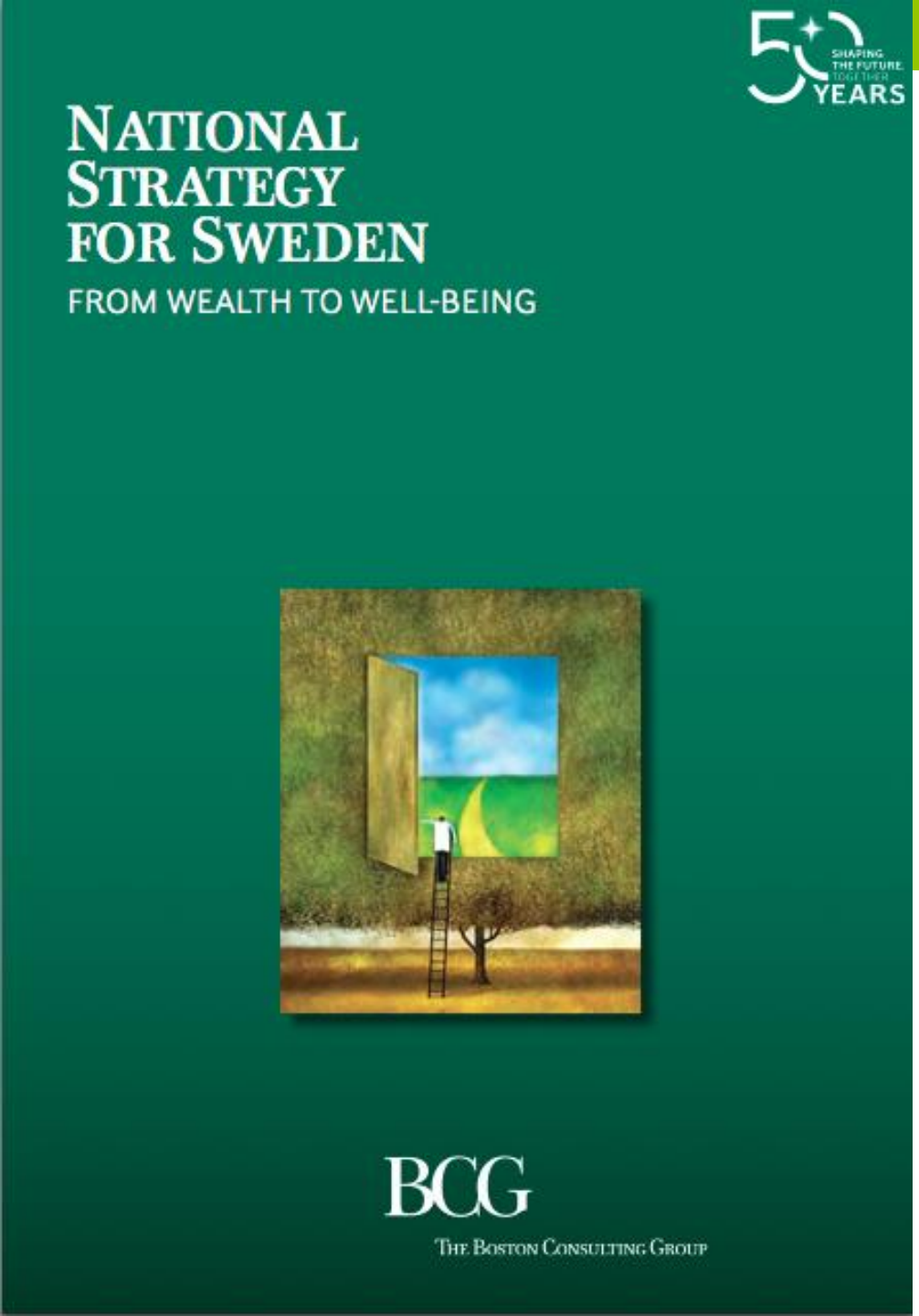
Endogeneous Growth (1963-2000)



Endogeneous Growth (1963-2000)




Growth Rate
Rich, Low F
Poor, High F
log(GDP/People)
log(fitness)
1
0
−1
−2
−3
−15
−10
−5
0
0.032
0.028
0.024
0.020
0.016
0.012
0.008
0.004
0.000



Boston Consulting Group
Report on the competitiveness of Sweden (public document)
October 2013

Ongoing and planned projects

- Refinement of database with respect to anomalous products (product network) and anomalous Countries, i.e. Ethiopia optic fibers. Check product complexity by eliminating one country at a time.
- Analysis of Sectors. Focus on countries with an appreciable hidden potential and look at emerging sectors (before RCA) and look at their position in Product Space
- Analysis of companies, often few products, technologies? Patent data (?) and Technology data For sectors and companies specialization becomes the leading property. Bloomberg data on companies revenues assigned to individual sectors (products)
- Analysis of Sweden, NL and UK for government agencies, role of services and finance
- Analysis of Eurozone countries and the effect of the Euro in the past 15 years
- Analysis of Italy: Competitivity of small vs large industries (ISTAT)
- Geographic and demographic elements
- Generalization of Algorithm also including Weights
- Role of Import data in various roles
- Predictabily: New Concepts beyond regressions. Heterogeneous dynamics Similarity to weather predictions and dynamical systems
- Countries Spectroscopy. More than just Fitness. Detailed analysis of sector dynamics
- Dynamics in the Space of Products. Industrial planning for a country

- Theory for the emergence of the triangular matrix (diversification) For companies specialization seems to be important, Size effect? Combinatorial models. ABM models, other?
- Expansion of the Product Space. Development of new Technologies
- Relation to Keynes multiplicator and Minsky theory
- Application of Bipartite ideas to Industrial districts and cities.