

# Innovation Systems, Complex Systems and Sustainable Development: Transitions to a Low Carbon Economy

## Agent-Based Modelling for Transitions in Transport Jonathan Köhler

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# 1. Research Questions

Investigate the conditions under which we can move to a low carbon society in transport: how to get people out of cars

while 97% of individual passenger trips are short distance (100km or less)  
50% of car passenger km are over longer distances

Aviation: 200% growth by 2030?

International Shipping: 5-8% growth / year now have 12000TEU giant container ships

## A bit of background

Sustainable innovation is policy driven: will not happen on its own (Köhler, Whitmarsh, Michie and Oughton 2008)

Radical change necessary, consumers' preferences have to change too.

Kondratiev wave analysis (and current events) shows motor industry to be mature, oligopolistic and unprofitable in its current form.

Industrial structure unstable, gives possibilities for new products and institutional changes.

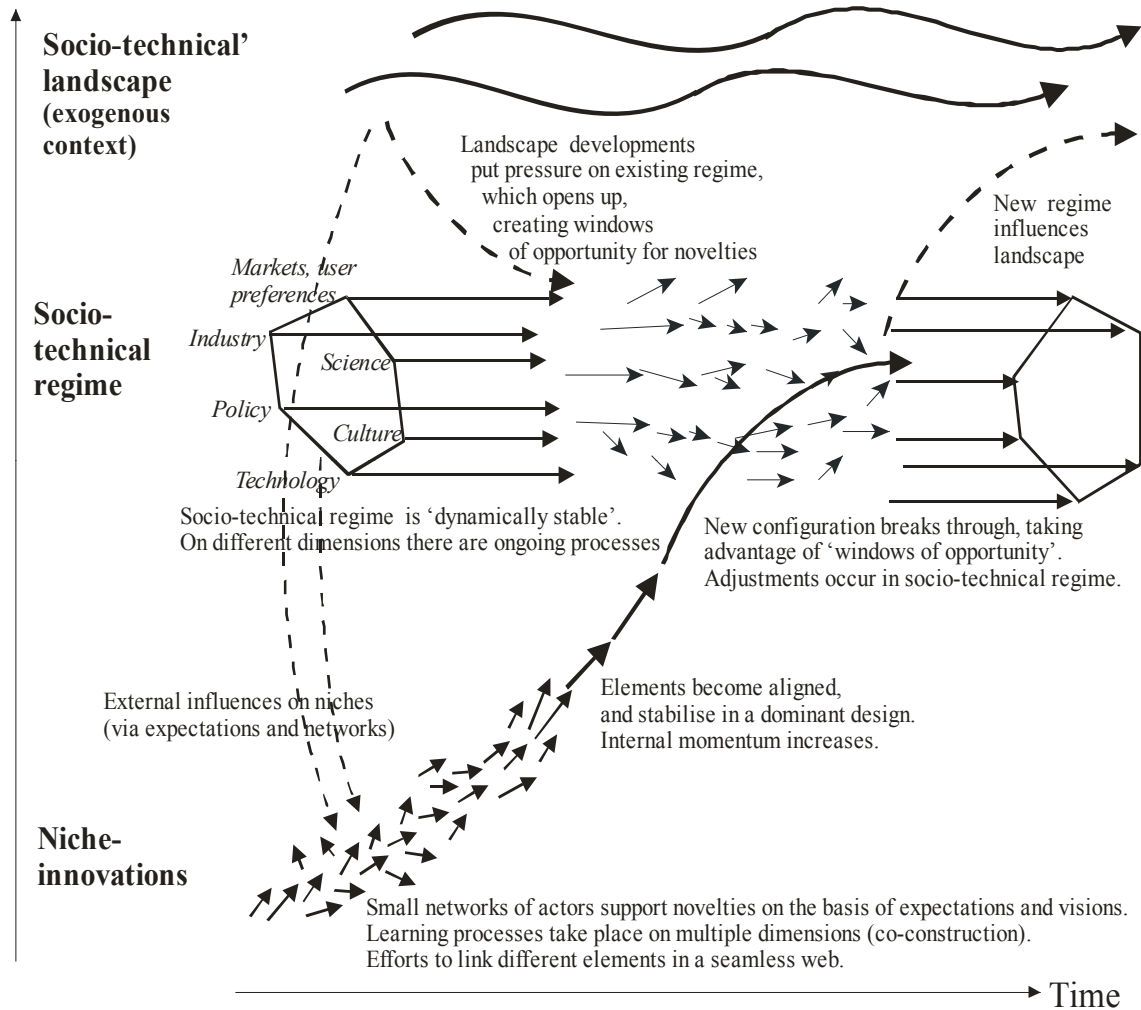
## Automobile industry becoming like shipbuilding?



# Transitions

Multi-level perspective on transitions  
(adapted from Geels, 2002: p. 1263)

Increasing structuration  
of activities in local practices



# Transition

A **Transition** in the sense of transition theory (Rotmans, Kemp and van Asselt (2001) is necessary

Change in consumer behaviour, technology and industrial structure, institutions

The insight of transition theory is that radical change comes through the development and growth of socio-economic-technical niches

## 2. Insights from complexity theory

- what makes a system complex? 'Overdetermined' – many redundant feedbacks
- redundancy is important – Peter Allen's example of species in the Gulf of Mexico
- system responds in unpredictable ways to shocks
  - But within bounds? E.g. Oil price? Or not?
  
- linear analysis and regression approximation does not capture the system properties, except in regions close to the observed data – not applicable to a structural change like a Transition
- A system is more than the sum of its parts, so have to model the parts i.e. agents explicitly – microeconomic analysis becomes macro

## Hu Jintao

### Insights from complexity theory: 2

**Policy does not determine what will happen, it can only set some (local) landscape conditions**

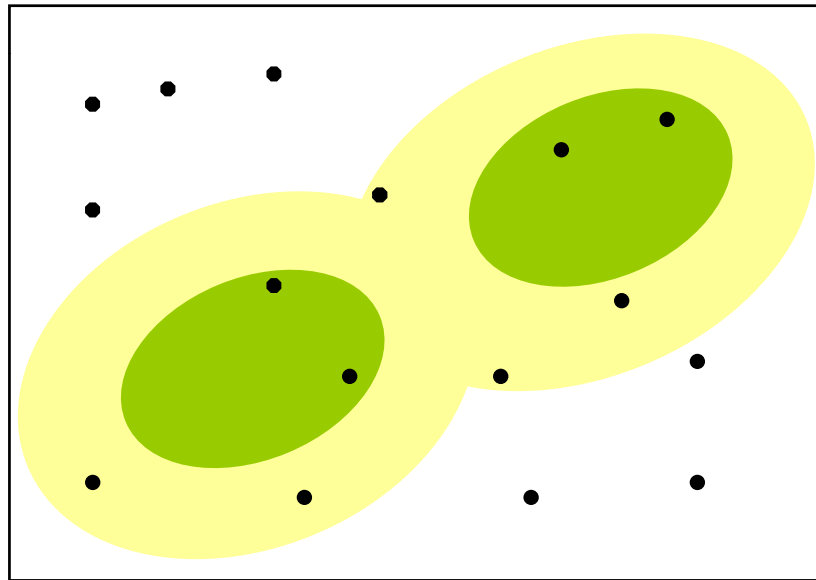
- the system is not predictable e.g. economic forecasting of GDP, energy demand etc. etc.
- cannot, as a society, choose a path and go down it
- not just a matter of convincing politicians – Obama, Brown, Berlusconi!?! To put in place the 'correct' policies. They only have a moderate influence.
- subject to many opposing pressures from voters, industry, NGOs, consumers.



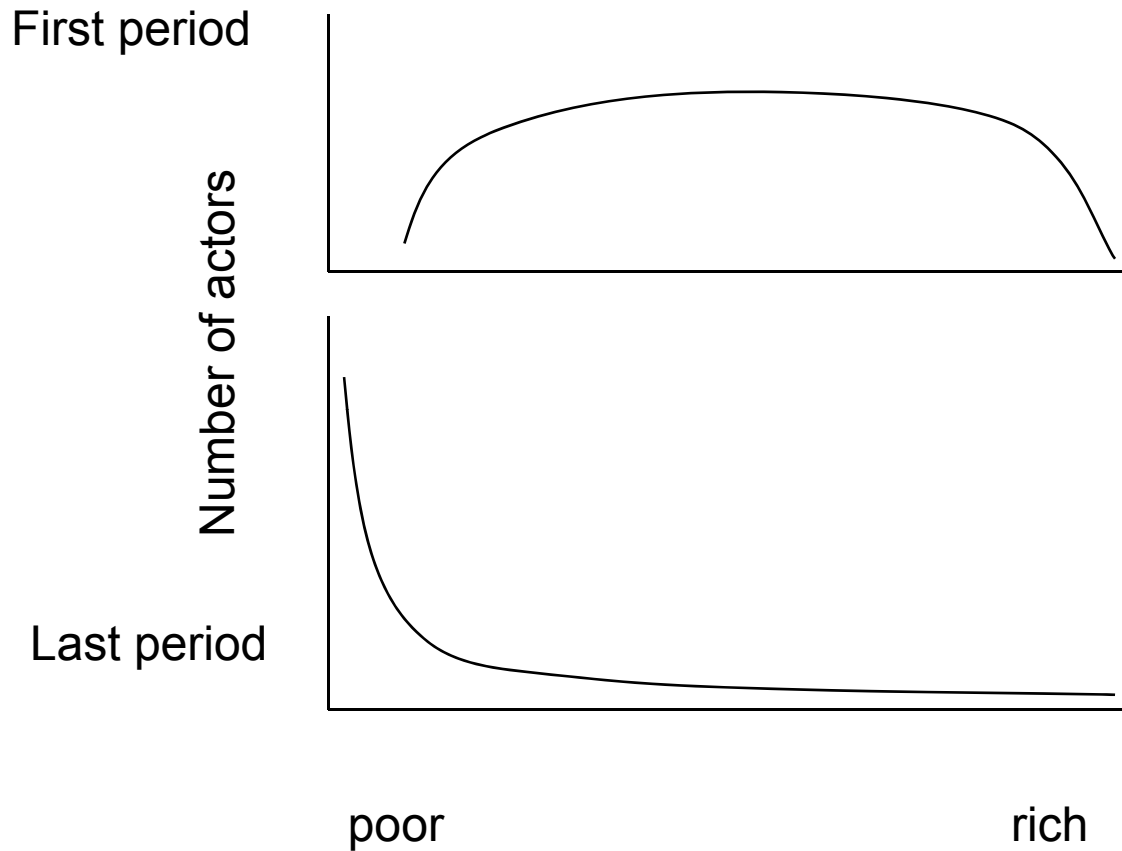
# What can Agent Based Models do? Beinhocker

- show how systems with lots of simple, but heterogeneous agents can demonstrate emergent properties

Epstein and Axtell 1996 Sugar World



# Epstein and Axtell 1996 Sugar World wealth distribution



# Sugar World: Emergent properties

Each agent has a different path, dependent on initial position, chance, effectiveness

2 goods world (sugar and pepper), trade only possible when two actors meet.

- trading developed in particular places.
- no market equilibrium, different prices in different places and times.
- lots more trades than needed to get to an equilibrium.
- specialist traders (as opposed to hunter-gatherers) emerge.
- when loans allowed, specialist banks emerge, including wholesale and retail banks.

## What do Agent Based Models NOT do?

Have interactions at a distance (but random graphs do)

Show how networks form

### 3. State of the art in transitions modelling for transport: our MATISSE model

#### A transitions model for sustainable mobility

Jonathan Köhler,  
Lorraine Whitmarsh,  
Björn Nykvist,  
Michel Schilperoord,  
Noam Bergman,  
Alex Haxeltine

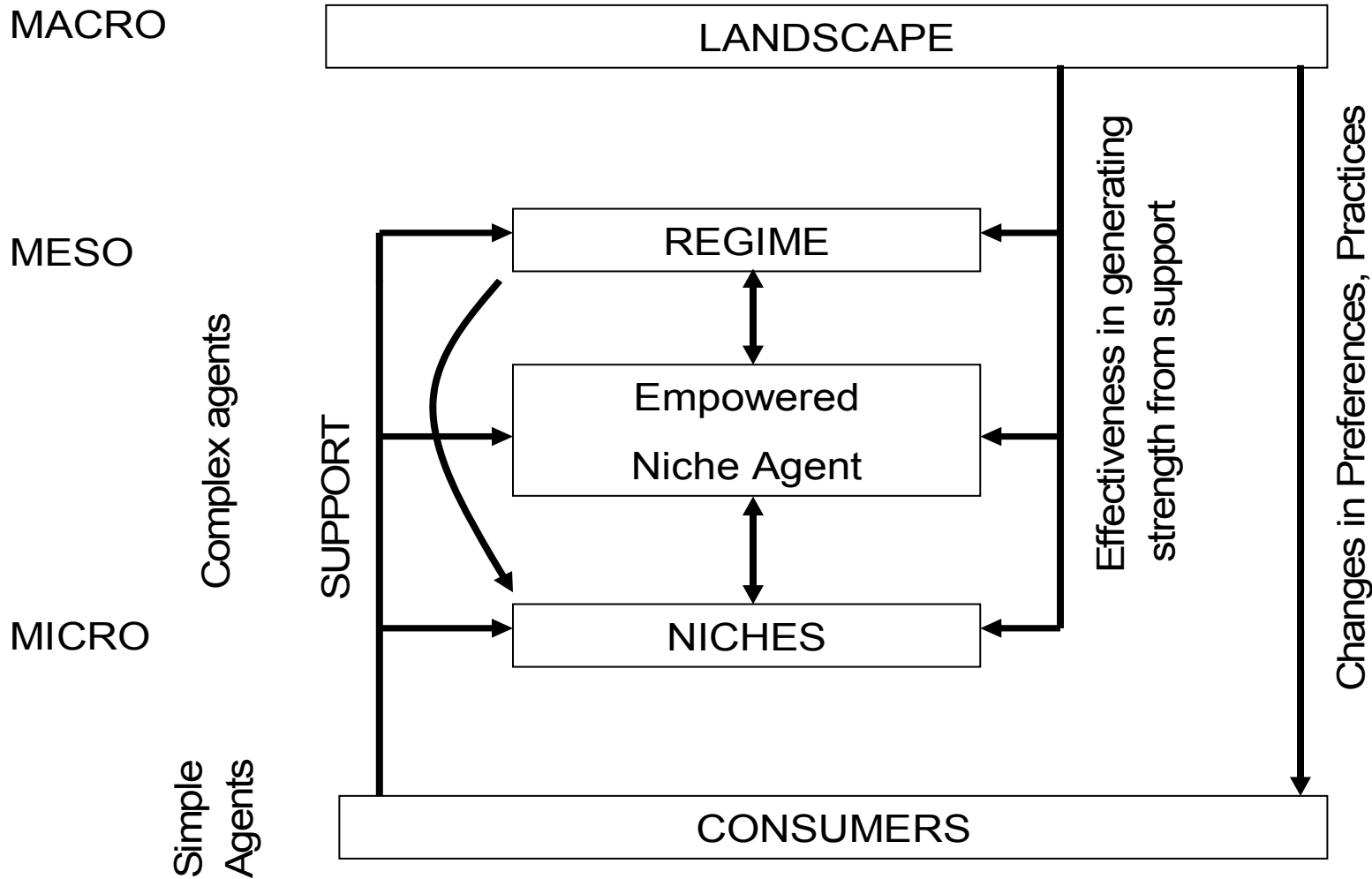
Research carried out in the EU project  
MATISSE



- small number of complex agents, which have an internal structure and are therefore sub-systems within society,
- larger number of simple agents
  
- practices as the metric through which agents position themselves in society and over which behaviour is defined.

represented as values along different axes, constituting a multi-dimensional *practices space*. Agents are differentiated by their positions in the multi-dimensional practices space.

# Overall structure of the model



# Landscape

strength and a direction in the practices space, which determine its push on the supporters

changing locations of the supporters force the agents to adapt or lose support and power

# Regime and Niches

## Car technology agents

- regime of internal combustion engine (ICE) motor cars,
- 3 Car niches: ICE/electric hybrid cars, biofuel cars and hydrogen cars (FCVs).



## Other niches:

increased use of public transport product to service shift (from car ownership to car sharing).

Reduced transport demand can be identified as adoption of slow modes (walking and cycling) and urban ICT.

# Practices

## Quantitative

- CO2 emissions of vehicles (gCO2/km),
- cost of transport (€/yr),
- public/private transport distribution

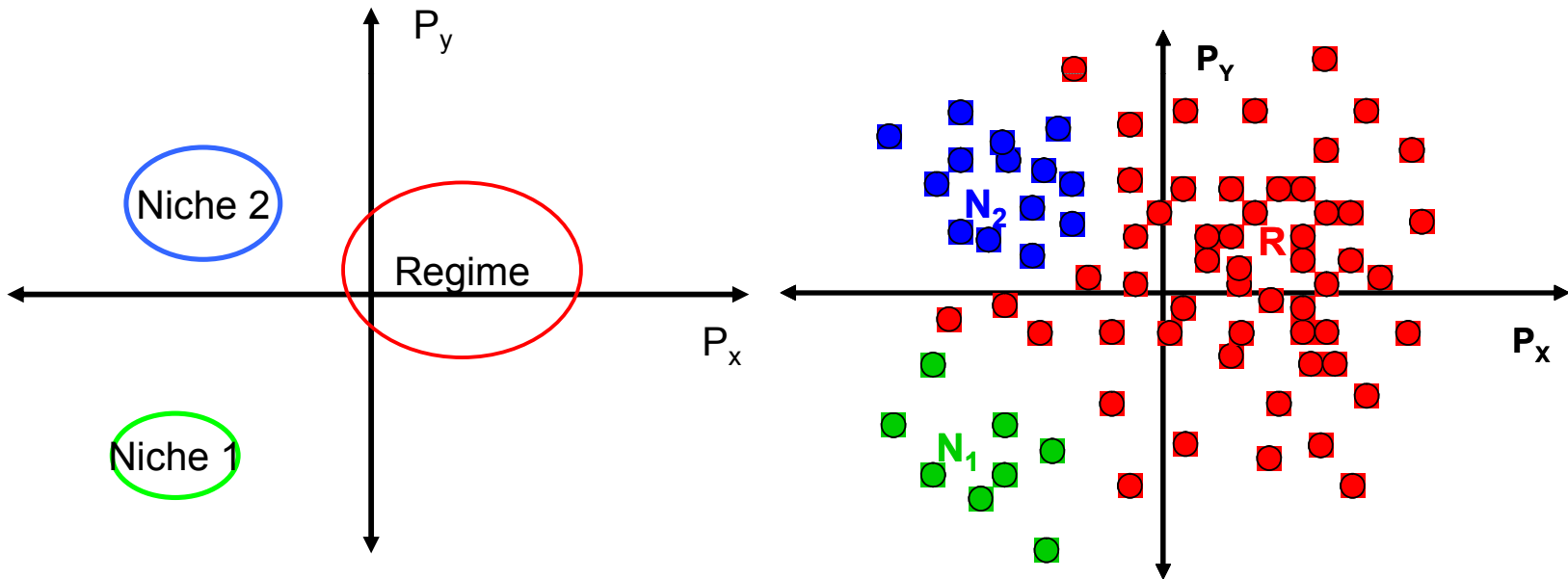
## Qualitative

- ICT use,
- structure of the built environment (mixed use of zones affecting mobility decisions)

# Support

Individual agents interact with niches and the regime via their decision to support the regime or a niche

Two illustrations of a two-dimensional practices space, with practice axes  $P_x$  and  $P_y$ . Left: regime and niches, which can move in the space and interact with each other. Right: the consumer agents showing supporters scattered in the practices space, coloured by the agent they support, red = regime (R), green = niche 1 (N1), blue = niche 2 (N2).



A transition occurs either when a regime is

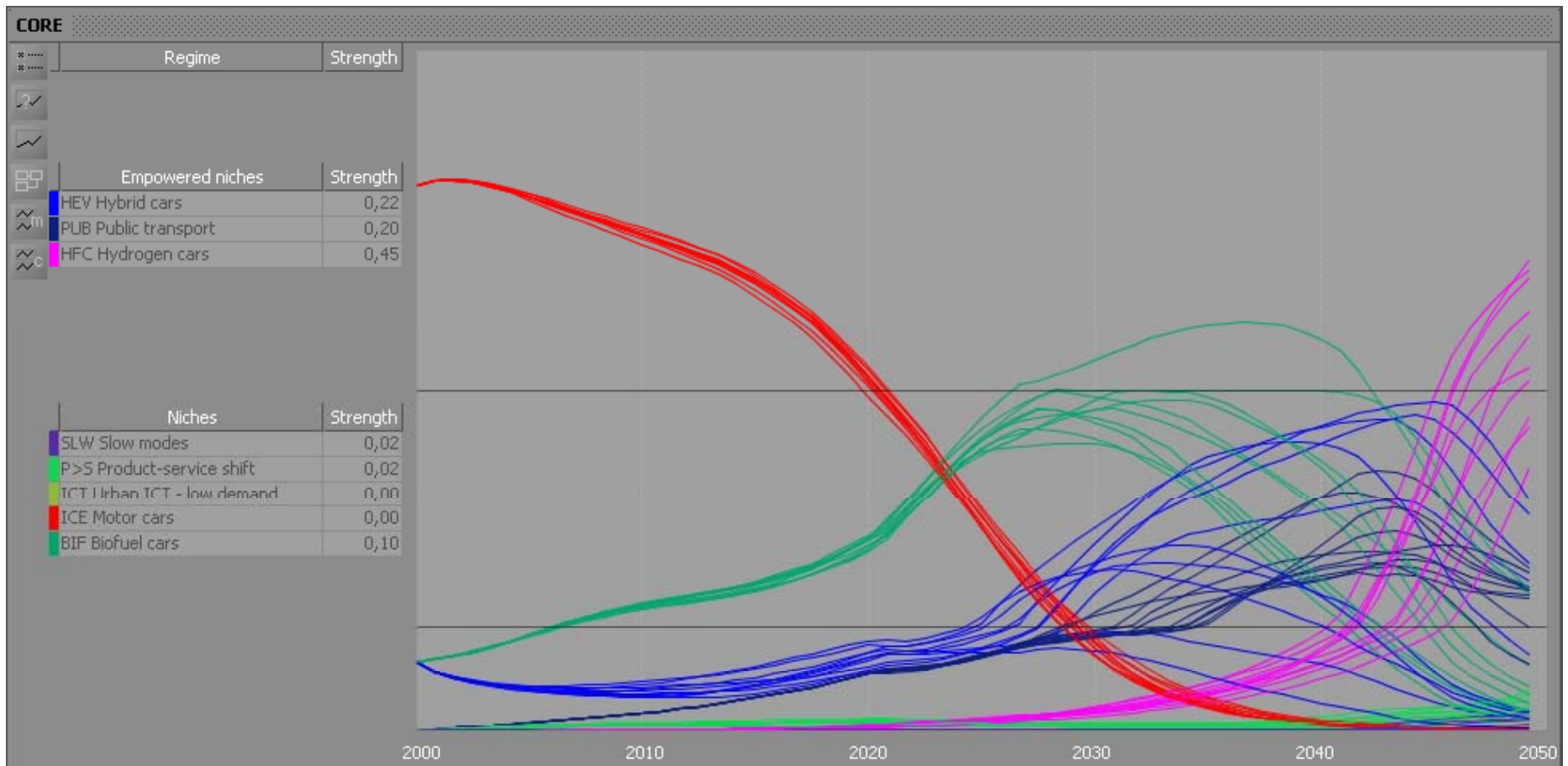
*transformed*

Regime responds to the systemic and landscape changes by changing some of its practices and rules, and possibly replacing some institutions and actors.

*regime change*

Regime unable to weather the changes, it collapses or is overthrown, and is (eventually) replaced by a new regime better suited to the new conditions,

# Main runs, demonstrating a transition to sustainable mobility



# Results

- Hydrogen fuel cell vehicles (FCVs) dominate, very long run (after 2030).
- Biofuels and ICE-electric hybrids main alternatives in the next 10-30 years, they are already developed  
they fit better into current infrastructures
- If all-electric vehicles were included, they might form the new regime and not FCVs.

Battery problems

## Results 2

- more radical shift in lifestyles, product-service shift and even public transport do not have a significant share in any of the results.

Such fundamental changes take a very long time,

require other forms of support than are currently modelled. Viable social change occurs most easily when innovations are consistent with the interests of the dominant groups, and to some extent the existing infrastructures and systems.

# Conclusions

- large-scale shift in both public perceptions and policy action is a prerequisite for a transition to a sustainable mobility system.

Must be maintained for a long time (20-30 years), for the radically different technologies to be able to develop to the point where they can out-compete the initially cheaper and preferred current and near-to-market technologies.

- the most successful alternative in the next 10 years may not be the best option in the long run, must support radical alternative niches
- radical institutional and behavioural change will probably be harder to achieve than technological change

challenge for policy-makers to inspire and connect to grassroots support for social change in order to effectively introduce potentially unpopular changes (e.g., fuel tax increases, parking restrictions); and to demonstrate the wider benefits of such changes

## Papers

Transport Application – resubmitted to Ecological Economics

Bergman, Noam, Haxeltine, Alex, Whitmarsh, Lorraine, Köhler, Jonathan, Schilperoord, Michel and Rotmans, Jan (2008). 'Modelling Socio-Technical Transition Patterns and Pathways'. *Journal of Artificial Societies and Social Simulation* 11(3)7 <<http://jasss.soc.surrey.ac.uk/11/3/7.html>>.

Haxeltine, A., Lorraine Whitmarsh, Noam Bergman, Jan Rotmans, Michel Schilperoord and Jonathan Köhler (2008) A Conceptual Framework for transition modelling, *Int. J. Innovation and Sustainable Development*, Vol. 3, Nos. 1-2, 93-114.

## 4. What to model next

Visions of the future – these are missing in the current debate



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## Develop with stakeholders



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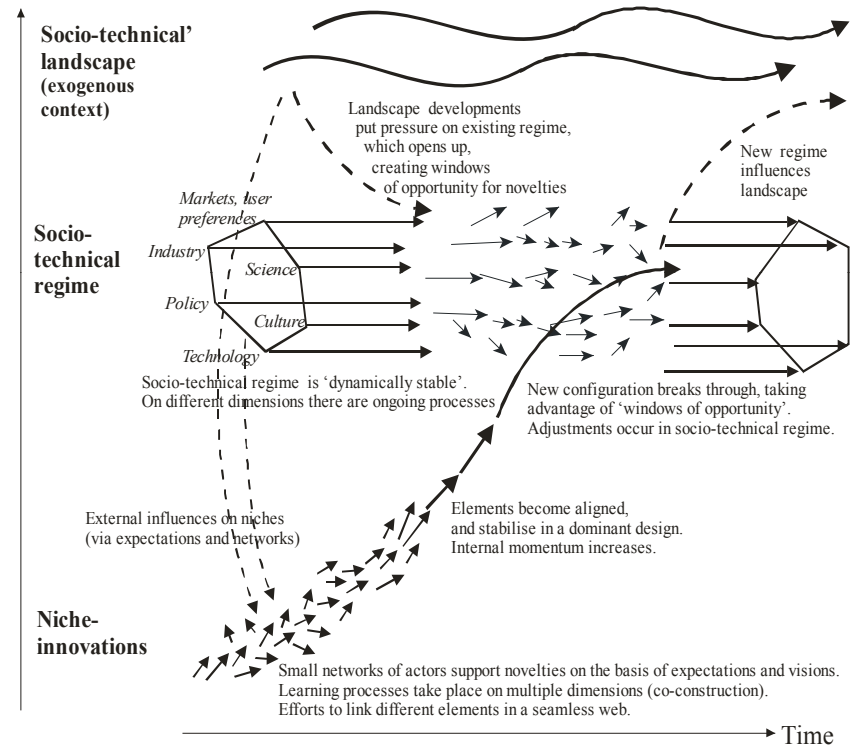
# Transition theory again

How do niches arise?

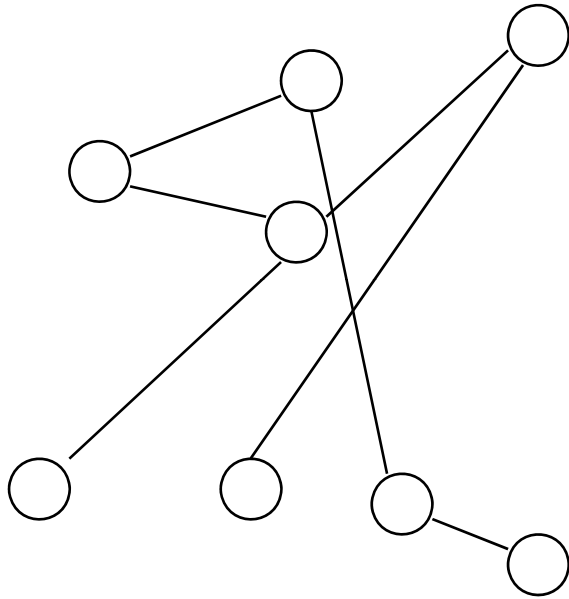
Under what conditions do they grow?

the problem with Geels is that he is mainly descriptive

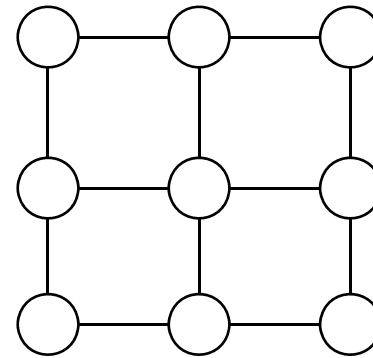
Increasing structuration of activities in local practices



# Niches (and regime) as networks



Random graphs



grids

# Niches (and regime) as networks

What are the connections between network 'nodes'?

- Market transactions
- Information to reduce search costs for new technologies
- Information about new lifestyles and services/products (housing, transport) to enable them
- Finding other actors who are doing similar/complementary things – i.e. similar positions in practices space

# Niches (and regime) as networks 2

Actors as members of multiple overlapping networks

With the internet, no longer completely geographic – the regime is everywhere anyway?

# What are the elements of a low carbon transport niche?

Actors:

consumers/households – or people???, firms, network entities – NGOs, International organisations, national, regional, local government

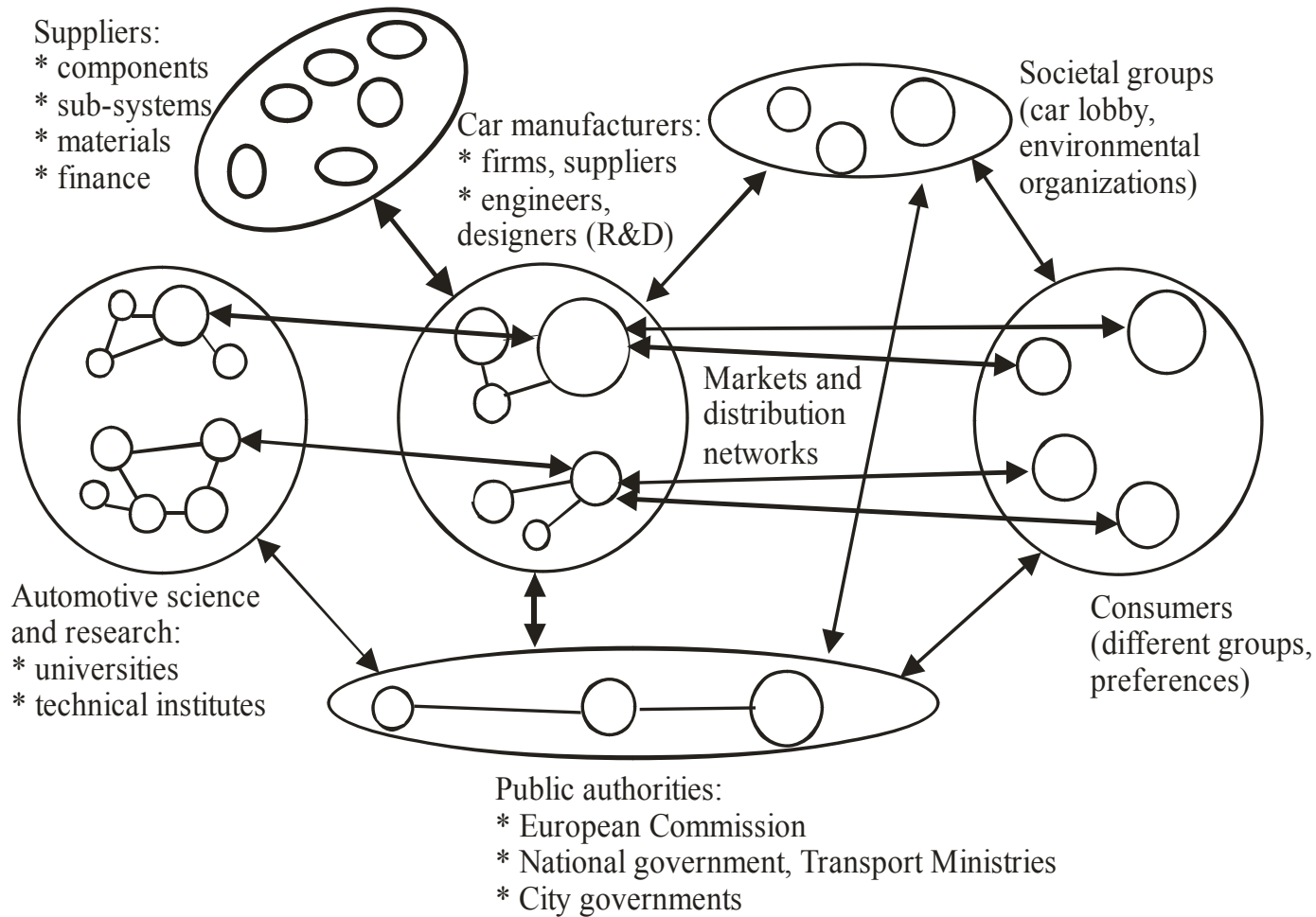
Start from demand: how and why do people change their travel behaviour?

'travelling' agents, location decisions, transport comes after?

Which of these can be regarded as part of the Landscape?

- Model of infrastructure expansion
- Model of changing urban morphology and transport provision
- Inter-urban vs. Urban – different services, but combined technologies?

# Organizational field with regard to car transport system Frank Geels



# What are the elements of a low carbon transport niche? 2

- How and why do people change their travel behaviour?
- Model of infrastructure expansion
- Model of changing urban morphology and transport provision
- Inter-urban vs. Urban – different services, but combined technologies?

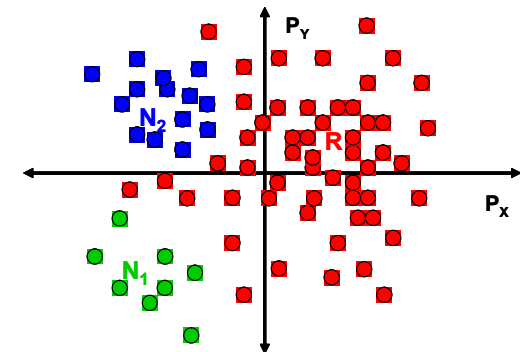
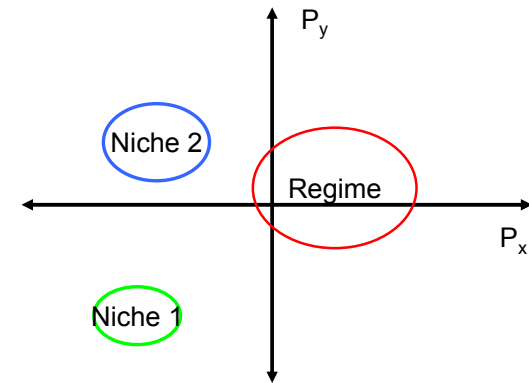
# Summary

Investigate the conditions under which we can move to a low carbon society in transport: how to get people out of cars

## Transition in the sense of transition theory

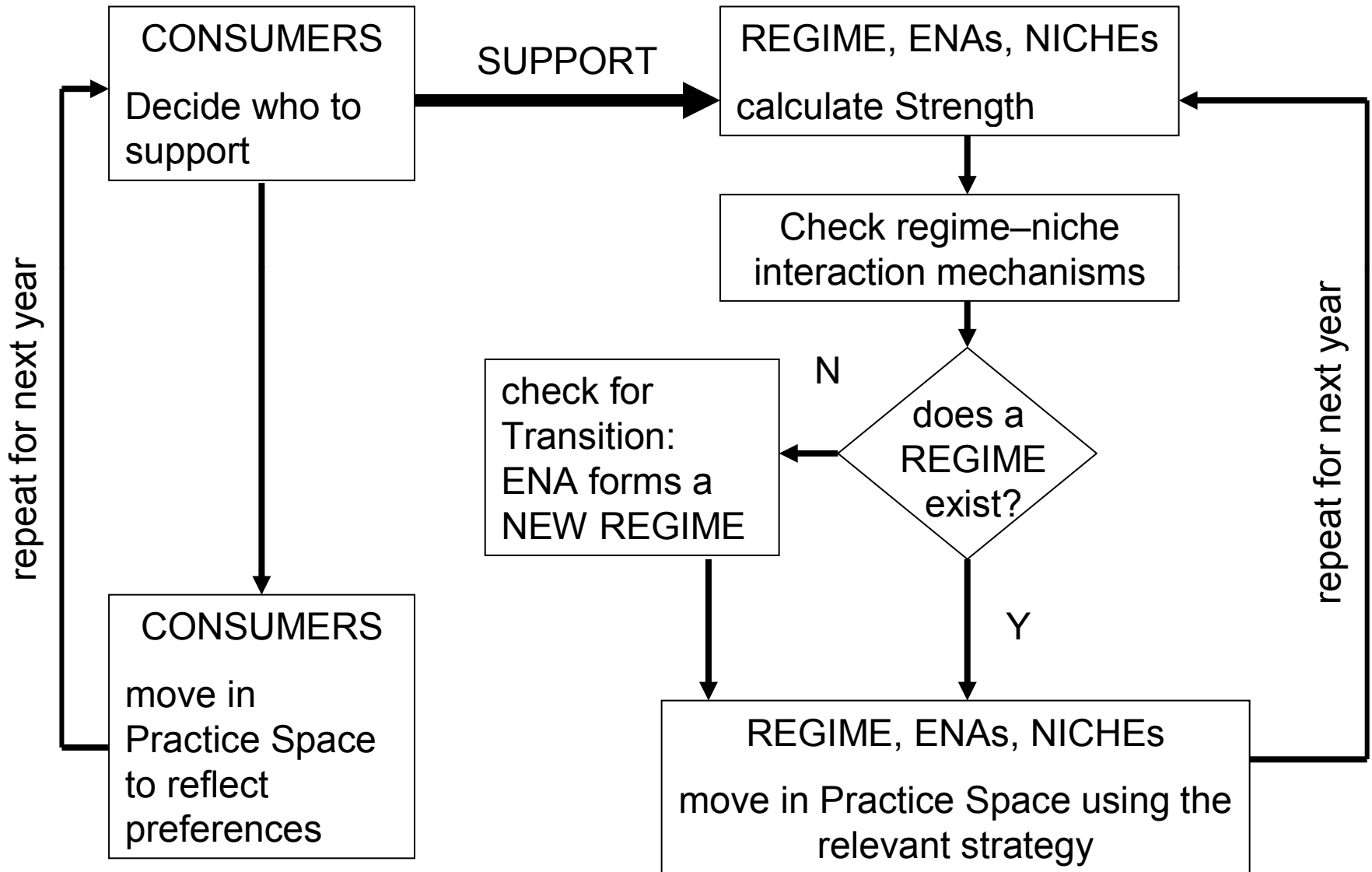
Niches (and regime) as networks

- How and why do people change their travel behaviour?
- Model of infrastructure expansion
- Model of changing urban morphology and transport provision



## Extra model description slides

Each period/year



# Model dynamics

- Adaptation

a change in practices possibly by assimilation, in order to improve fitness, i.e. to increase strength or support. Agents are constantly changing their position in the practice space

- Emergence of niches (birth)

parts of the practice space are not served by any existing agent, leading to unanswered demand. i.e. niches appear at random in locations in the space where there are supporters, but no nearby agent.

- absorption of a niche by the regime.

Transformation: change of an agent from one type to another:

Gaining strength: niche becomes an ENA, or an ENA becomes a (new) regime.

Losing strength, a (deposed) regime transforms into an ENA, or an ENA becomes a niche.

## Policies and landscape signals

integrated technological and behavioural change narrative for a possible mobility transition 2000-2050

*2000–10: opening up of a regime under pressure*

*2010–25: Take-off of public transport, ICT and alternative transport technologies*

*2025–40: Shared mobility, ICT and inter-modal transport challenge private car dominance*

*2040–50: Modal shift/ICT victory–demise of the private car*

# Landscape signals for the transport model

