Multi-level modeling of economic innovation dynamics and its implications for analyzing emission impacts

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Presentation at the ECF-workshop „System dynamic models of coupled natural social systems“

Outline

I. Introduction
II. Modeling innovation dynamics
III. Linking innovation dynamics and growth
IV. Driving forces and dynamics of environmental impacts
V. Assessing political measures
VI. Conclusions

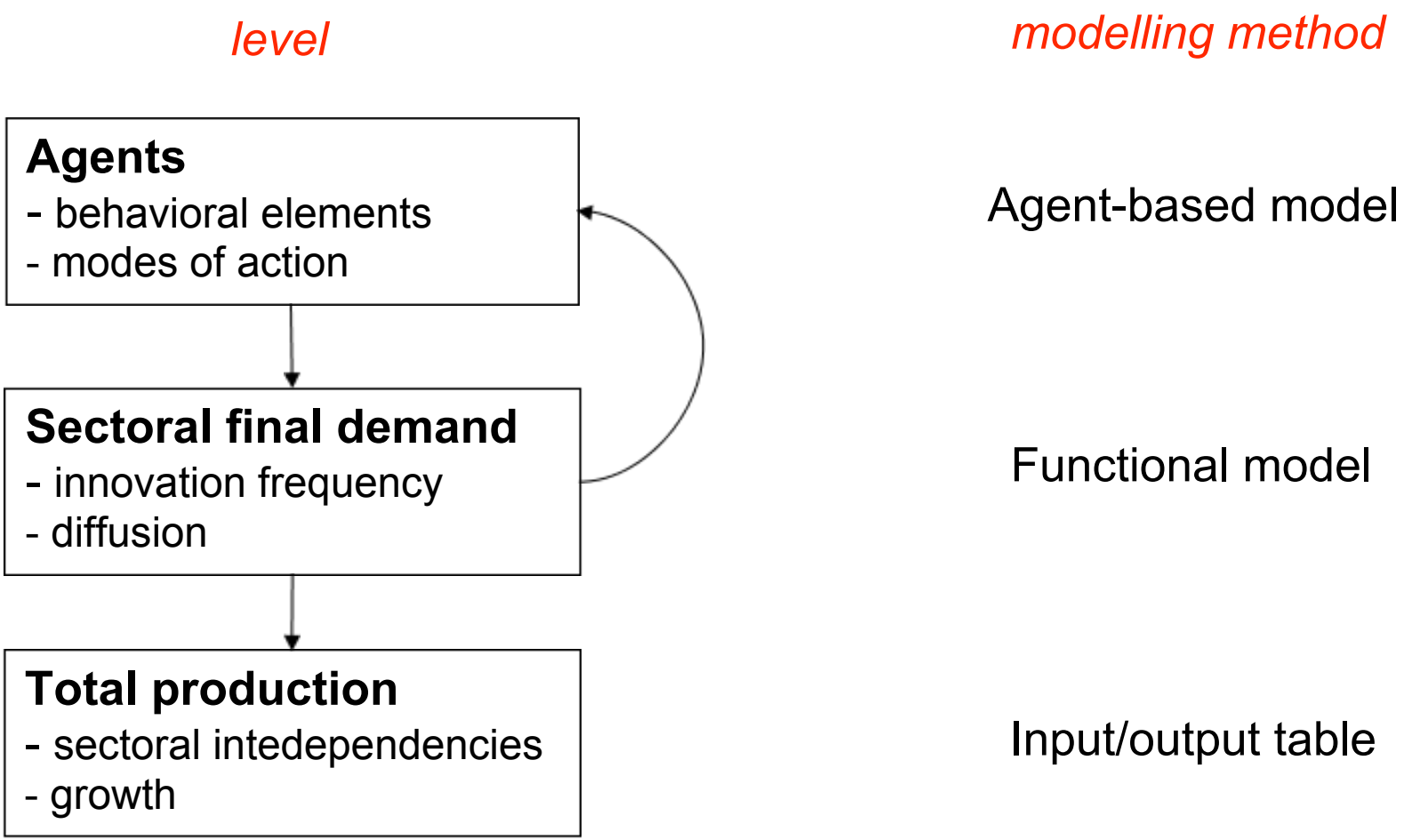
I. Introduction

- Subject matter
  - Refering to growth (and stagnation) of economic aggregates as a background for ecological impacts
  - Problem of endogenous explanation for growth dynamics
    - lack of microfoundation
    - non-linear interaction effects
  - Identifying the driving forces: competition and innovation
    - microfoundation: behavioural trigger conditions for innovations
    - interactions: diffusion dynamics and sectoral interdependencies
  - Relating ecological impact dynamics and innovation dynamics
  - Constraints:
    - only supply side specified; simplified demand effects
    - only one exemplary emission

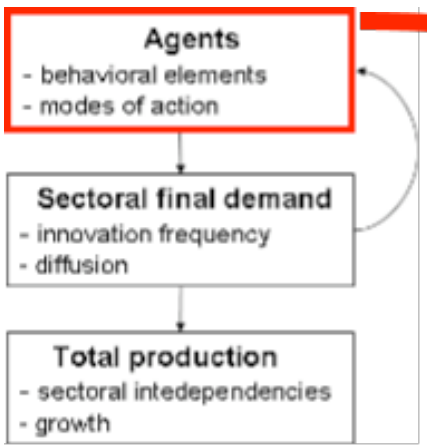
- Methodology
  - Economy as a ‘Complex Adaptive System‘ (CAS)
    - multi-scale property
    - emergent features
    - adaptation of agents
  - Multi-scale property
    - economic aggregates (on the national level)
    - sectoral interdependencies
    - intrasectoral interaction
  - Emergent features
    - diffusion of innovation
    - growth and the corresponding volume of emissions
  - Adaptation of agents
    - no uniform optimization behavior: ‘bounded rationality‘
    - autonomy and heterogeneiety
    - selecting different modes of interaction

II. Modelling innovation dynamics

- A multi-level approach is suggested
  - level 1: triggering conditions for innovation activities for autonomous agents
  - level 2: diffusion dynamics and market interaction in sectors
  - level 3: interdependencies between sectors and aggregation

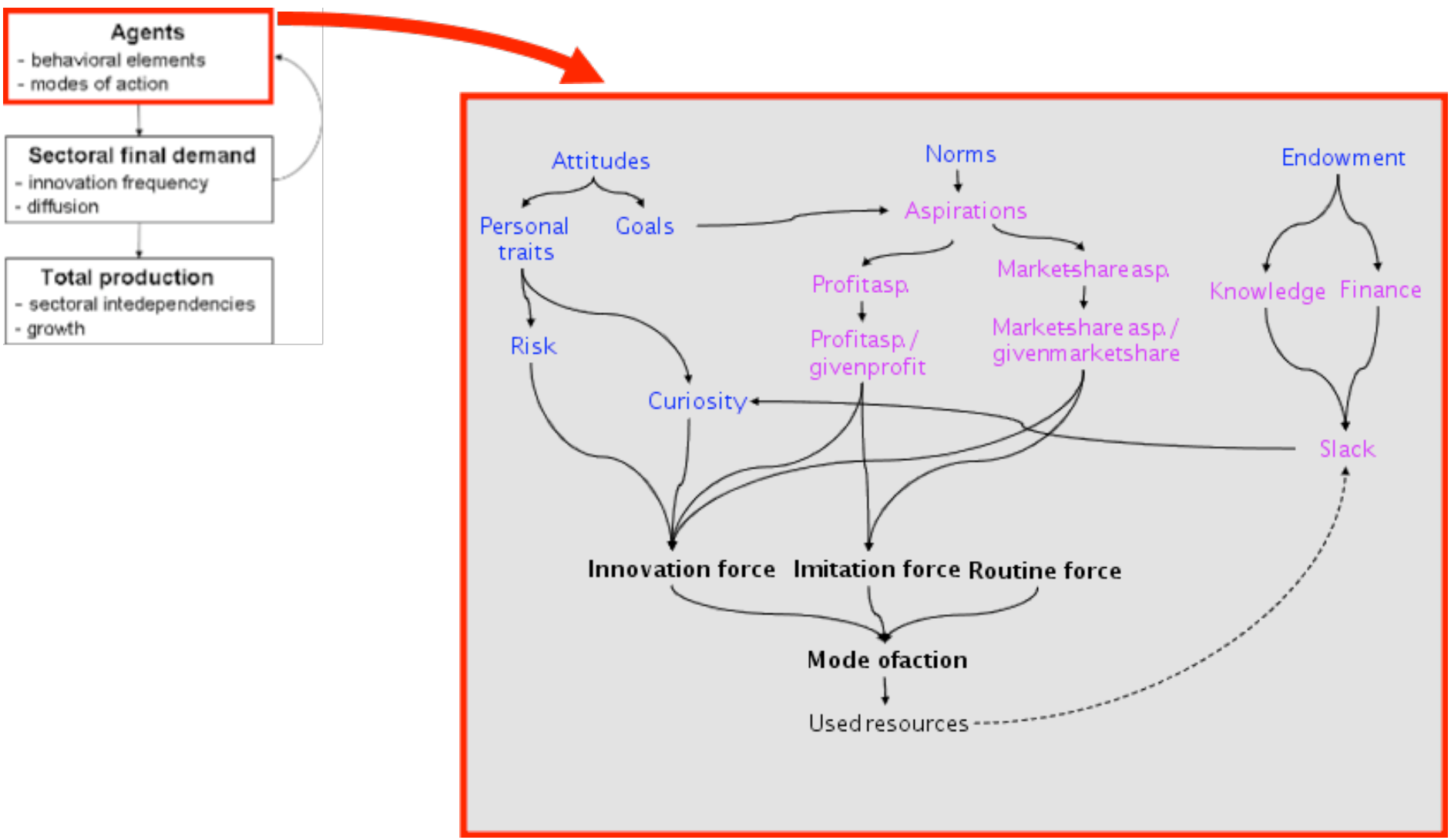


Level 1: Modelling the behavioural trigger conditions for novelty creating activities

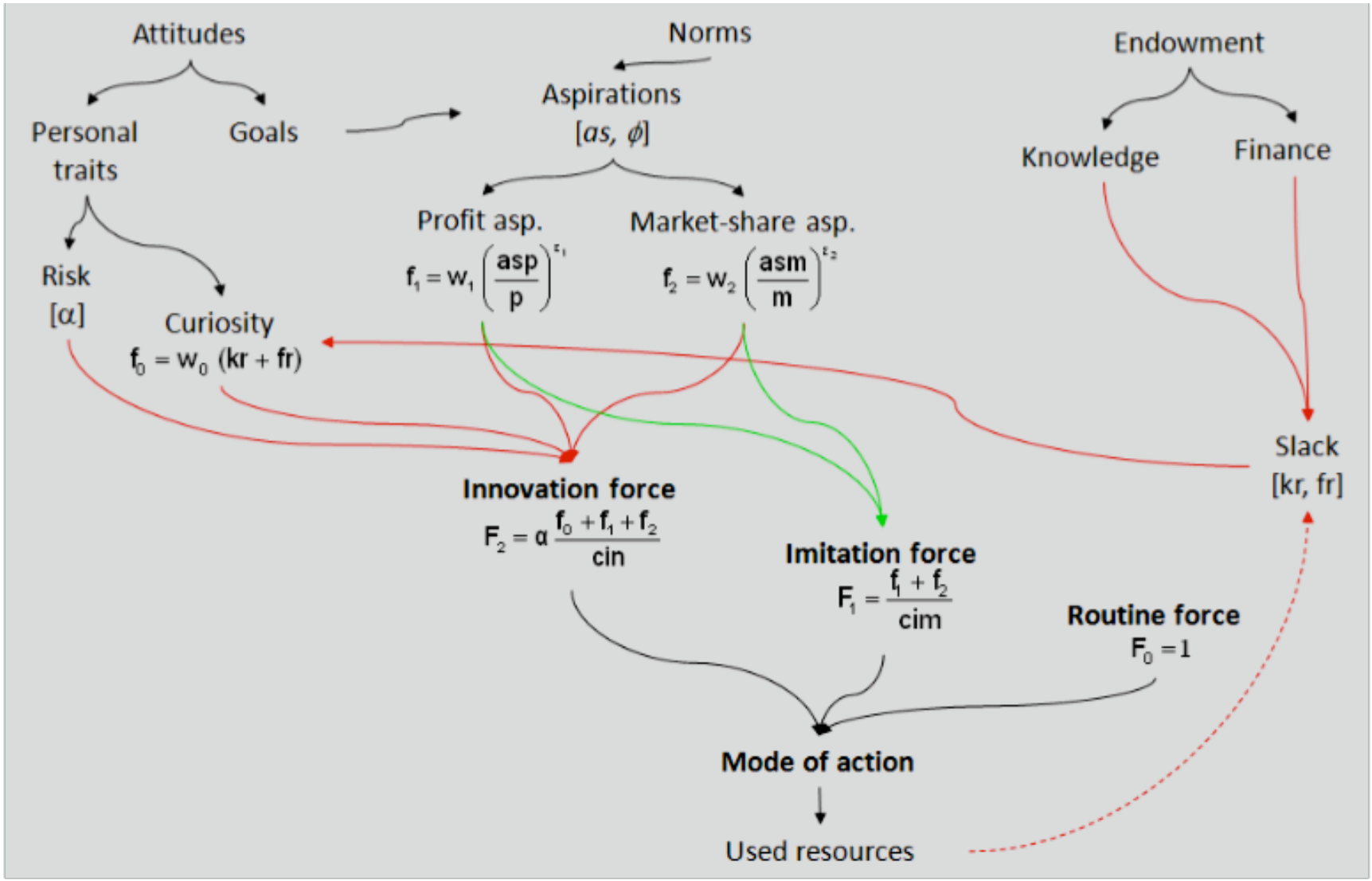


- Question to answer: Under what conditions and how do agents create novelties?
- Unsufficiency of functional and personal attempts to answer this question
- Need for behavioural foundation: role of attitudes, norms and endowment
- Ability to act is given in terms of different modes of action (routine, imitation and innovation)

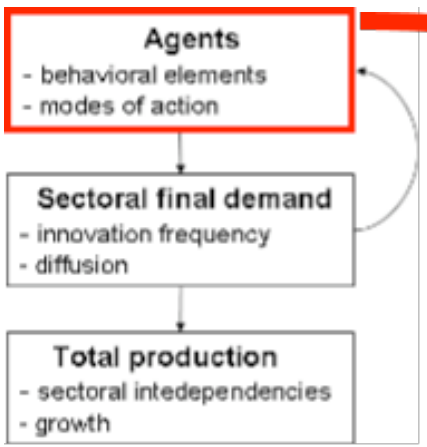
- Level 1: Modelling the behavioural trigger conditions for novelty creating activities/cont.



Formal specification: behavioural dynamics

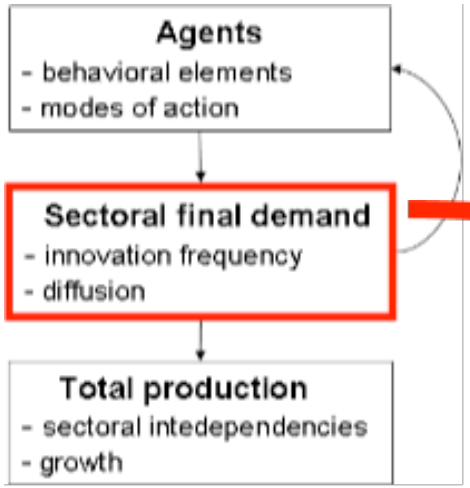


Level 1: Modelling the behavioural trigger conditions for novelty creating activities



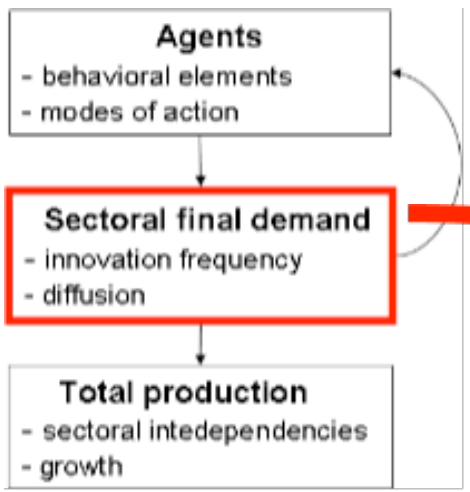
- What happens if the innovation mode is selected?
  - * individual innovation lottery
  - * cooperative innovation lottery
- What happens if the imitation mode is selected?
  - * limited observability of other agents
  - * imitation lottery
- What happens if the routine mode is selected?
  - * same procedure as before

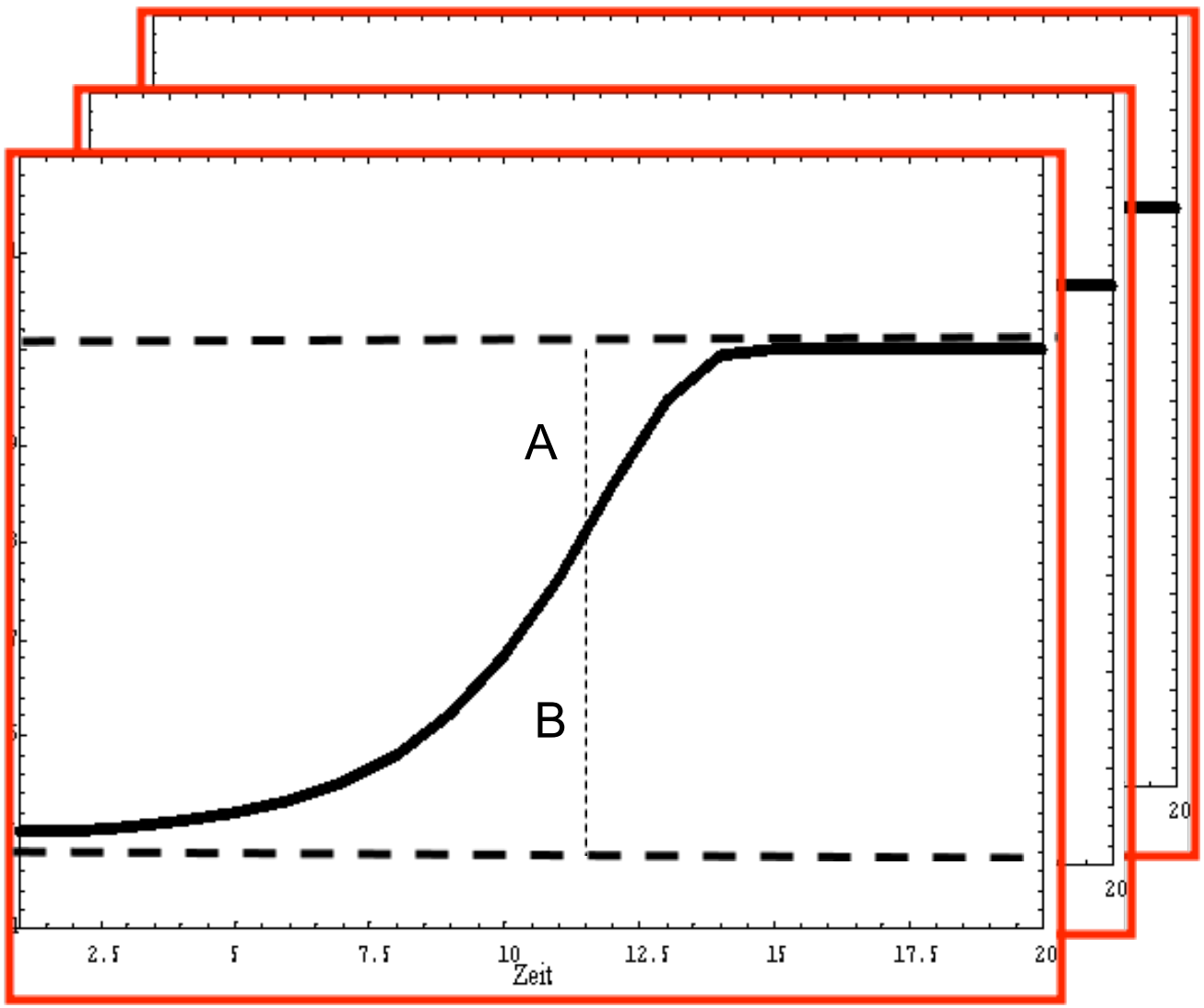
• Level 2: Modelling the sectoral diffusion dynamics



- Refering to stylized facts of diffusion analysis
- Assuming a ‚critical mass‘
- Assuming a S-shaped diffusion of new products
- Variable speed of diffusion
- Depending on its frequency successful novelty creation has
  - (i)a growth effect for sectoral final demand

- Level 2: Modelling the sectoral diffusion dynamics /cont.





Logistic diffusion dynamics for product specific demand

- demand potential: y_{po}
- critical mass y_{ts}

$$y(t+1) = y(t) + v\,\frac{(y(t)-y_{ts})(y_{po}-y(t))}{y_{po}-y_{ts}},\ \text{if } y(t) \geq y_{ts}$$

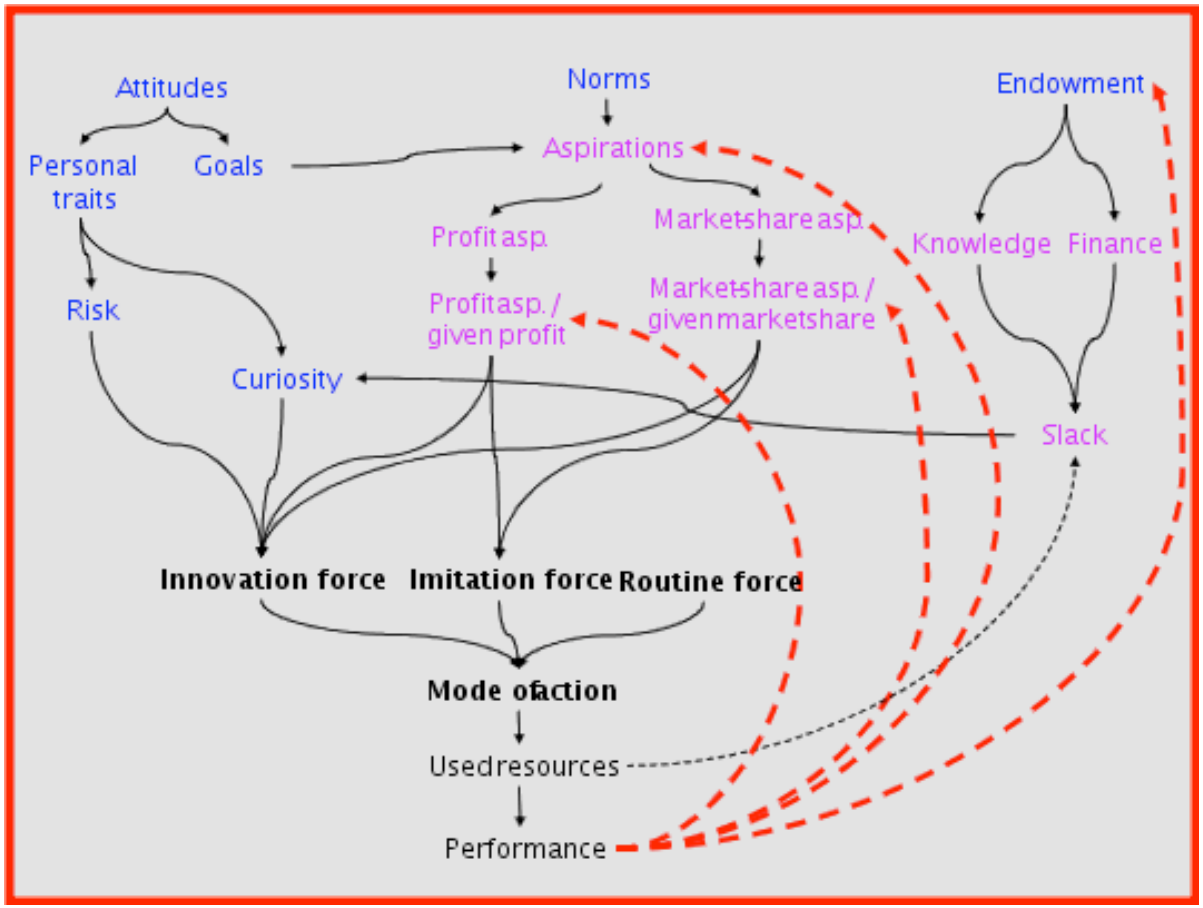
$$y(t+1) = y(t) + v\,\frac{y(t)(y(t)-y_{ts})}{y_{ts}},\ \text{if } y(t) < y_{ts}$$

Growth effect: $$w(t+1) = \sum_{k=1}^{r} (y_k(t+1) - y_k(t))$$

Substitution effect: $0 \leq su \leq 1$

Growth rate for sectoral net production: $$\frac{Y(t+1)-Y(t)}{Y(t)} = \frac{(1-su)w(t+1)}{Y(t)}$$

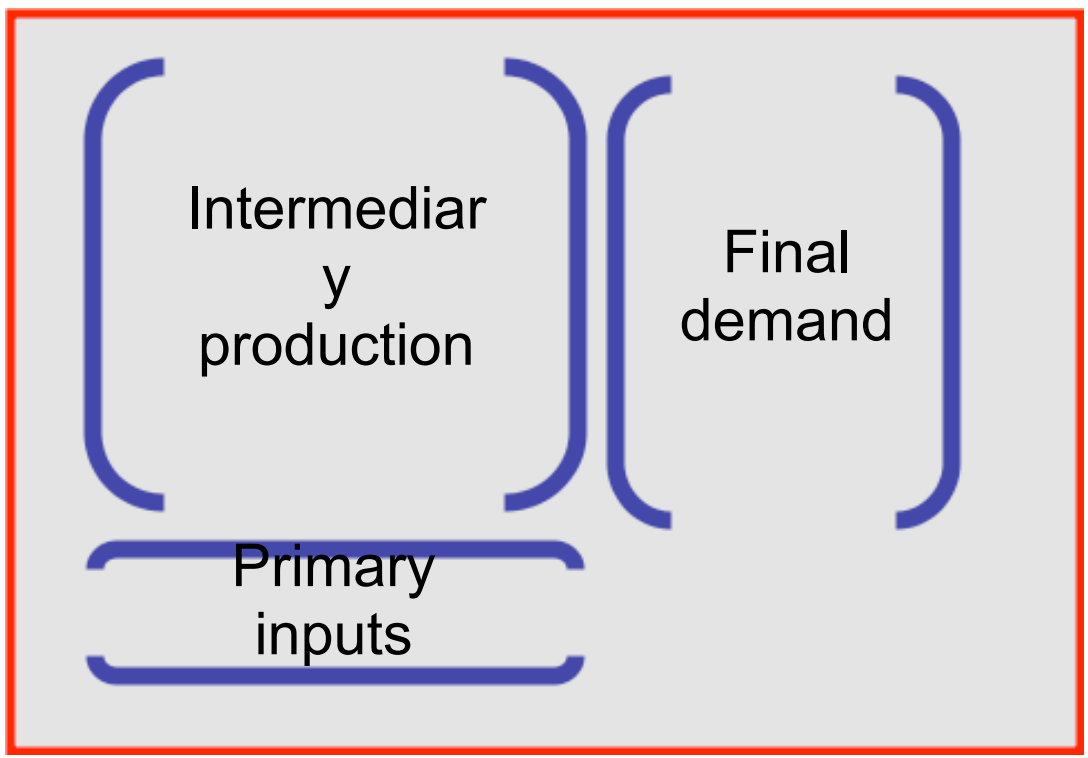
- Feedbacks from the sectoral level (level 2) to the agent level (level 1)



Level 3: Modelling the intersectoral dynamics and gross production

- Using input/output tables (IOT) as an accounting scheme
  - (i)aggregation problem
  - (ii)static nature
- Mapping innovation into IOT
  - (i)Assuming fixed production coefficients
  - (ii)Sectoral final demand dynamics is the driver for the intersectoral dynamics

- Level 3: Modelling the intersectoral dynamics and gross production/cont.



Vector of sectoral net production : **Y(t)** = $\{Y_i(t)\}$

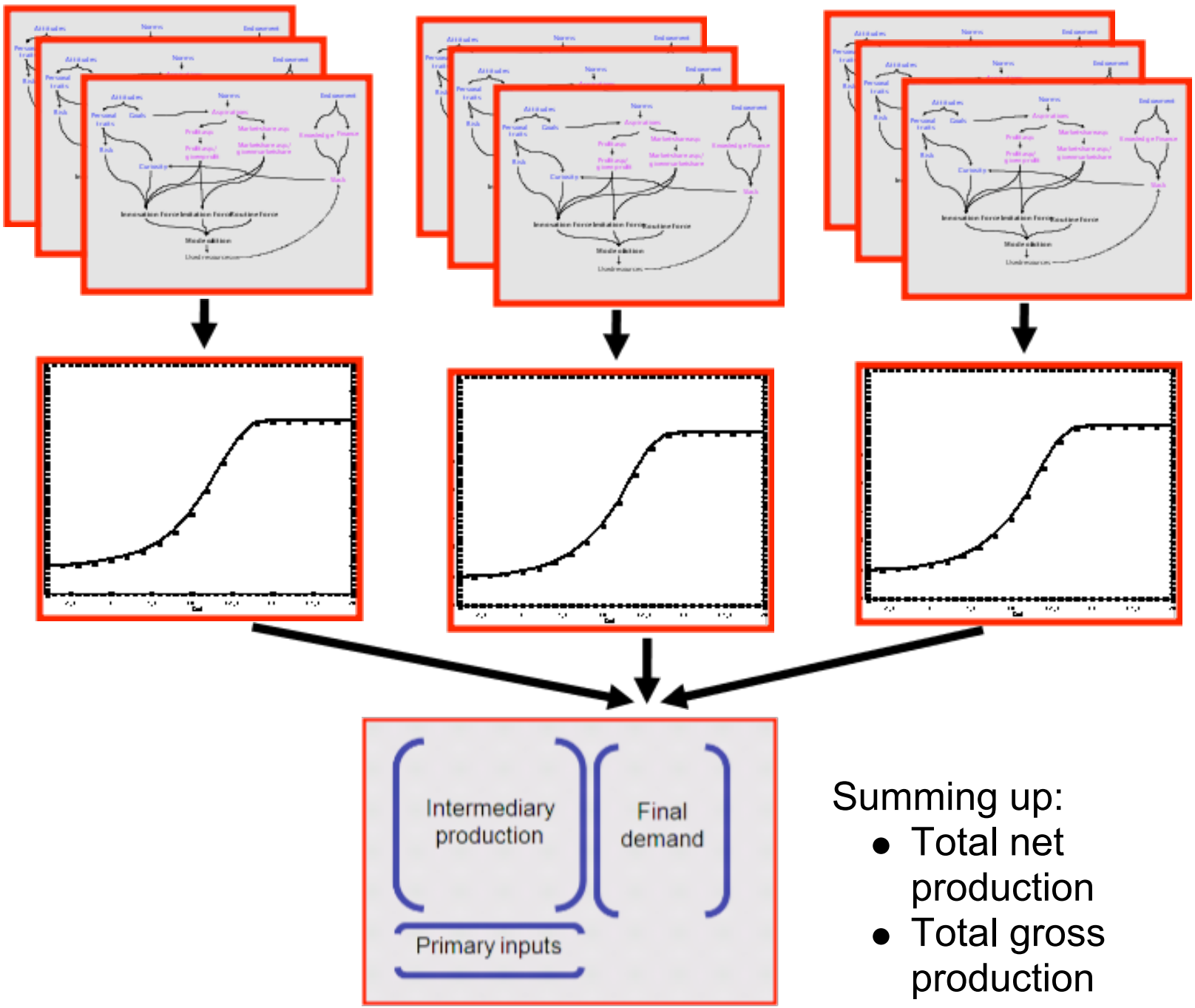
Matrix of ‘technical‘ production coefficients: **A(t)** = $\{a_{ij}(t)\}$

Vector of secoral gross production: $\mathbf{X(t)} = (\mathbf{I} - \mathbf{A(t)}^{-1}\mathbf{Y(t)}$

Aggregated net production: $Y(t) = \sum_{i=1}^{n} Y_i(t)$

Aggregated gross production: $X(t) = \sum_{i=1}^{n} X_i(t)$

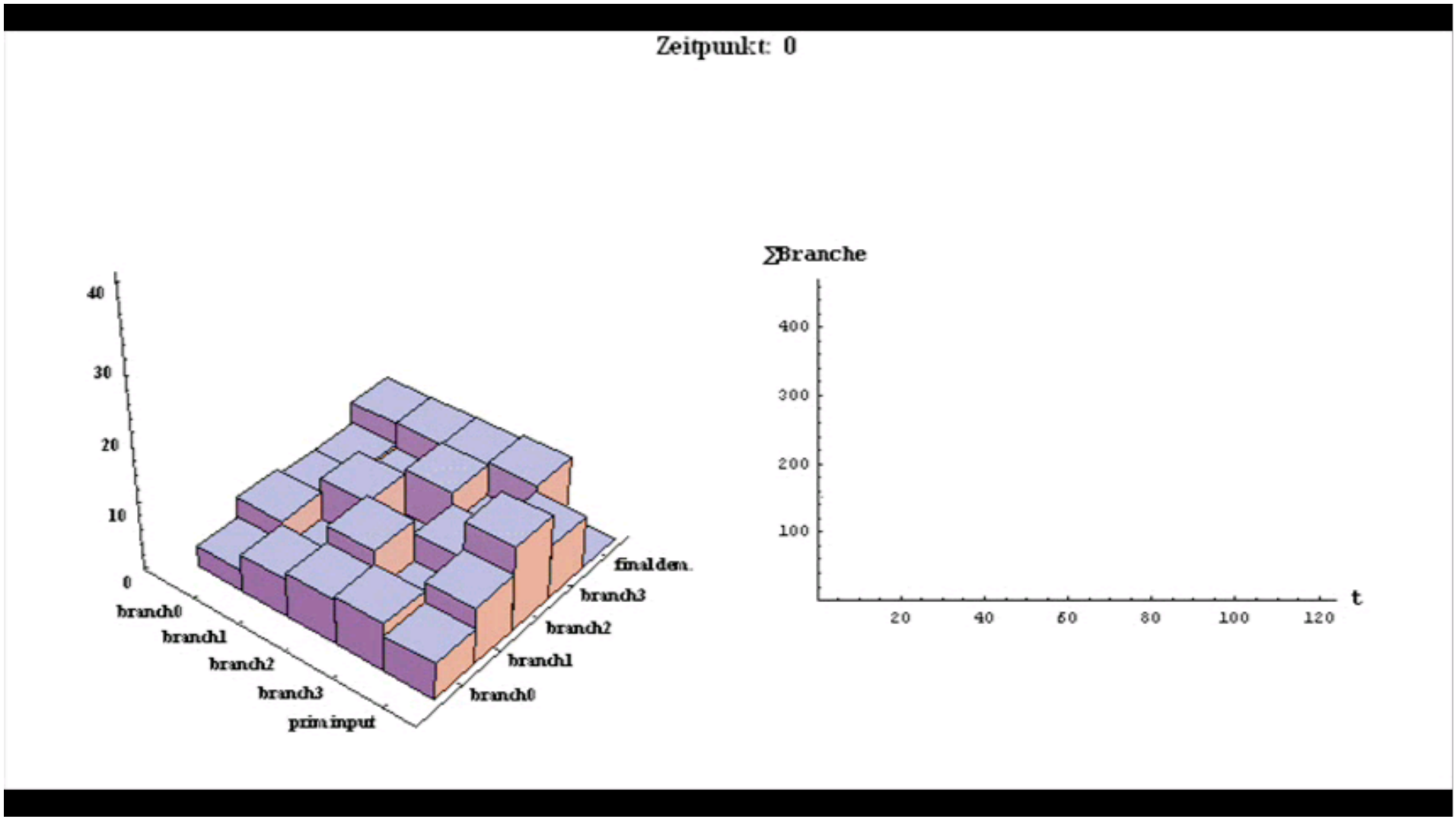
IV. Linking innovation dynamics and growth



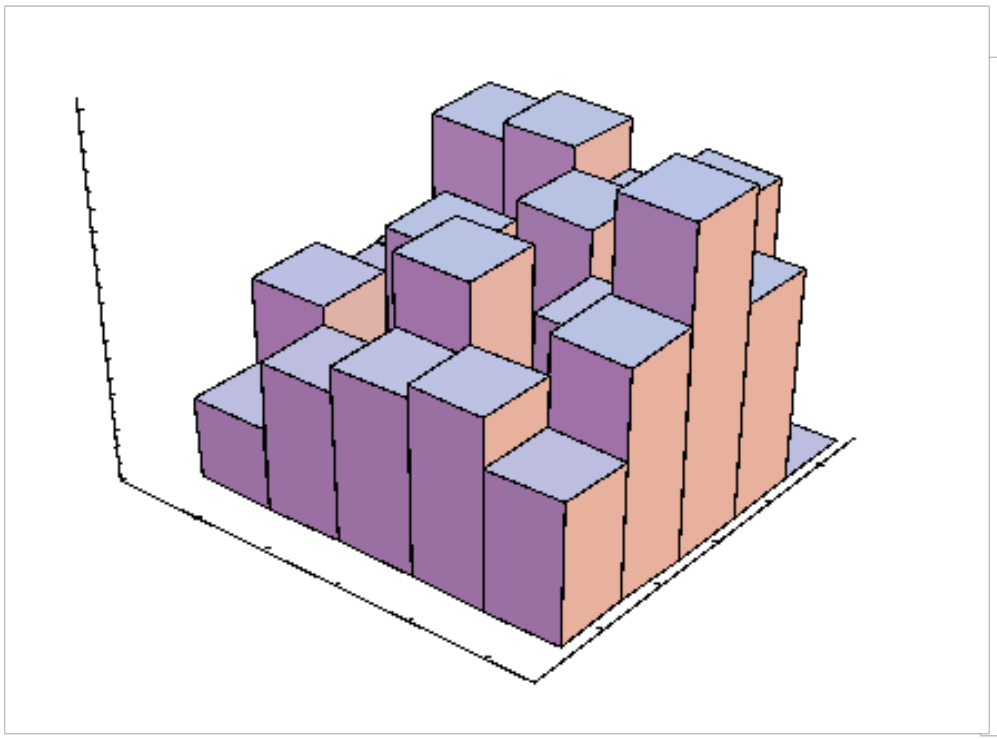
Summing up:

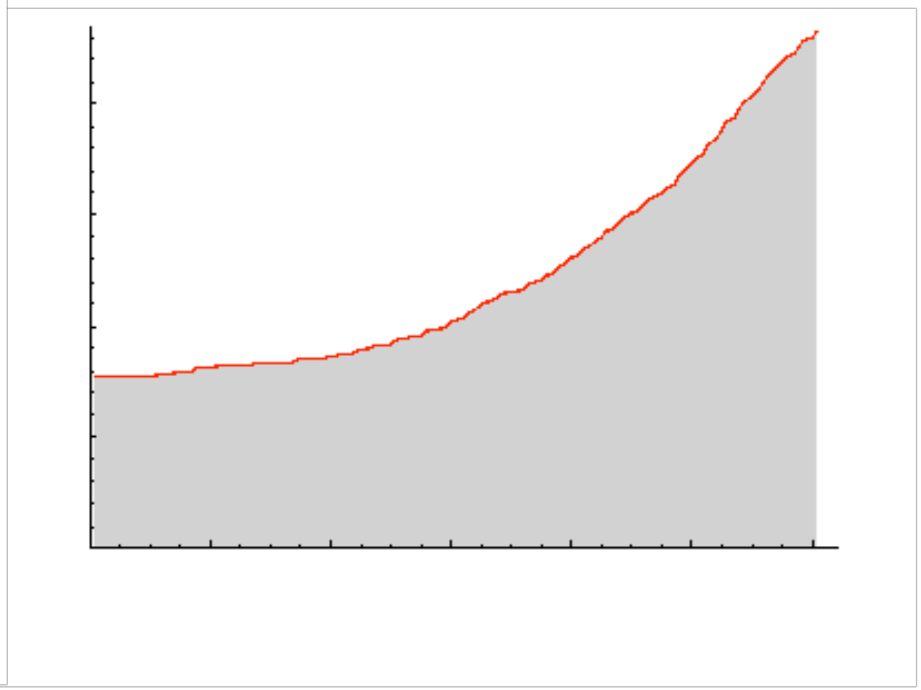
- Total net production
- Total gross production

- Macro level: intersectoral dynamics and total gross value production

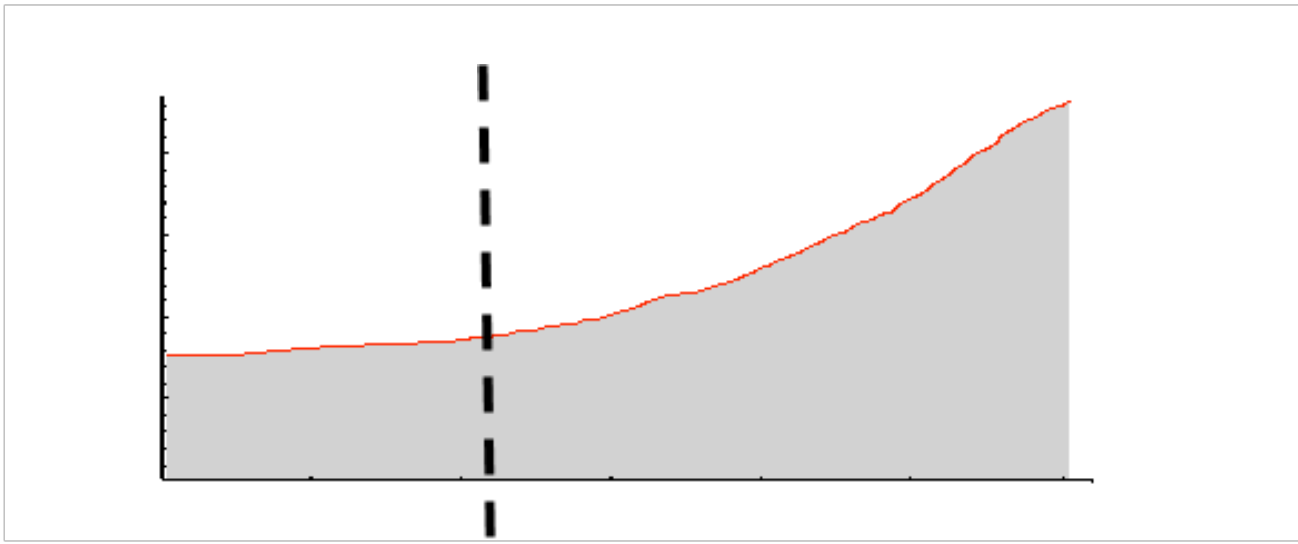


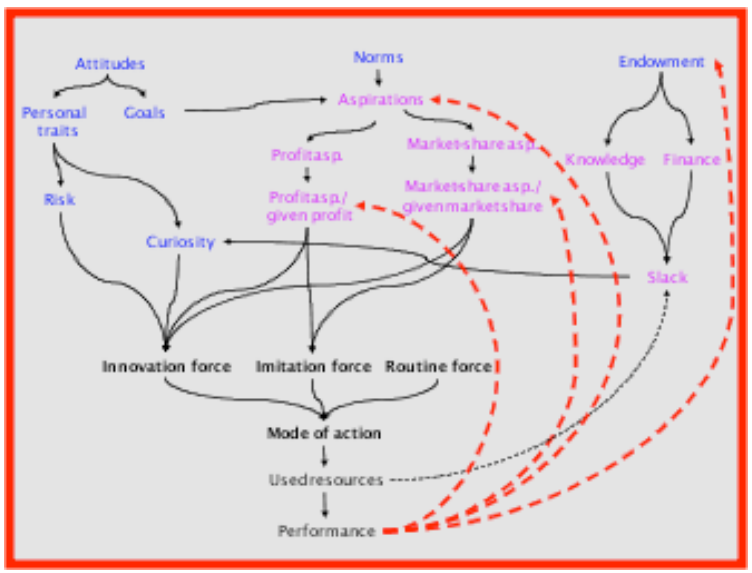
- Macro level: intersectoral dynamics and total gross value production

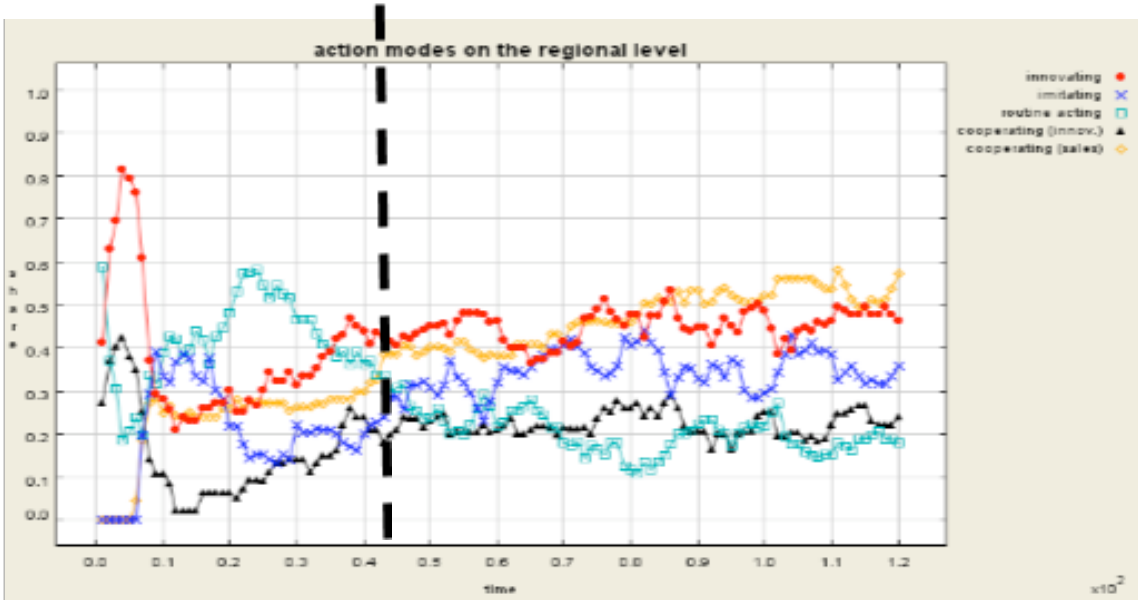




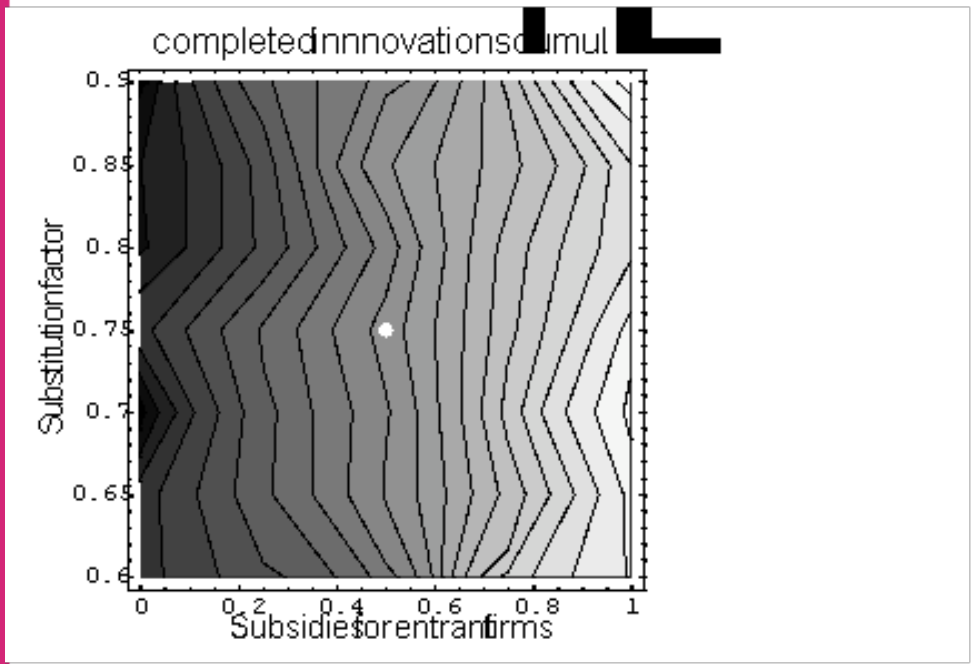
- Comparing macro-level and micro-level

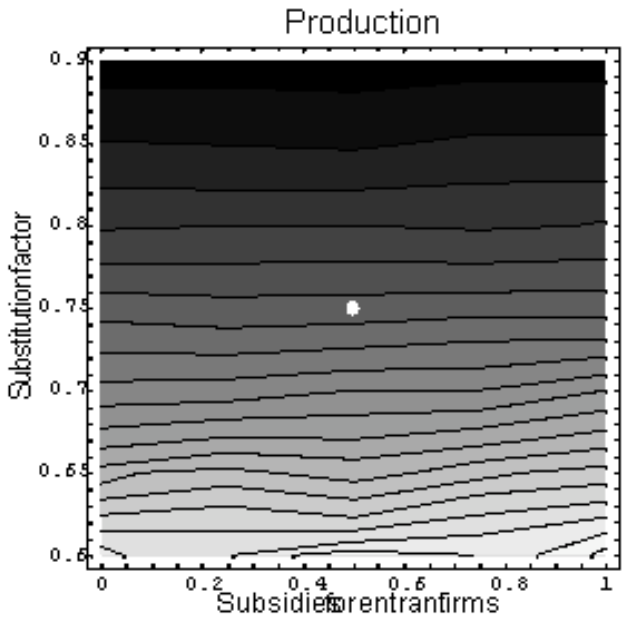


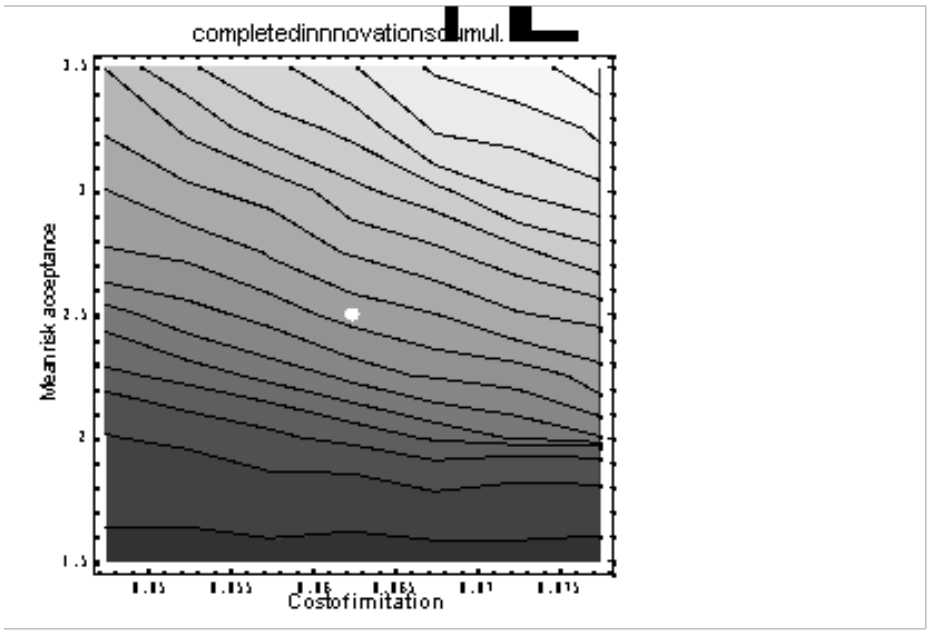


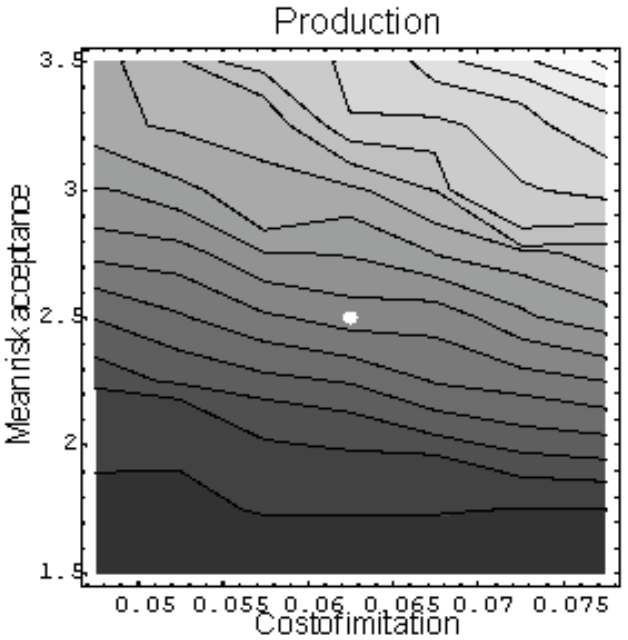


- Sensitivity analysis as regards innovation and growth (gross production)









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V. Driving forces and dynamics of environmental impacts

- Assumptions
  - only one exemplary type of emission (e.g. CO_2)
  - emissions related to the level of economic activity
  - homogeneous sectors in terms of initial emissions

- Driving forces for emission dynamics
  - frequency of innovation
  - type of innovation as regards emission
  - diffusion of innovation (critical mass, growth vs. substitution)
  - intersectoral effects
  - vintage structure of aggregates

Formal specification of emission dynamics on the sectoral and national level

$$em_i(t) = \frac{em_i(t-1)\,Y_{i,old} + \sum_{j=1}^{P_i(t)} em_{i,j}(t)\,Y_{i,j}(t)}{Y_{i,total}}$$

$$em_{i,j}(t) = M\,em_{i,j}(t-1)$$

$$Em_i(t) = em_i(t)\,X_i(t)$$

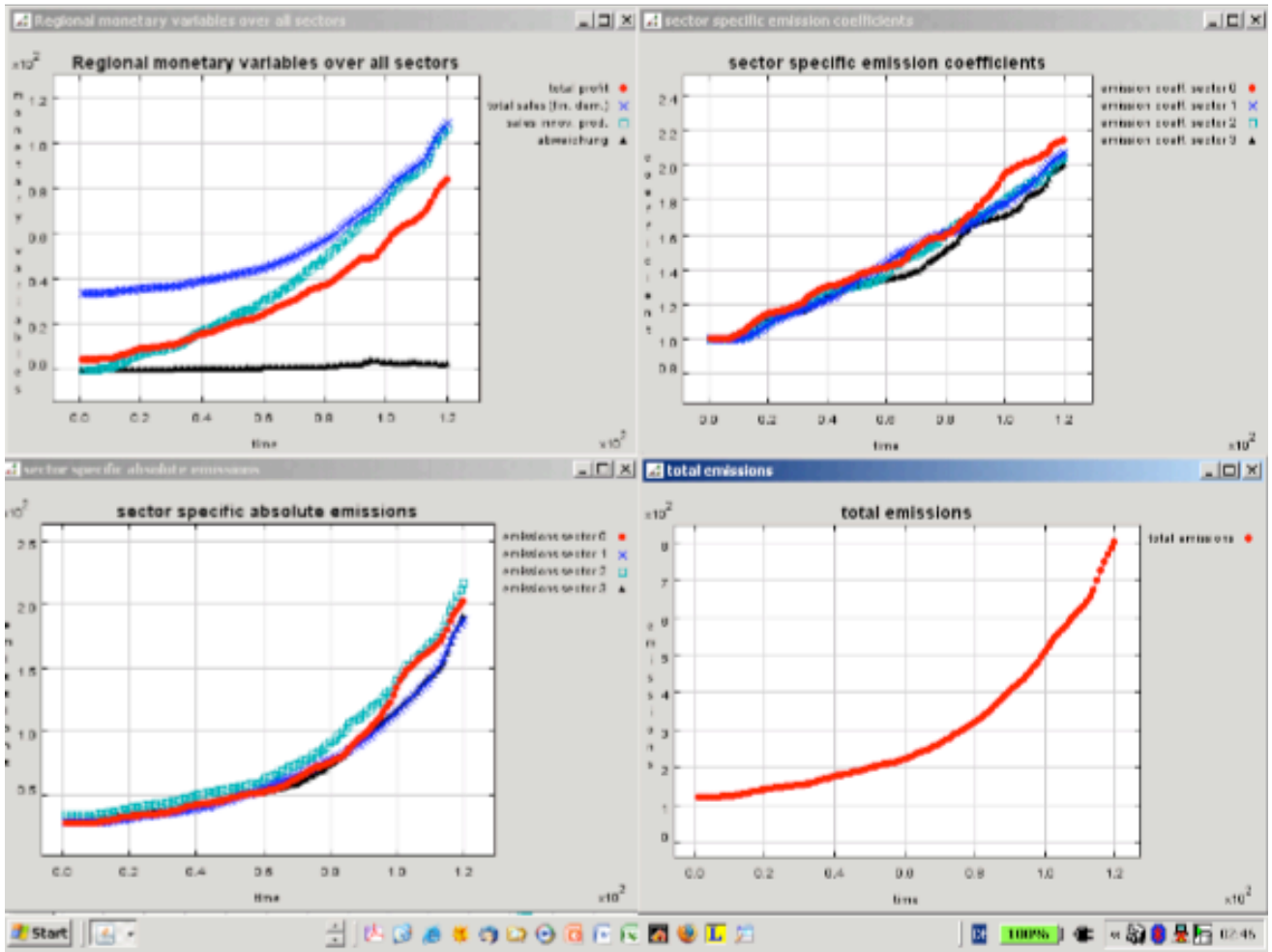
$$Em(t) = \sum_i em_i(t)\,X_i(t)$$

- Simulating the dynamics of environmental impacts

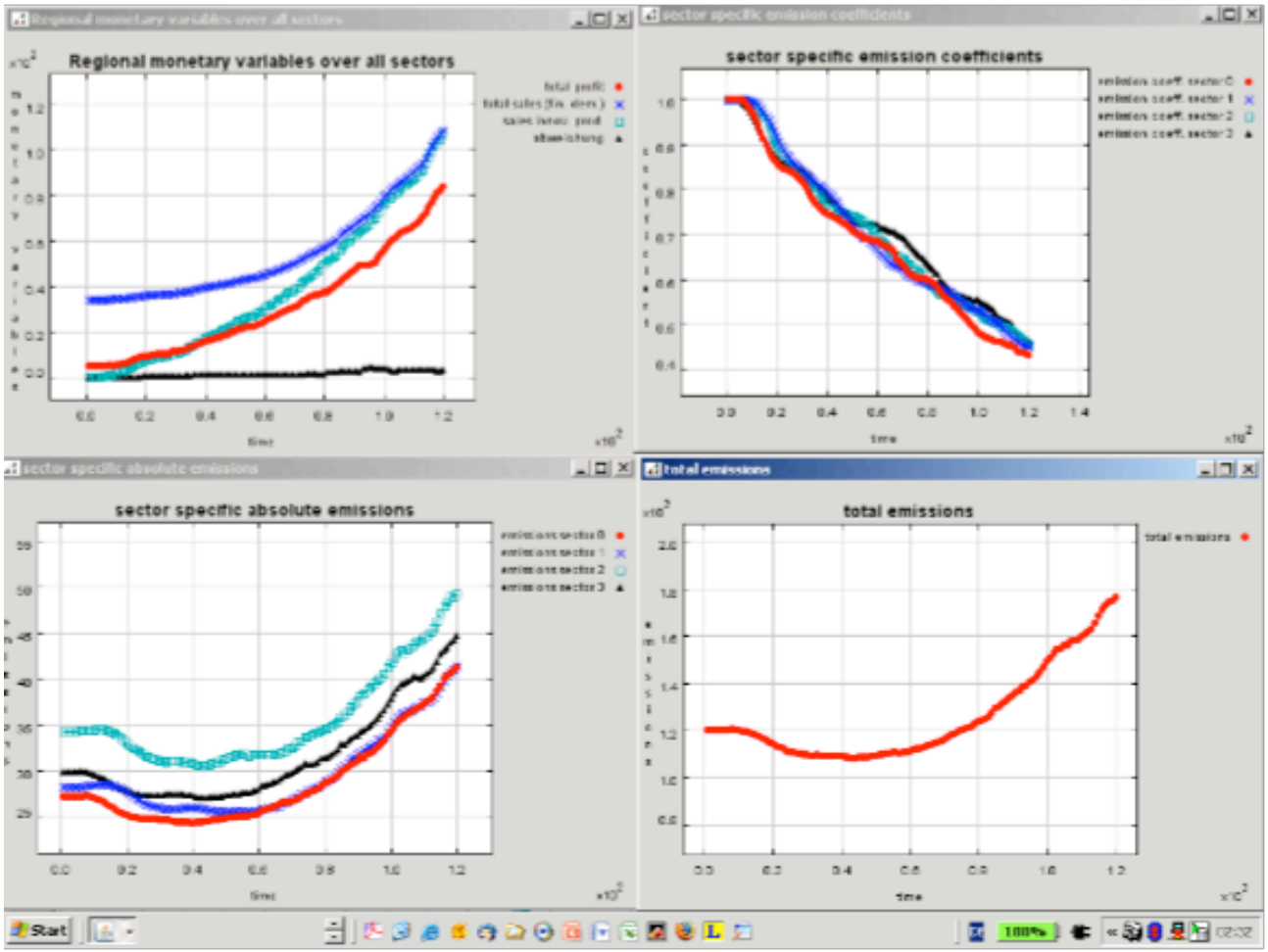
- Classification of cases

Increasing emission (M>1)/ fast diffusion (v high)	Increasing emission (M>1)/ slow diffusion (v low)
Decreasing emission (M<1)/ fast diffusion (v high)	Decreasing emission (M<1)/ slow diffusion (v low)

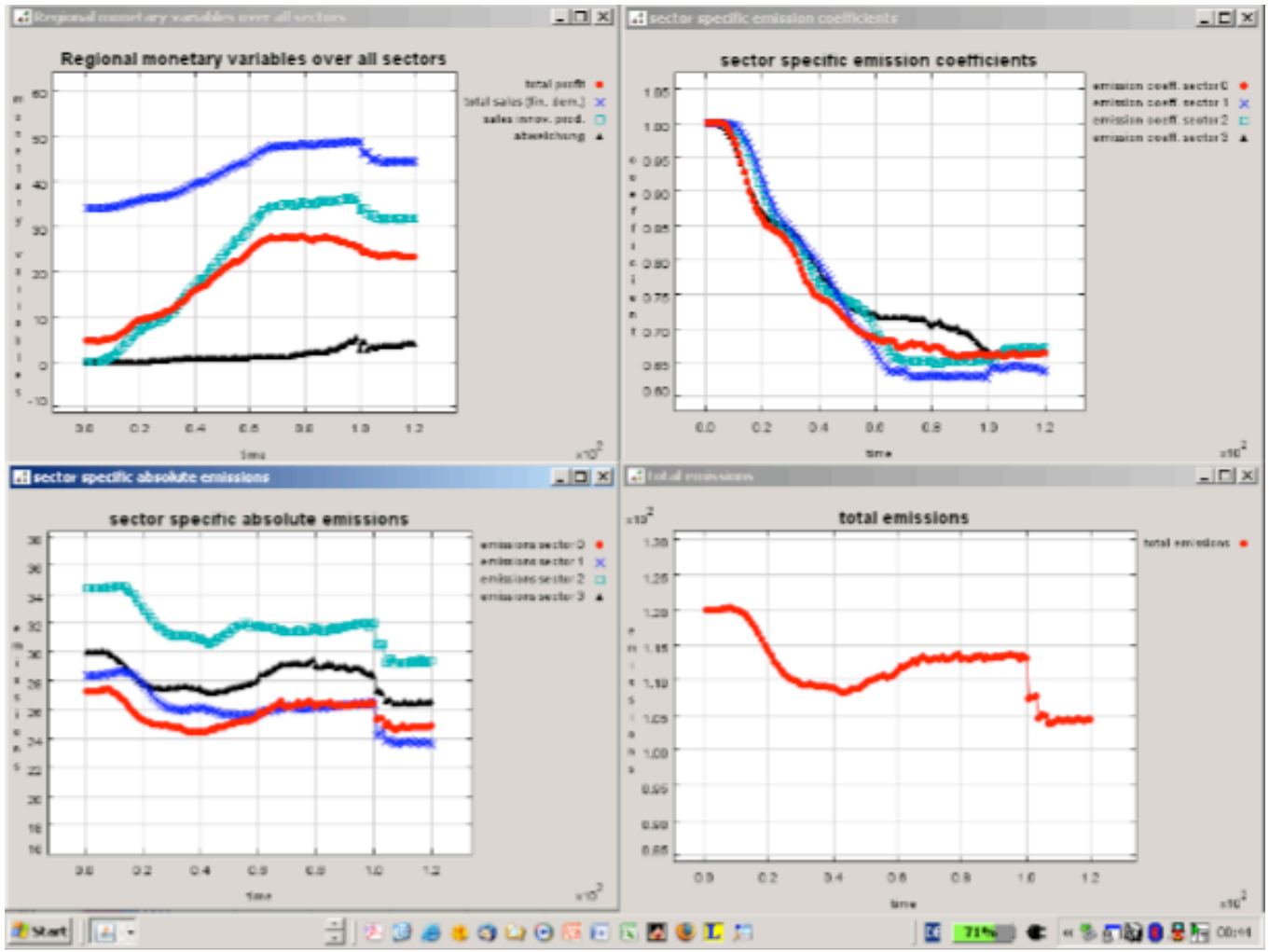
- Simulating the dynamics of environmental impacts/cont.
  - case increasing emission/fast diffusion: specifying the worst case



- Simulating the dynamics of environmental impacts/cont.
  - case decreasing emission/fast diffusion: specifying the rebound effect

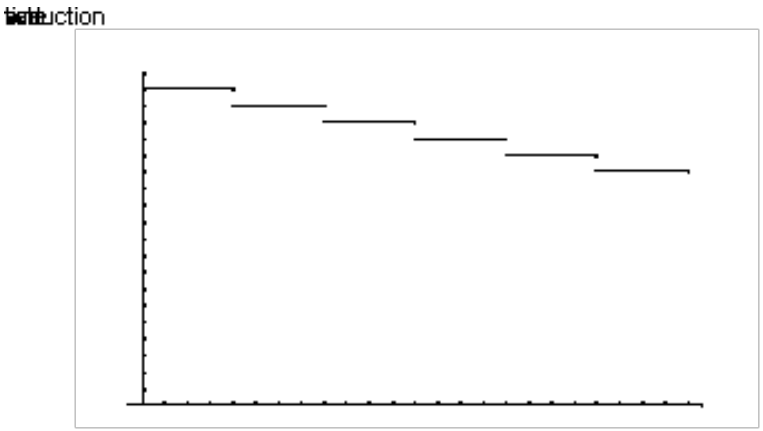


- Simulating the dynamics of environmental impacts/cont.
  - case decreasing emission/inter-rupted diffusion: specifying the crisis effect

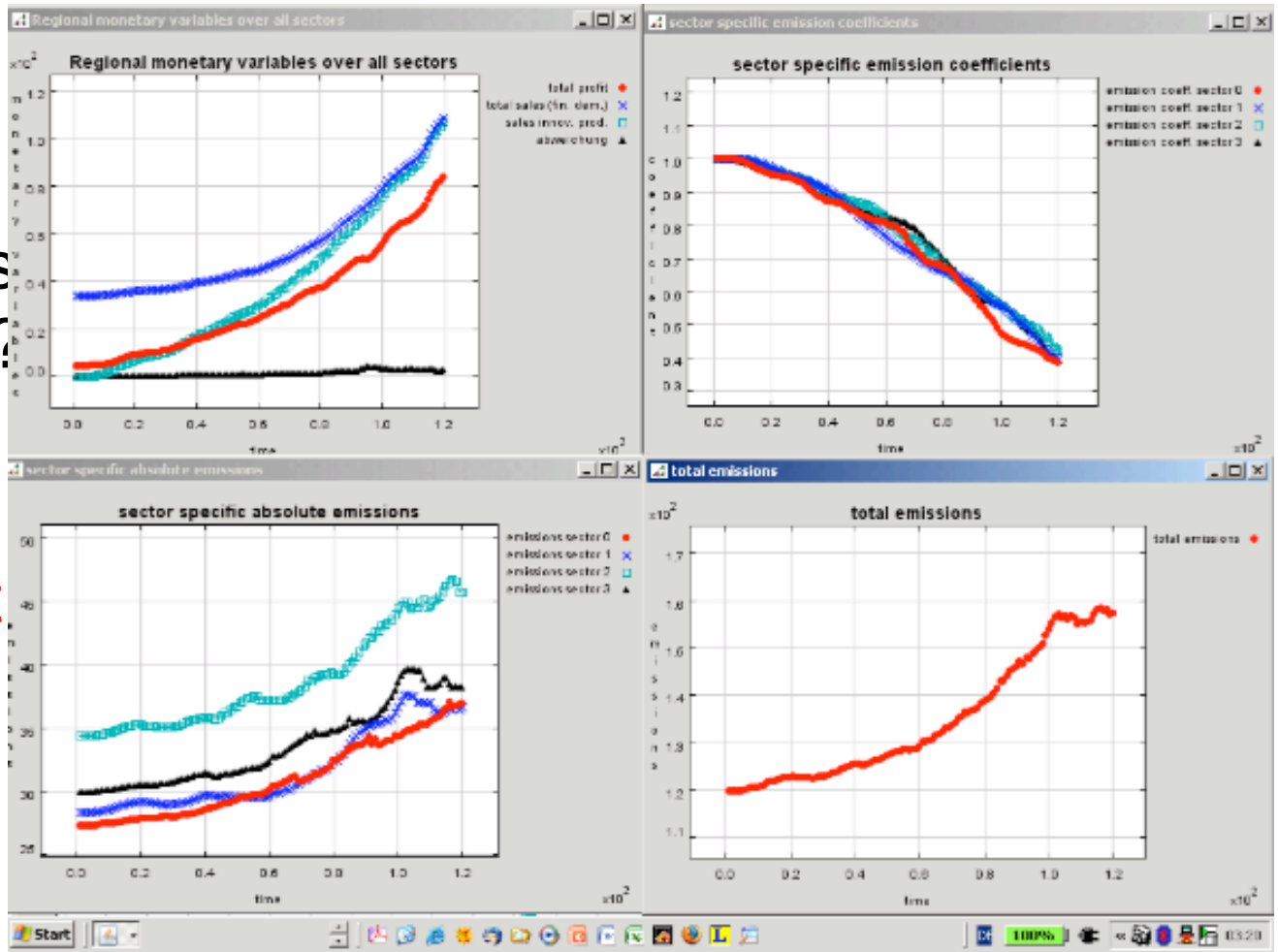


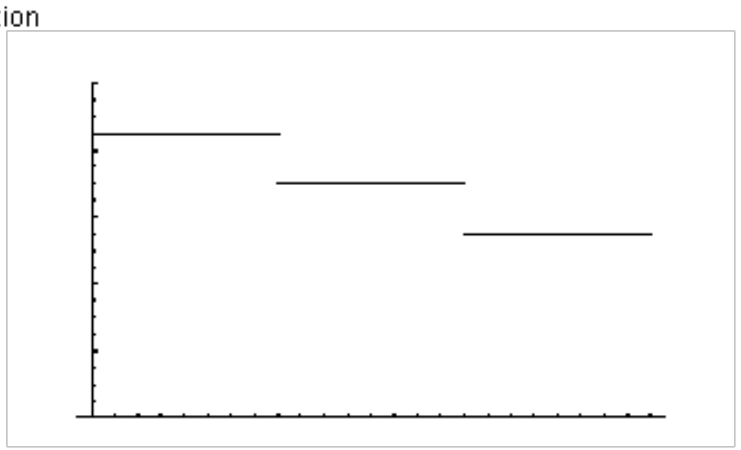
VI. Assessing policy measures

- Core of market-induced innovation dynamics
  - self-organized nature
  - unpredictable outcome
  - „innovation trap“
- What are the policy options?
  - blocking the core?
  - fostering differentiation?
  - redirection?

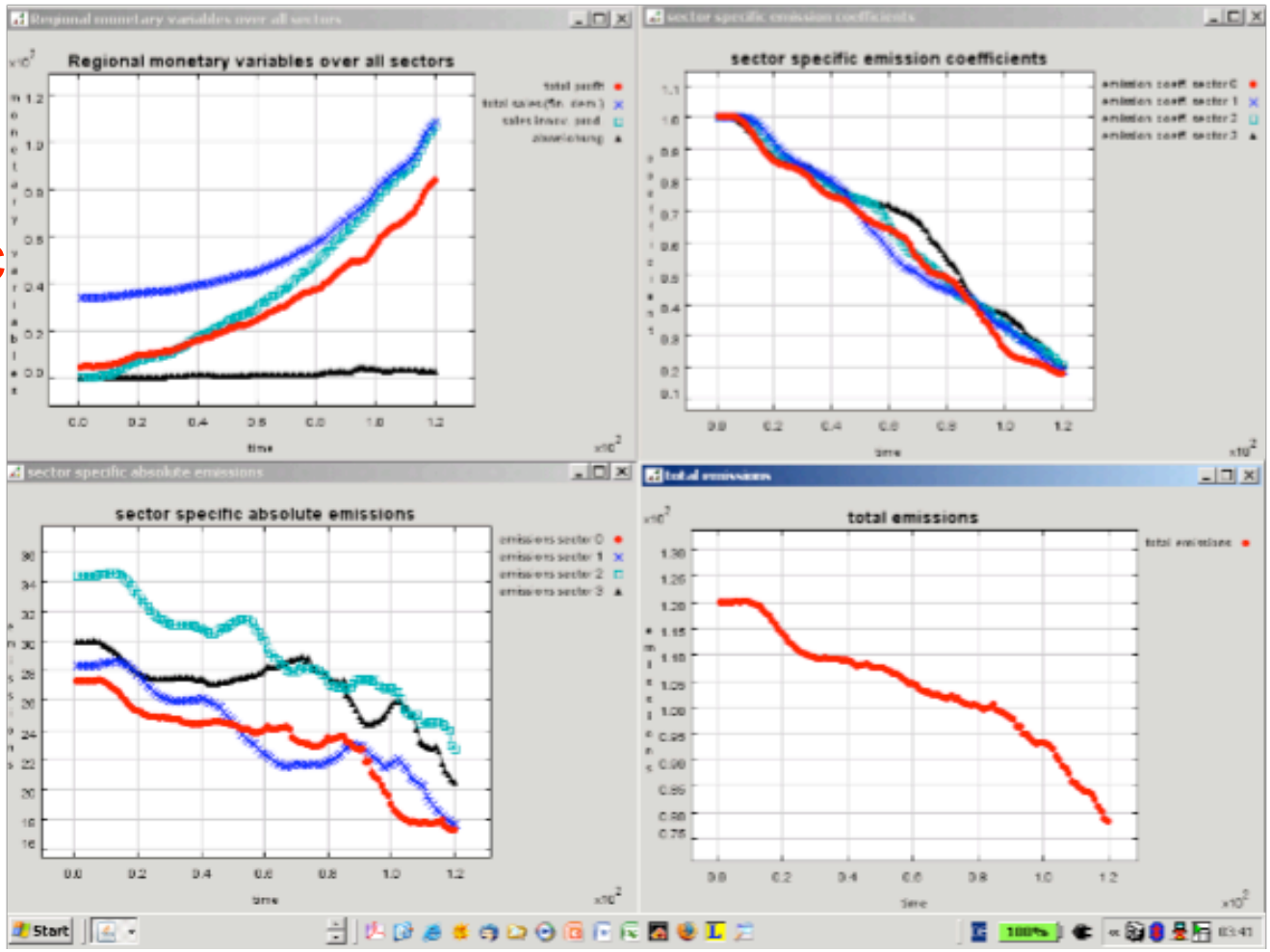


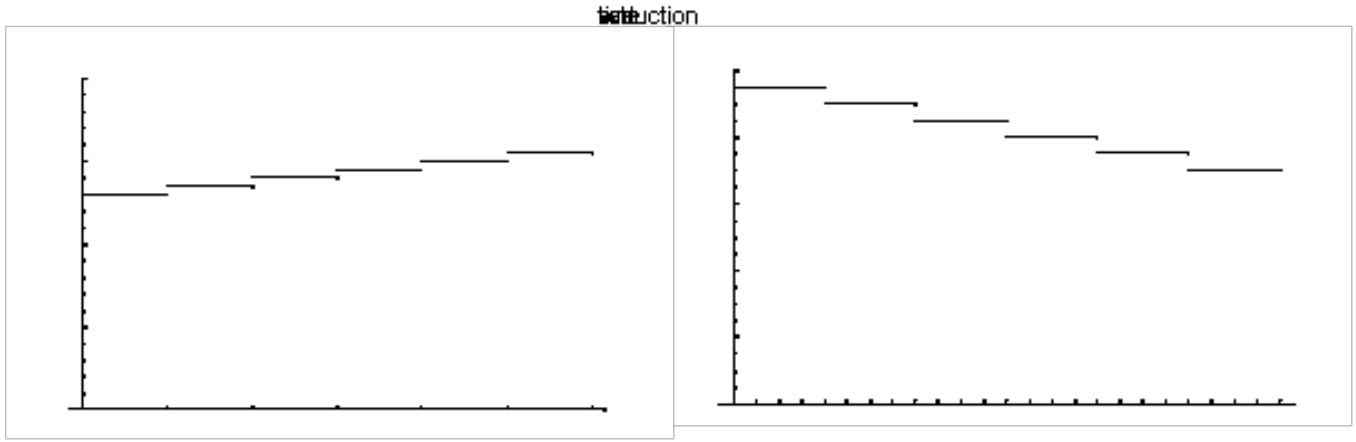
- Redirecting innovations
  - which measures are appropriate?
  - incremental dynamic short term abatement



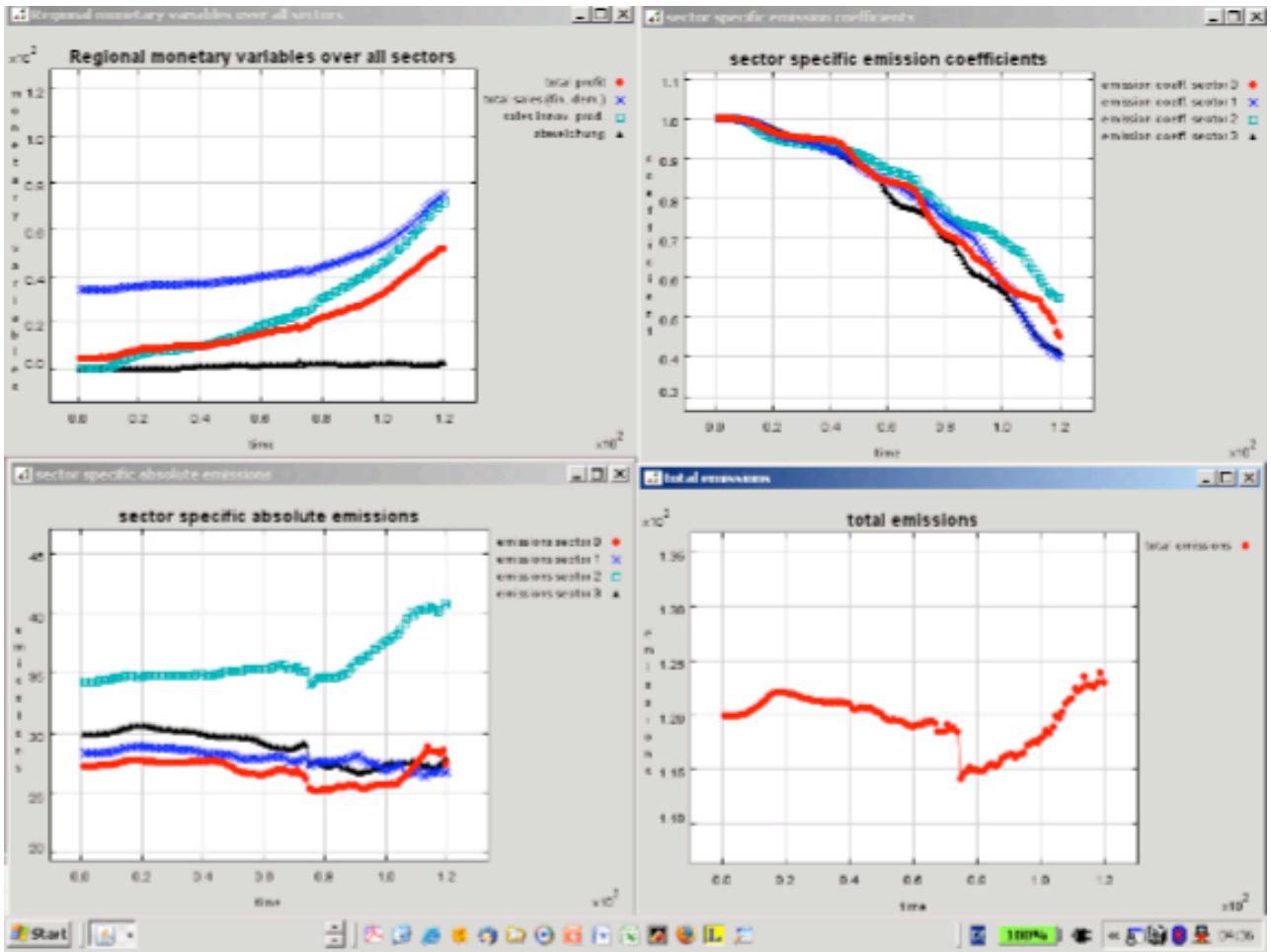


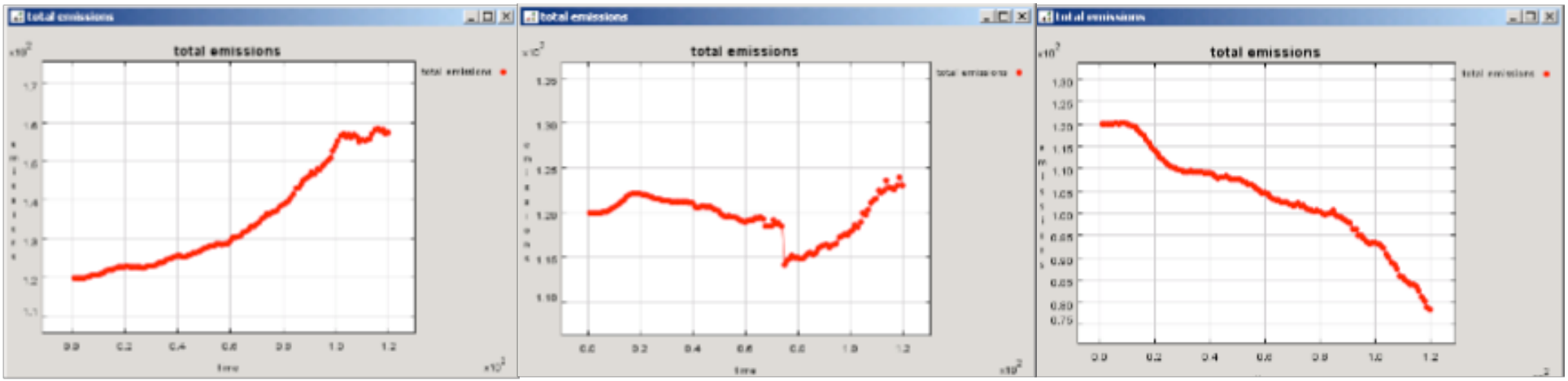
- Redirecting innovations
  - radical dynamic long term abatement





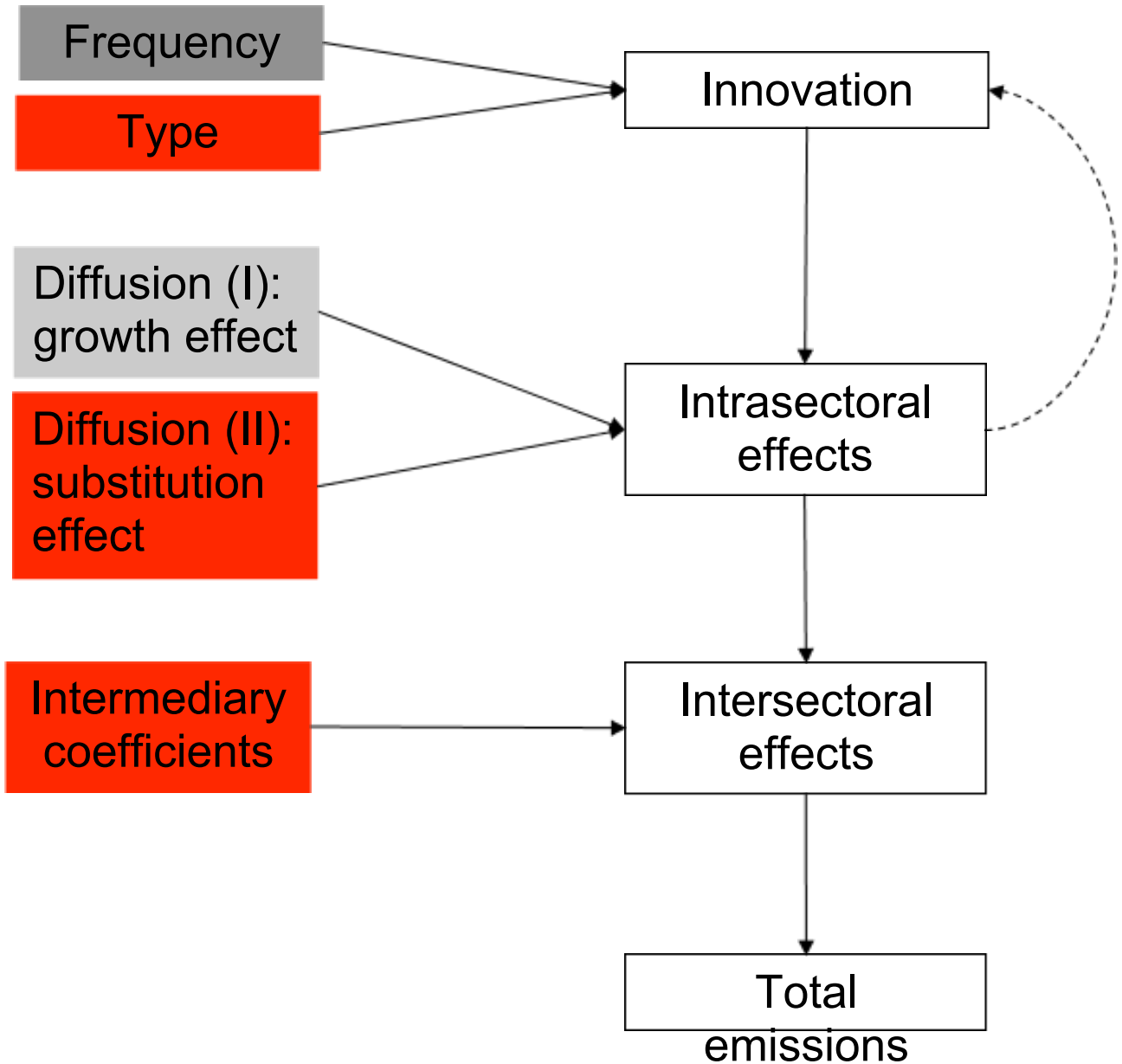
- Redirecting innovations
  - incremental dynamic short term abatement
  - incremental increase of innovation costs





- Trade off for reaching emission targets
  - failure of incremental improvements
  - ambiguous results of increasing abatement costs
  - radical change of innovation dynamics possible?
  - need for accomplishment by changing life styles/use patterns

VII. Conclusions



VII. Conclusions

- Need for bringing more conceptual realism into economic models
  - bounded rational agents
  - endogenous explanation of innovation and diffusion
  - multi-level analysis: bottom up and top down
- Multi-agent models indicate that emission targets are not sufficient
  - necessity to take agents into account
  - as well as: the context they are operating in
  - the time structure of regulation
- There are different paths to fulfill (or to miss) a target
  - need for selecting a path
  - updating according to observable results required
- Problem of path dependency

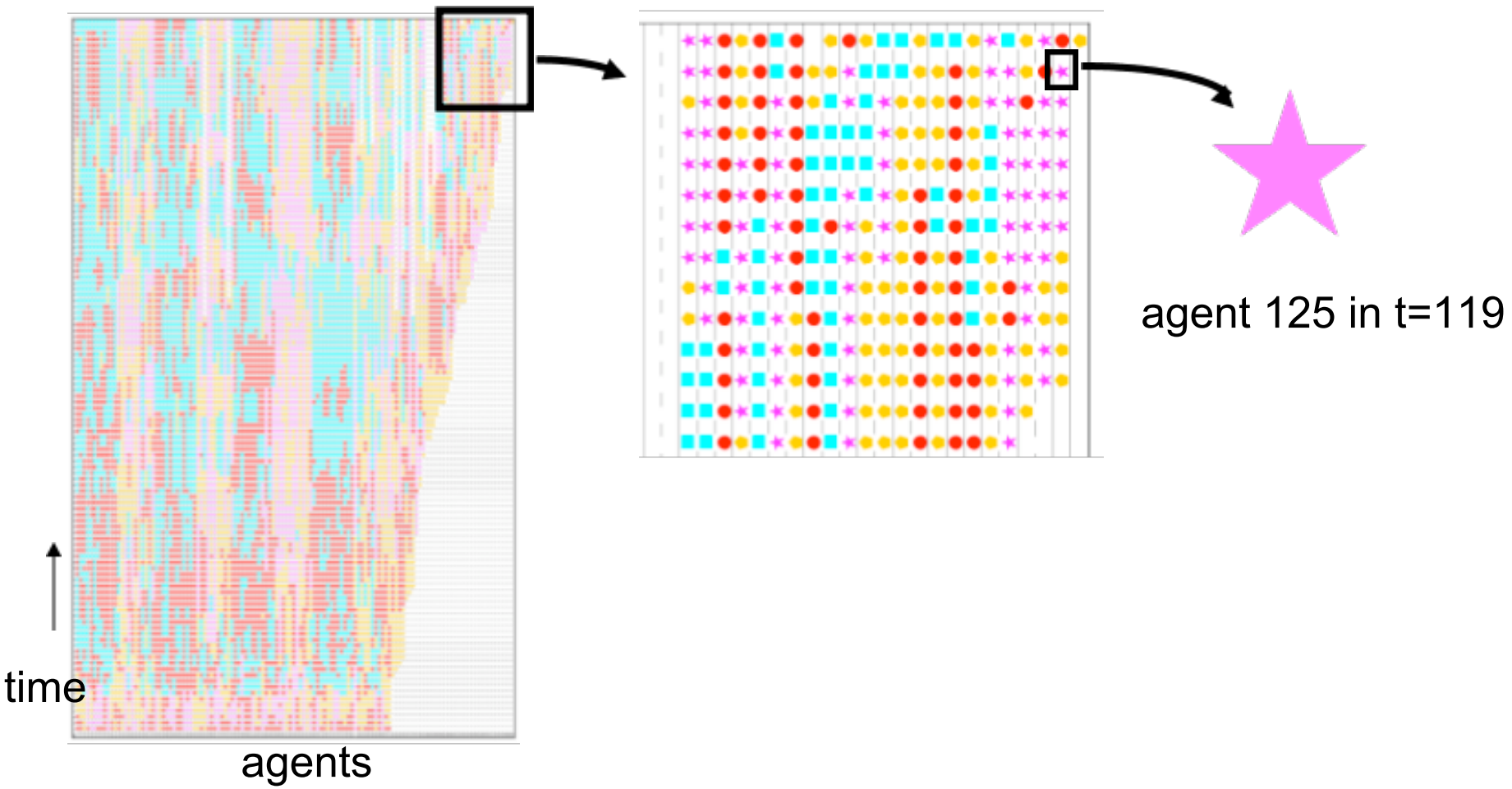
Thank You for Your attention!

More on agent-based economics:

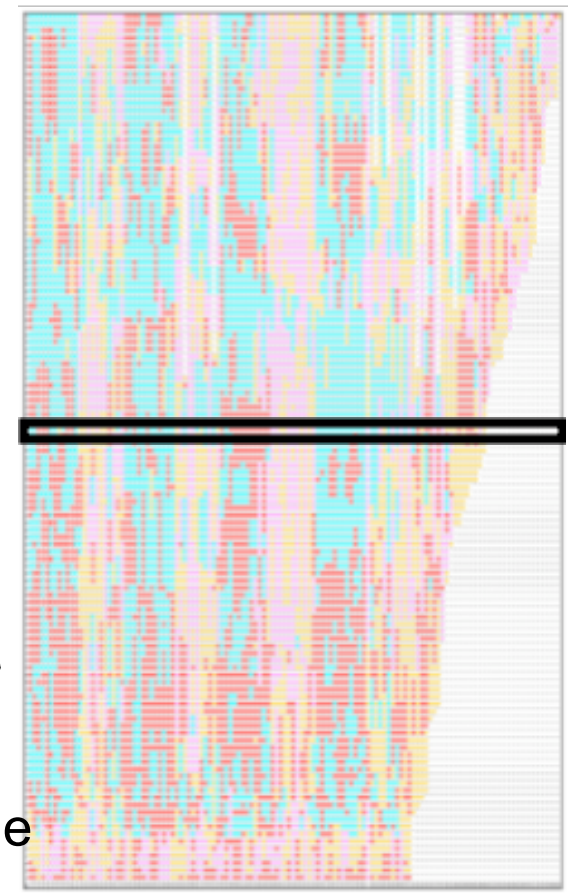
http://ivwl.uni-kassel.de/beckenbach/poabe.html

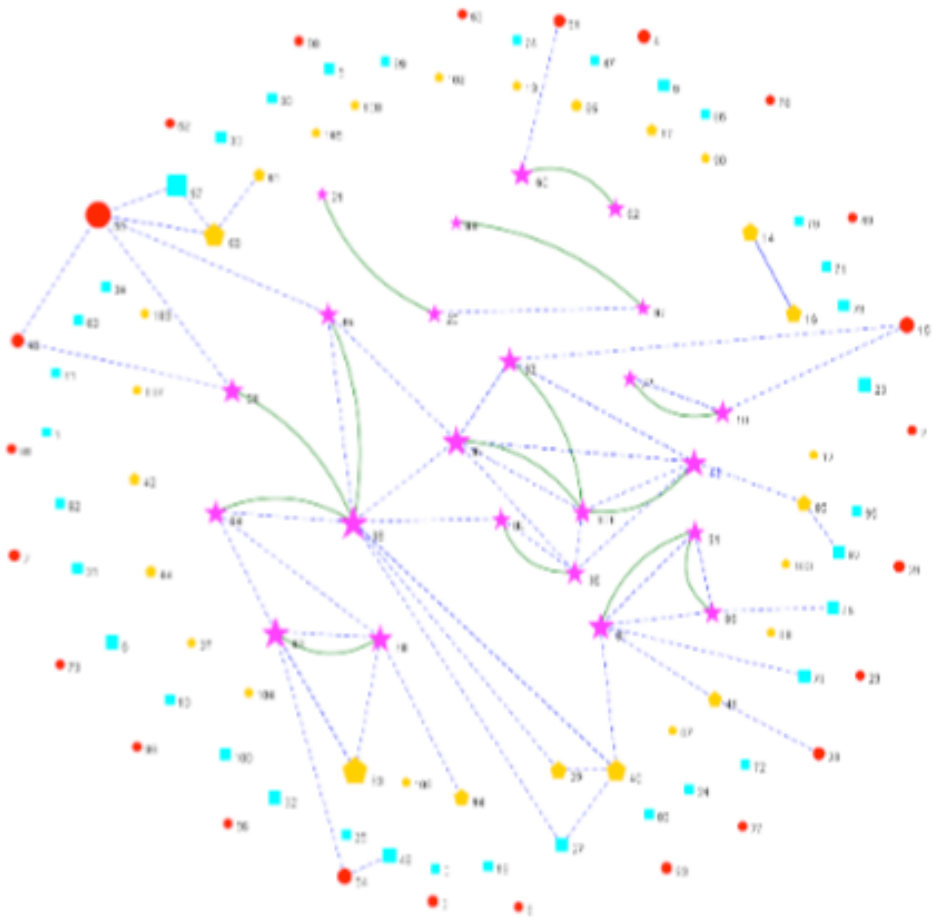
papers on agent-based economics

- New modelling perspectives: empirical agent-based dynamic modelling/cont.
  - What is it good for? (II): analysing states of agents over time



- New modelling perspectives: empirical agent-based dynamic modelling/cont.
  - What is it good for? (III): analysing interaction of agents as a generating force for overall regional development





layers and networks in t=60

Programming