Models of Technology Dynamics

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Where innovation starts

Introduction

- **Who am I?**
- **Who are you?**

An example

Another example

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From Euro 20.000

Successful innovation

- Is more than just a great technology
- It needs a well working innovation system in place
- And maybe a bit of luck?

- But this is really complex – how can we deal with it?

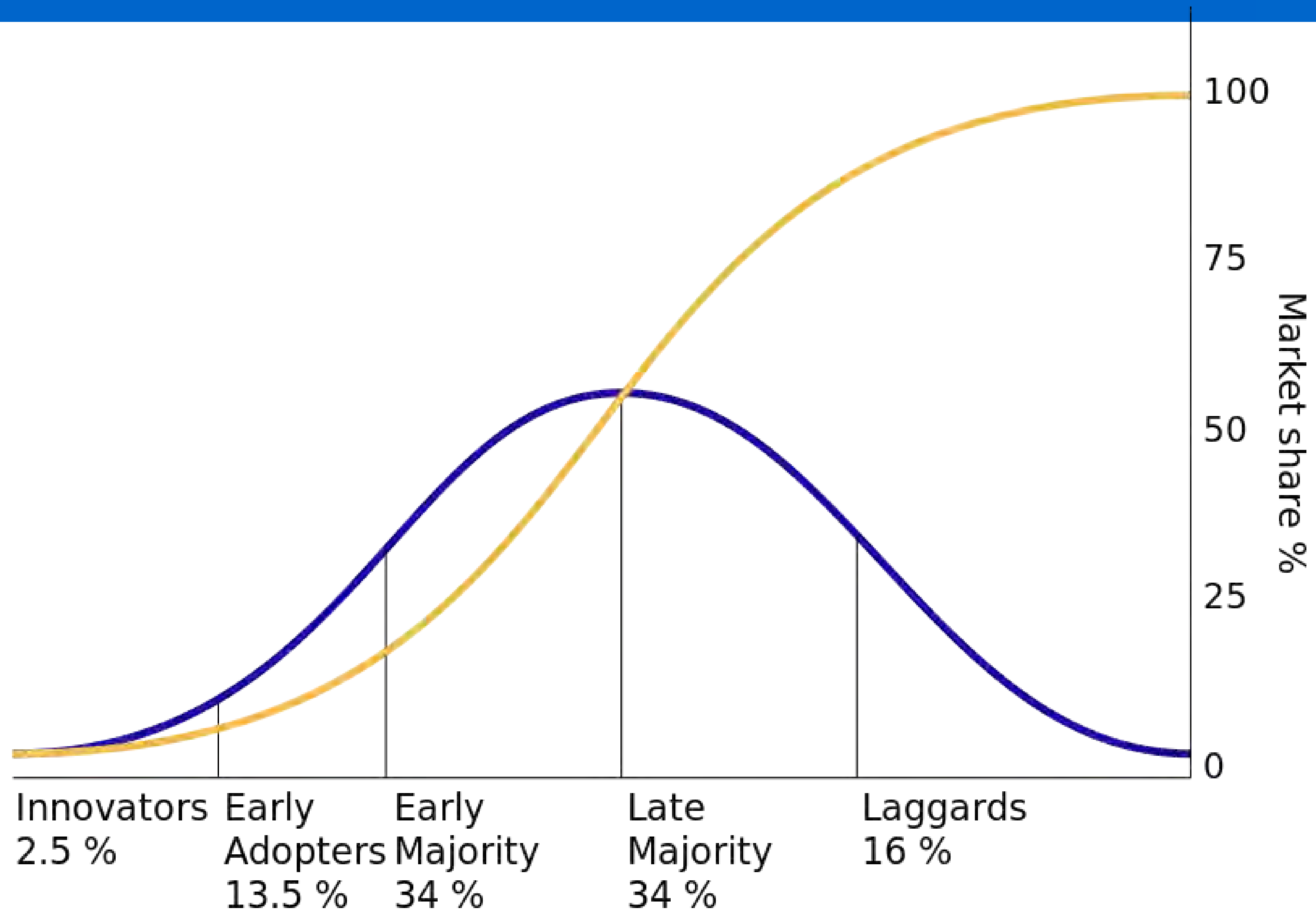
George Box:

"Essentially, all models are wrong, but some are useful"

Why models?

- What do you already know about innovation and technological change?
- What would you like to know...... If you were a:
  - Manager?
  - Policymaker?

Rogers: the diffusion of innovations



Model building

- Observe facts…
- Treat these facts as if they were the end product of a process that we do not know, and speculate about what that process might look like (i.e. build a model)
- Deduction: What would be other observable implications and consequences if our model of the underlying (but unobservable) process would be true?
- Test whether or not these implications and consequences do in fact occur (this is where you make your methodological choices!!)
- If necessary, go back to the drawing board to fine-tune your model, or to re-start from scratch

A small experiment 1

Can we think of a model that explains the S-curve?

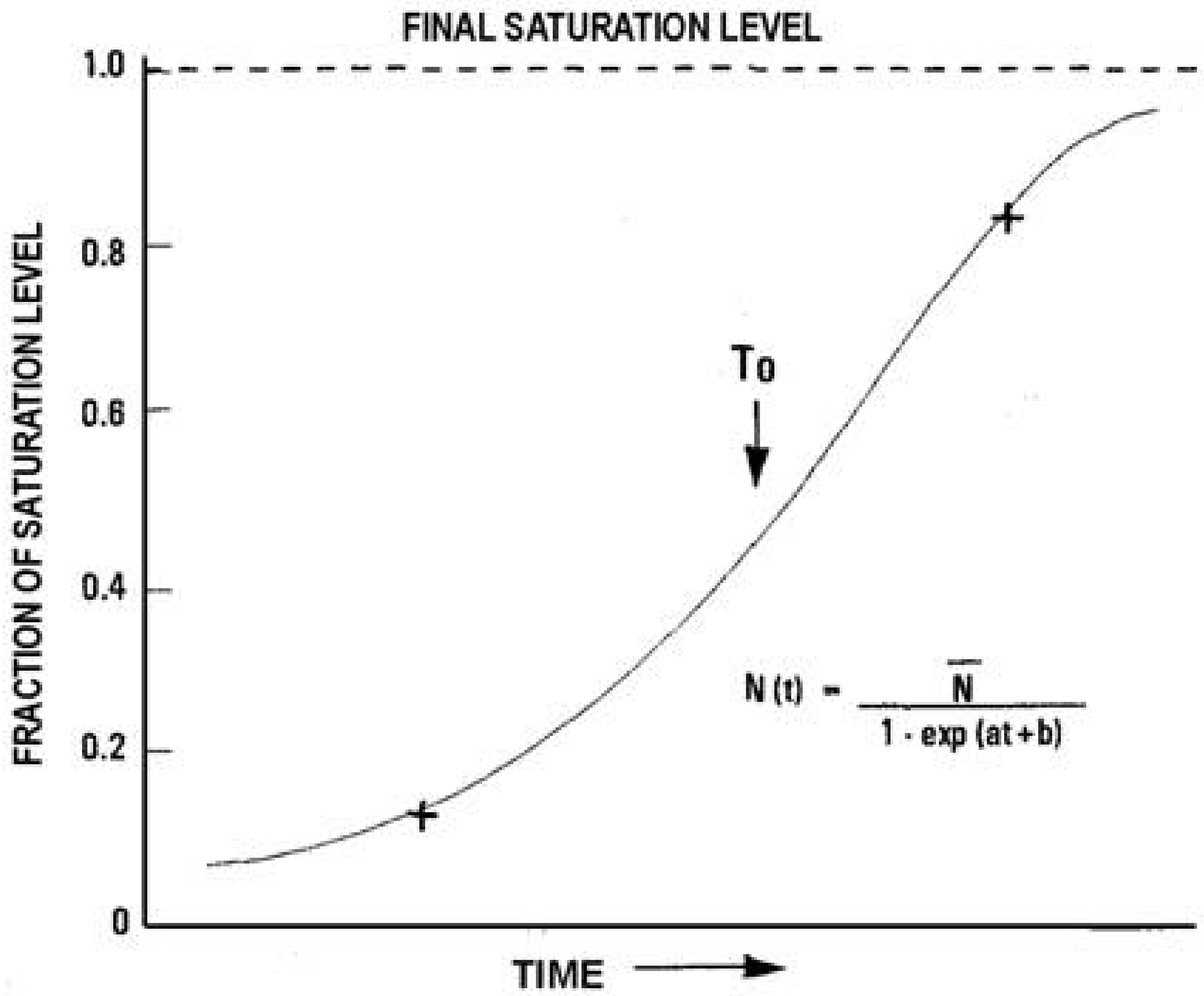
- **Form groups of 2**
- **Write down a single consumer rule**
- **If all consumers would follow this rule, the result would be an S-curve**

Diffusion models

- Rogers model has little predictive value
- Can we predict the shape of the curve before diffusion really takes off?

- Two models
  - The Bass model
  - The Fisher-Pry curve

The Fisher-Pry Curve



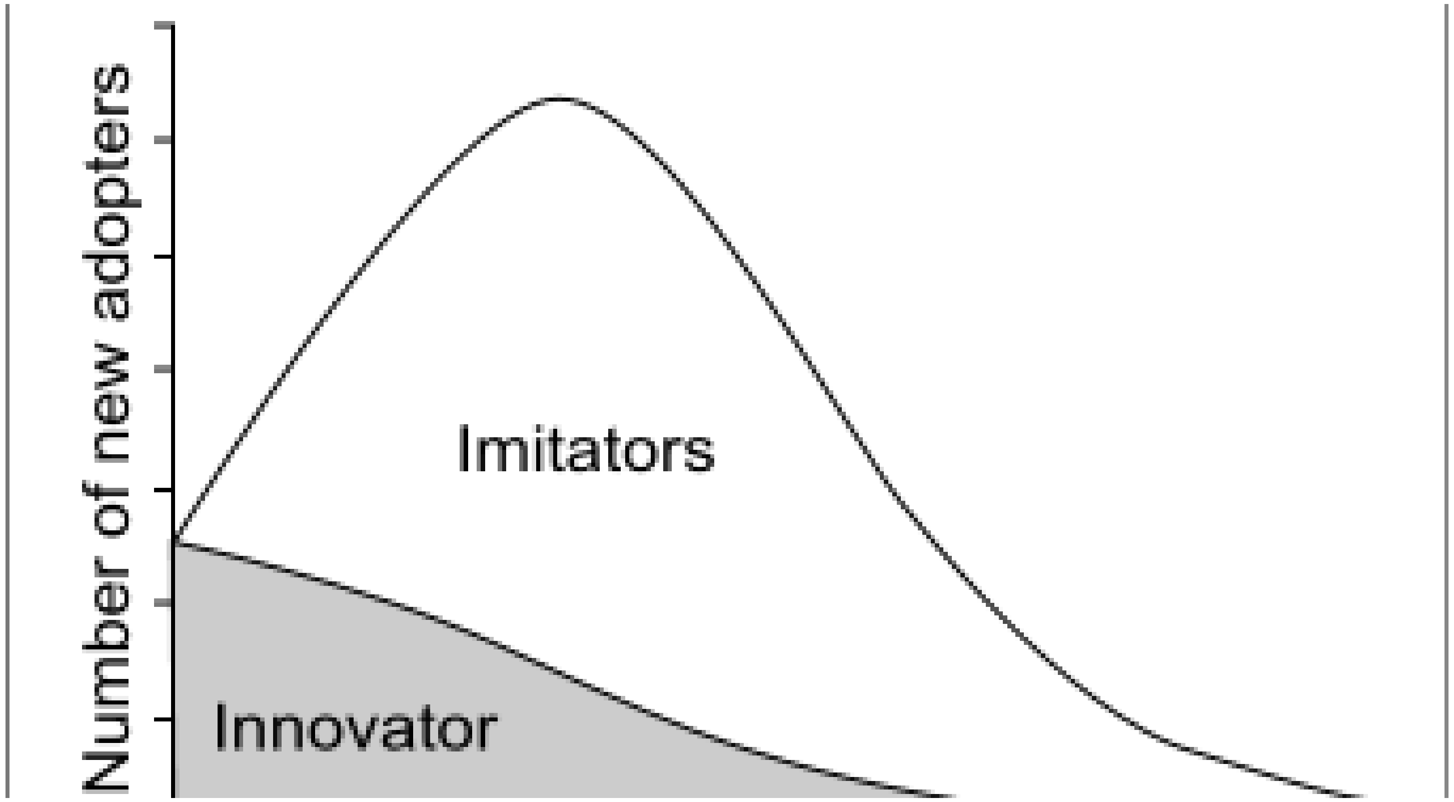
$f(t) = ½ [1+ \tanh \alpha (t-t_0)$

f fraction substituted

α half annual fractional growth in early years

At t_0, $f = 1/2$

The Bass model



The probability of adoption is a linear function of the total potential market (m), p the coefficient of innovation (external influence), and q the coefficient of imitation.

$P(t) = p + (q/m)\,Y(t)$

Where Y(t) is the cumulative number of adopters, so sales at time t ,

$S(t) = pm + (q-p)Y(t) – q/m\,Y^2(t)$

With two or more pieces of data on sales, you can estimate p and q

So

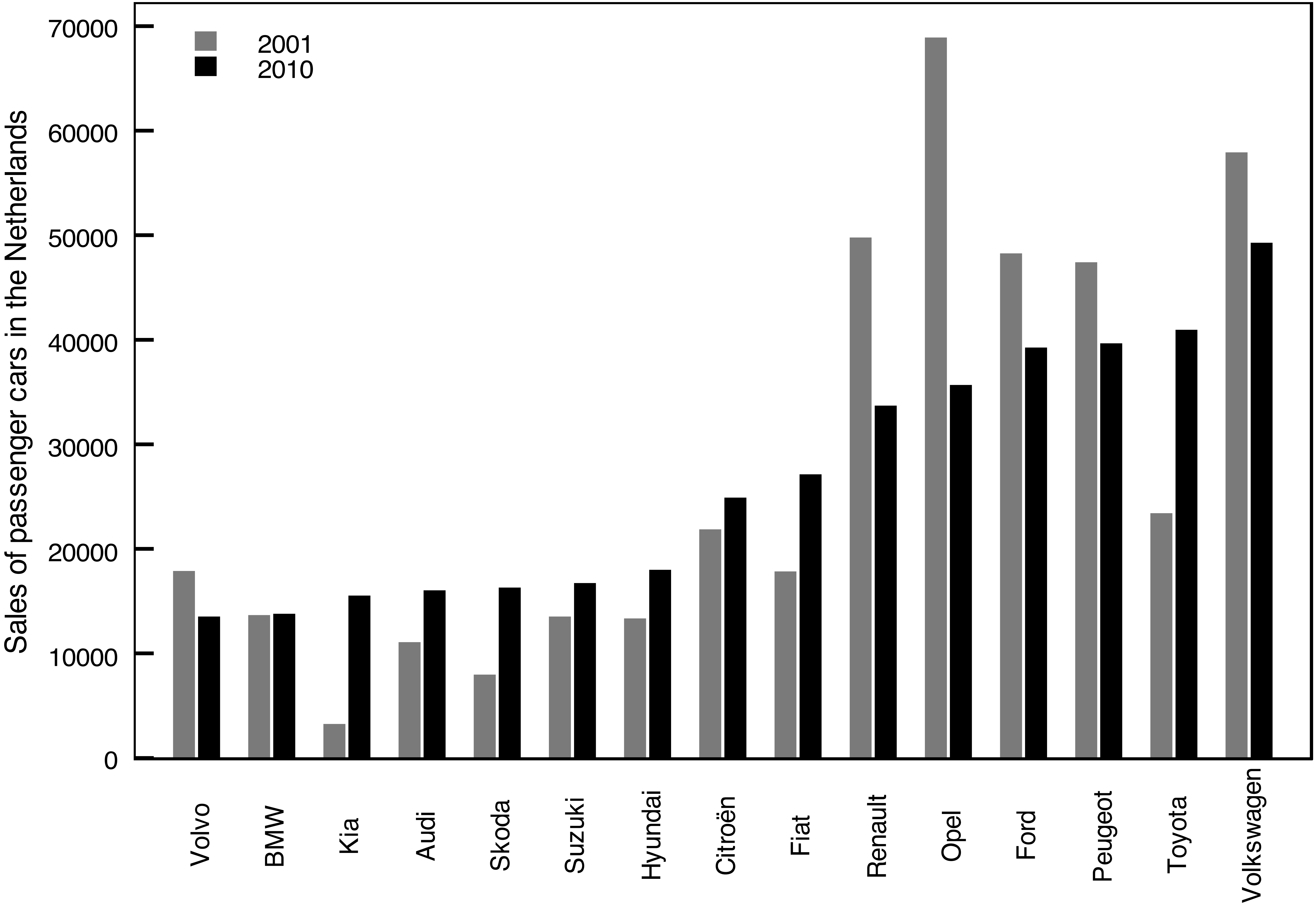
- **What information do you need to work with those two models?**

Example: sectoral change: the automotive sector

- Eco-labeling or energy-labeling increasingly popular
- Aim to stimulate demand for and supply of environmentally friendly goods
- But …. Mixed evidence
- The Netherlands have relatively strict environmental regulation, and early implementation of energy-labeling schemes
- No domestic car manufacturers

What did we do?

- To analyze the effects of energy-labels on the Dutch car market in the period 2001-2010
- Using a dataset consisting of all car models on offer on the Dutch market…
- As well as sales data



Sales of passenger cars in the Netherlands
70000
60000
50000
40000
30000
20000
10000
0
2001
2010
Volvo
BMW
Kia
Audi
Skoda
Suzuki
Hyundai
Citroën
Fiat
Renault
Opel
Ford
Peugeot
Toyota
Volkswagen

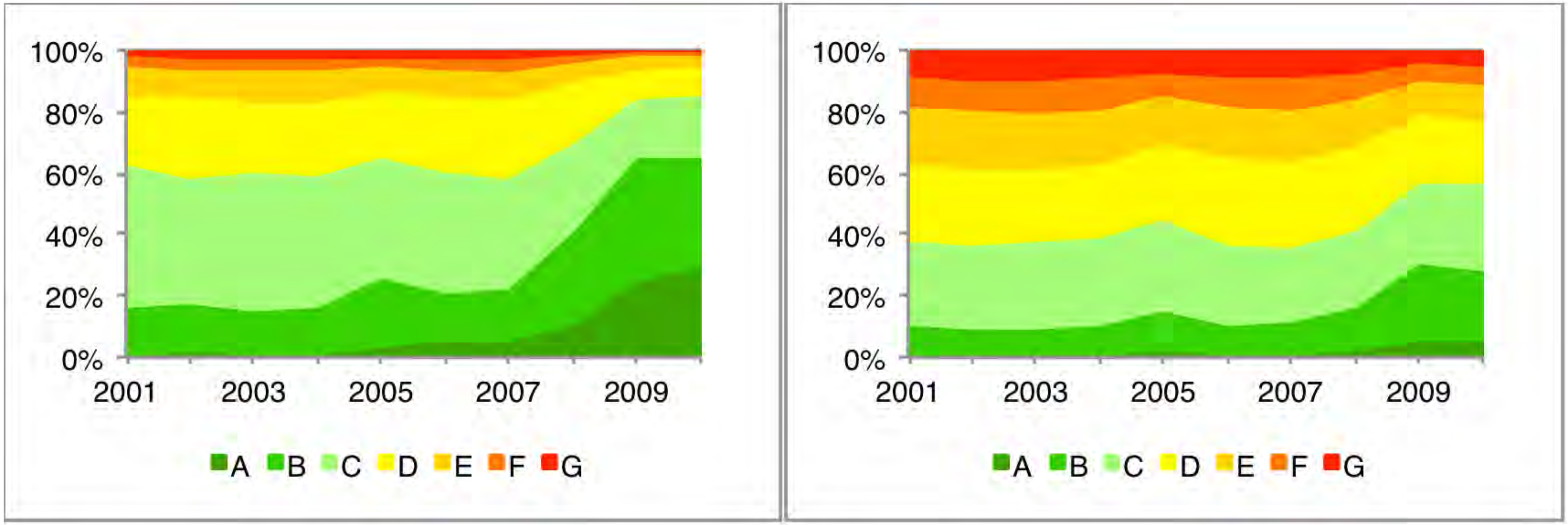


Figure 1. Distribution of passenger car sales (left) and supply (right) over energy-labels. Source: (CBS et al., 2012) based on data from RDW.

Theoretical framework

- Characteristics approach (Lancaster, Saviotti)
- The product portfolio of a firm can be described by looking at characteristics of the products offered by the firm
- Firms that offer products with similar characteristics compete
- There is an incentive to differentiate
- But there is also an incentive to move closer to product that are successful
- Energy-labels are an additional product characteristic

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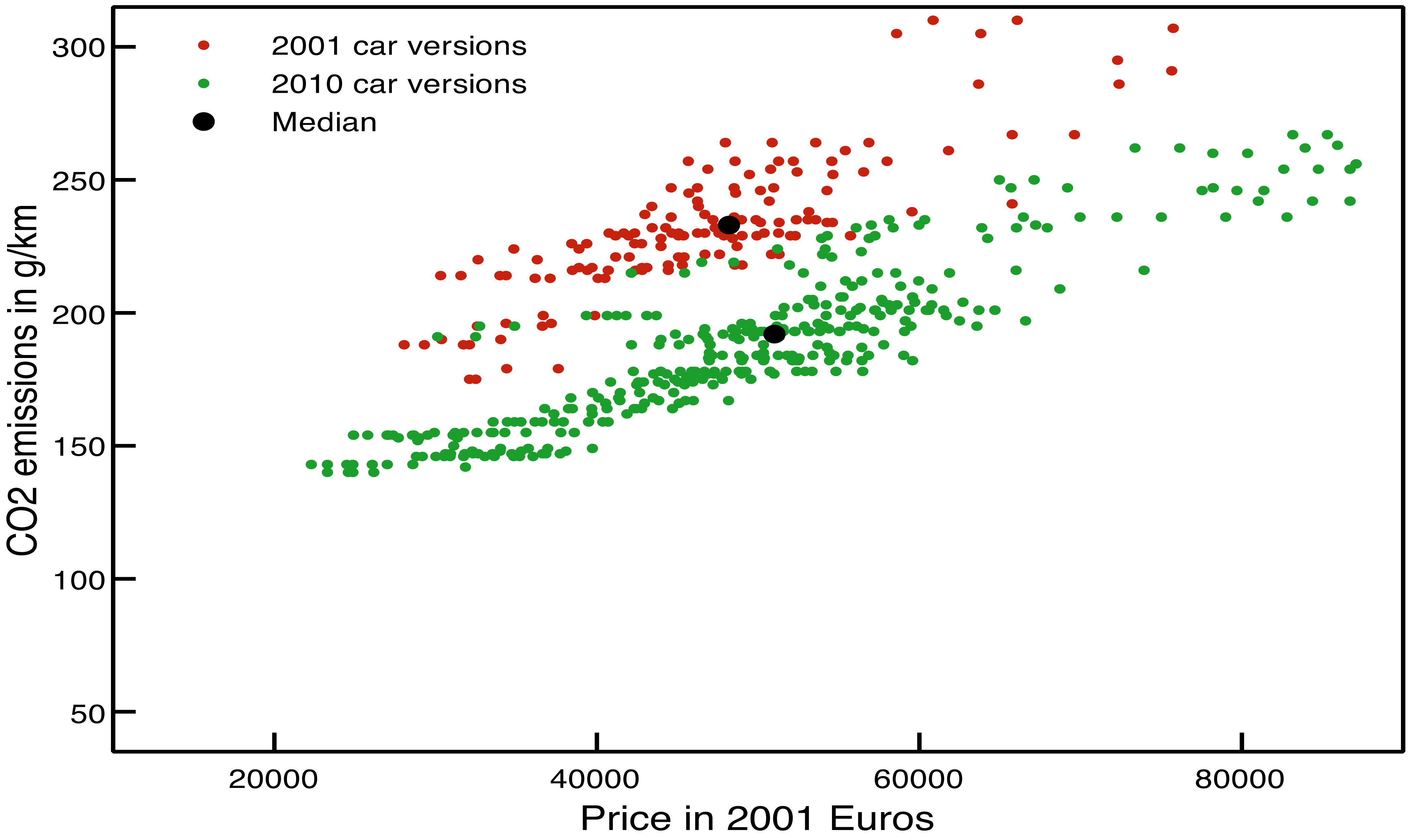
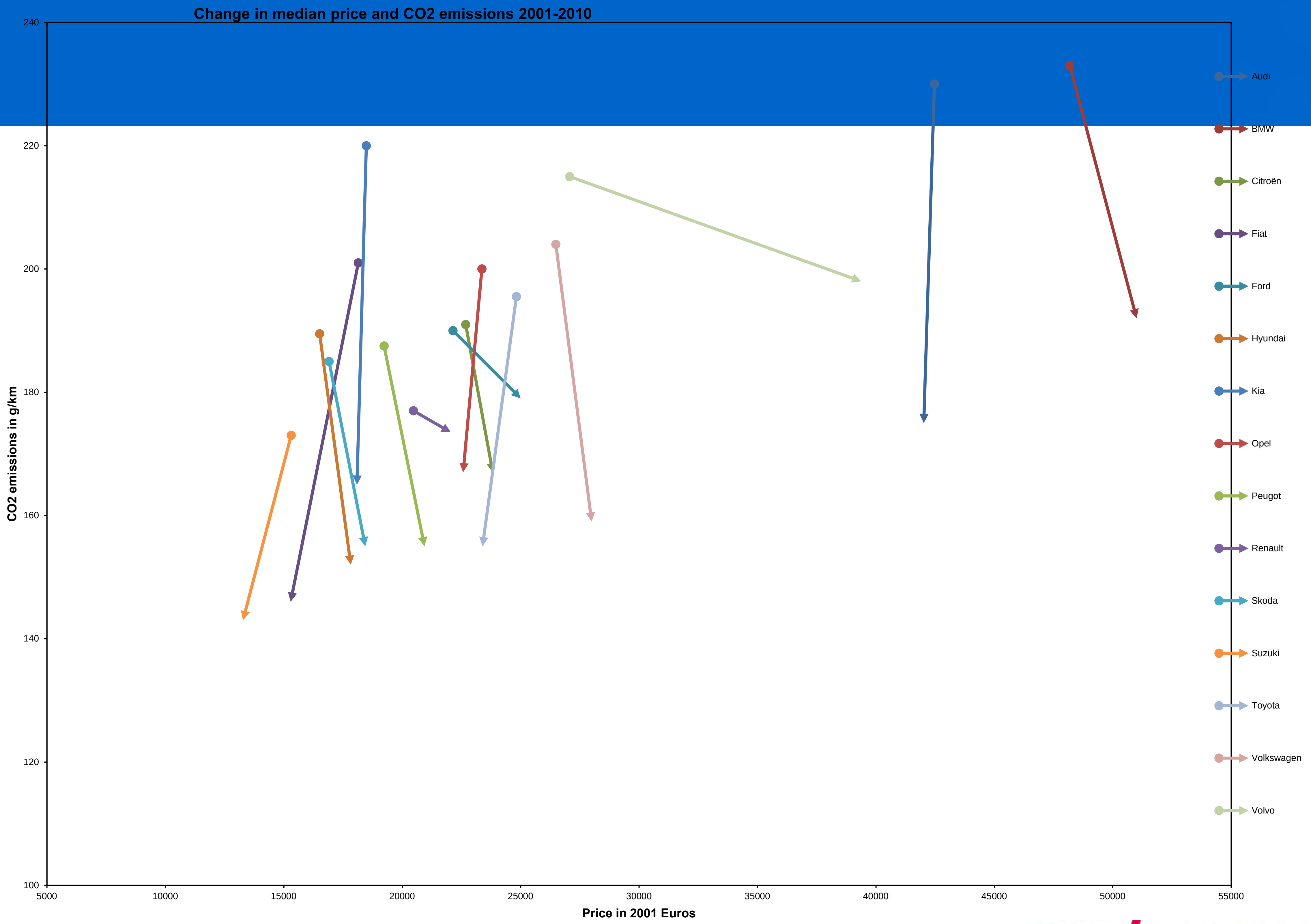
BMW


2001 car versions
2010 car versions
Median
300
250
200
150
100
50
CO2 emissions in g/km
20000
40000
60000
80000
Price in 2001 Euros



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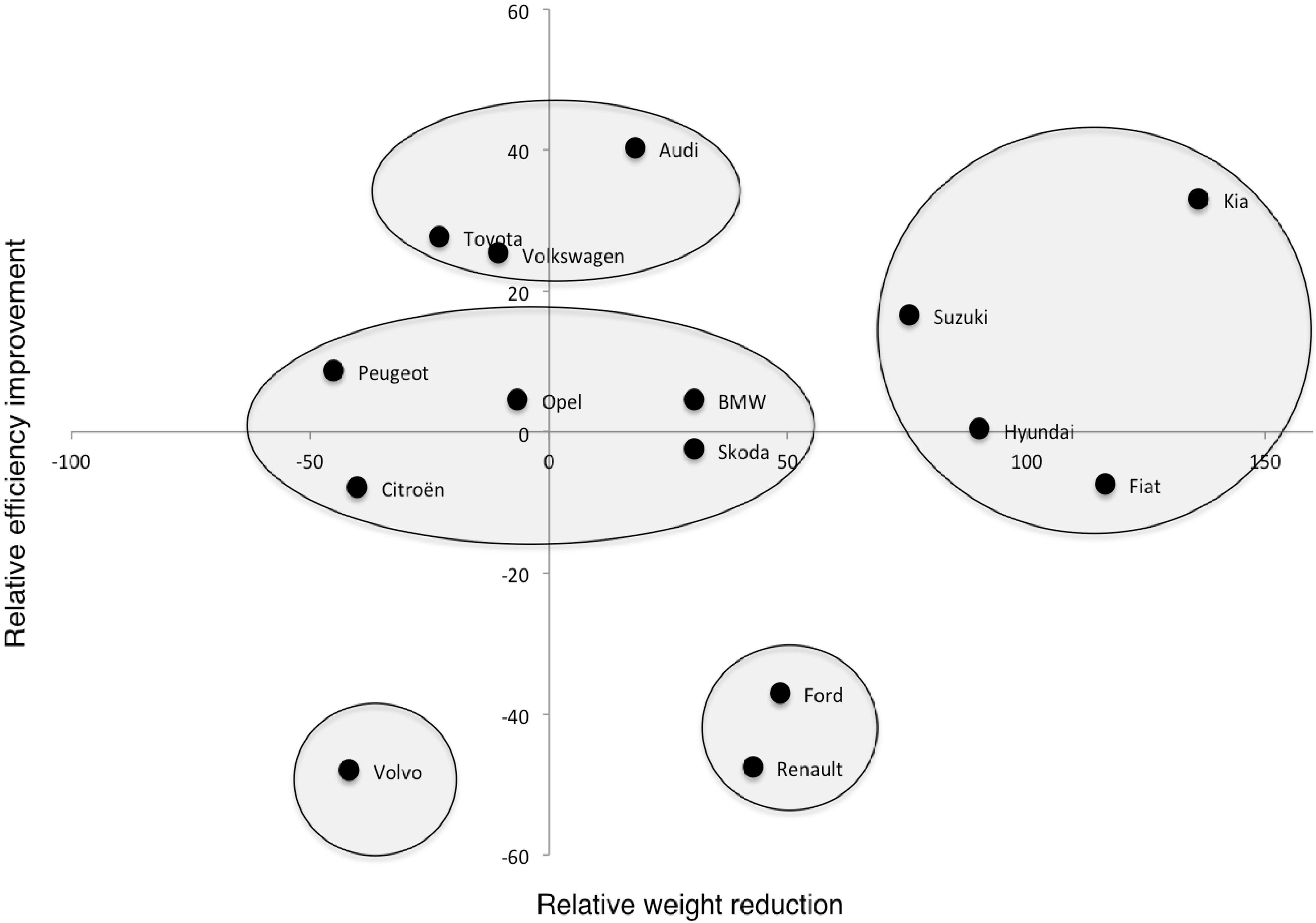
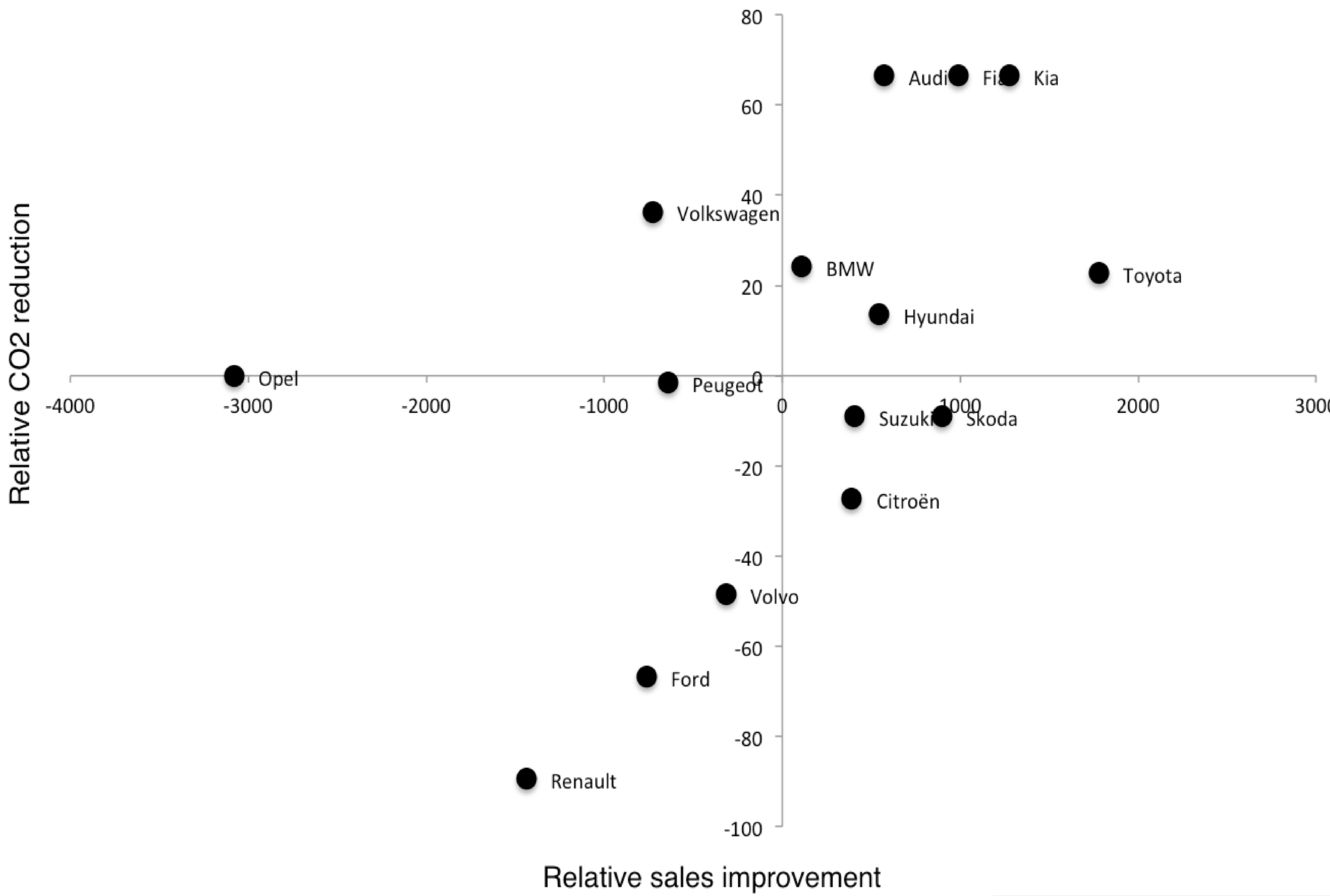
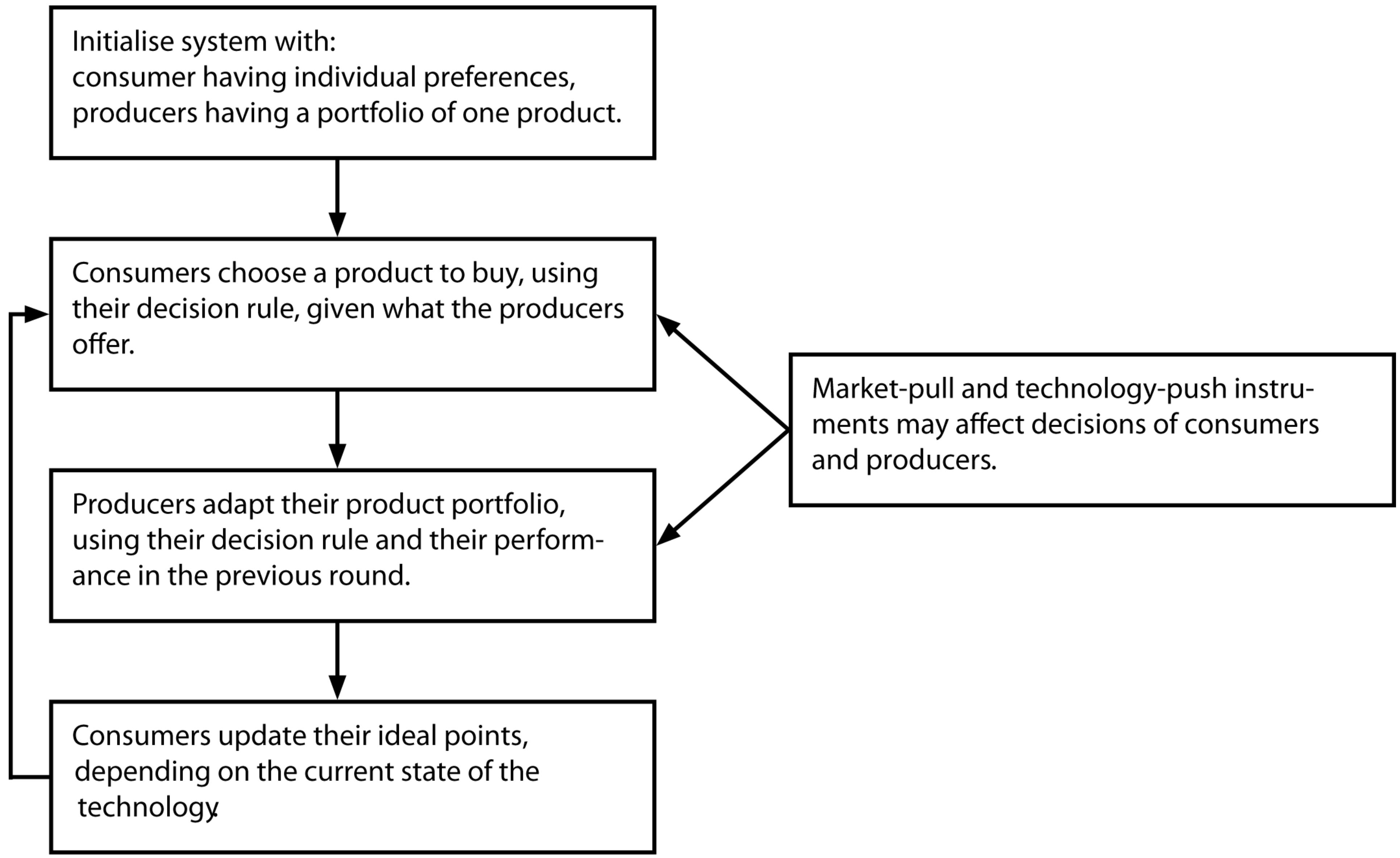
Firm strategies

- Two innovation strategies
  - Reduce portfolio weight
  - Use cleaner technology


Relative efficiency improvement
Relative weight reduction
60
40
20
0
-20
-40
-60
-100
-50
0
50
100
150
Audi
Toyota
Volkswagen
Kia
Suzuki
Peugeot
Opel
BMW
Hyundai
Skoda
Citroën
Fiat
Ford
Renault
Volvo


80
60
40
20
0
-20
-40
-60
-80
-100
-4000
-3000
-2000
-1000
0
1000
2000
3000
Audi
Fi
Kia
Volkswagen
BMW
Toyota
Hyundai
Opel
Peugeot
Suzuki
Skoda
Citroën
Volvo
Ford
Renault
Relative CO2 reduction
Relative sales improvement



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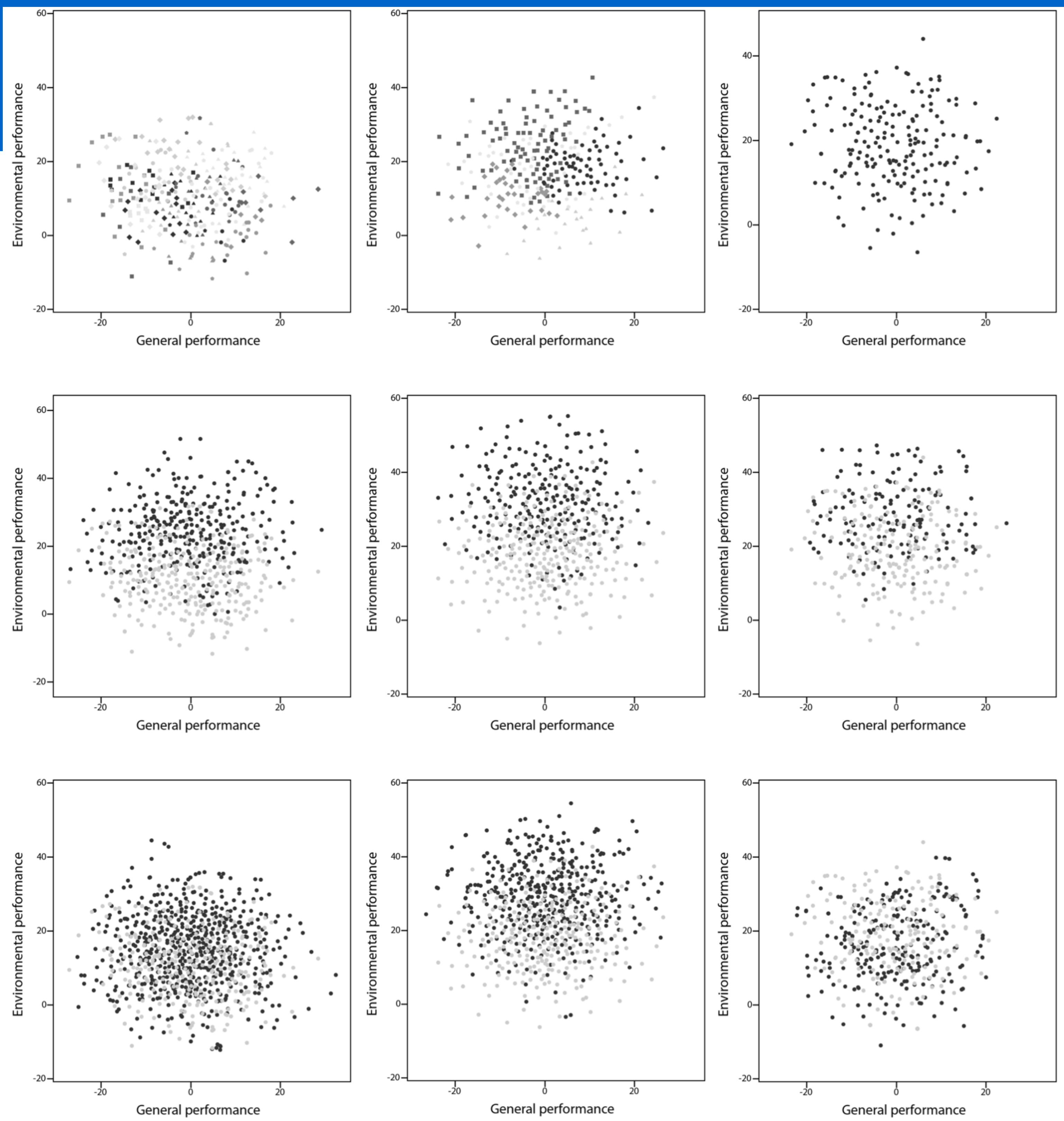
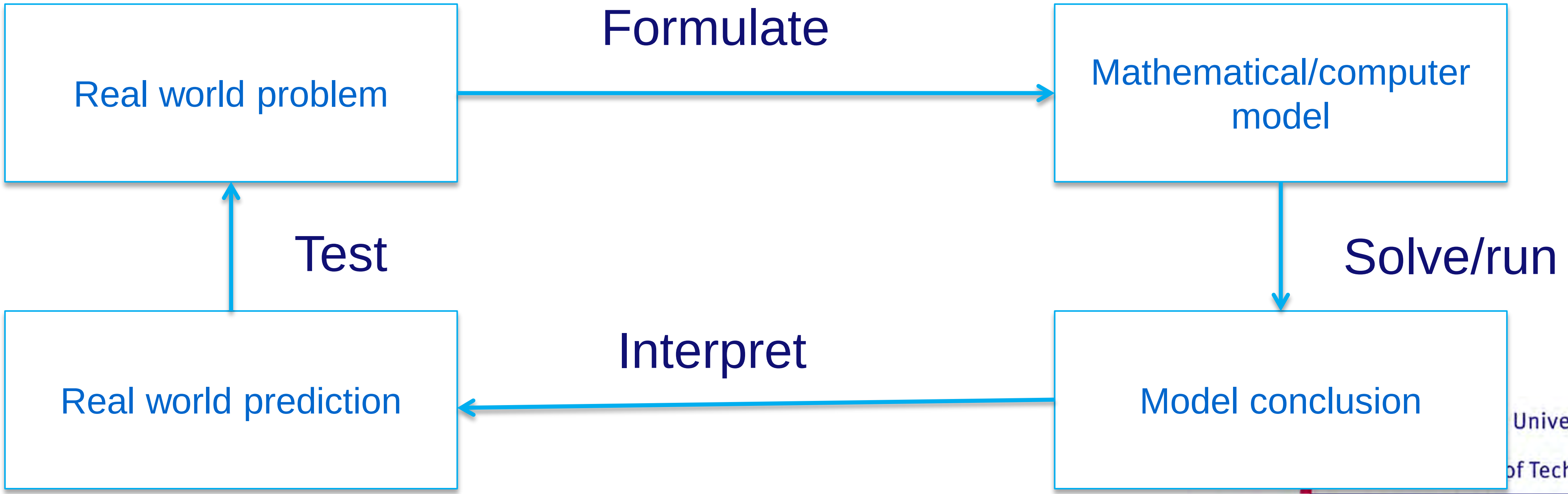

Environmental performance
General performance
60
40
20
0
-20
-20
0
20

Example: estimating the diffusion of EV

Methodology

- A step-by-step description of the actions necessary to answer the research question
- Be precise, complete and specific.
- A good methodology allows me to replicate your research!

Typical methodological approach for formal models or simulations:



Sustainable Innovation

- **Innovation: The implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations (OECD, 2005)**

- **Smart Grids: grids that integrate information and communication technologies (ICT) into the existing network to allow for a two-way flow of information and electricity between producers and consumers (Gerpott and Paukert, 2013)**

Invention ≠ Innovation

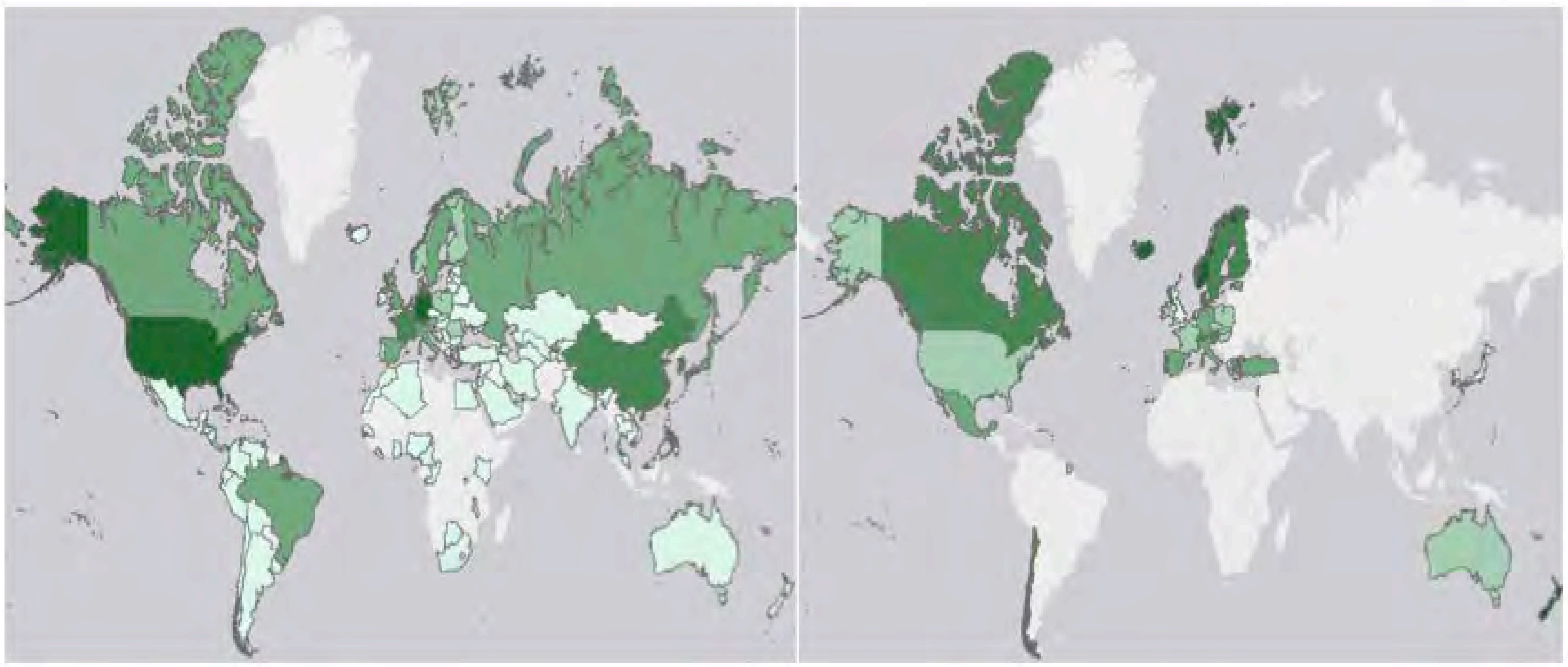


Figure 2: The uneven geographical distribution of cleantech patents worldwide (left) and cleantech diffusion as a Percentage of total energy produced for IEA countries (right). Darker colours indicate more patents (diffusion). Grey areas indicate missing data

An example

- Smart local grids
  - The adoption of electric vehicles
  - The adoption of solar panels
  - Smart grid technologies
  - Consumer behaviour

- Co – evolution!

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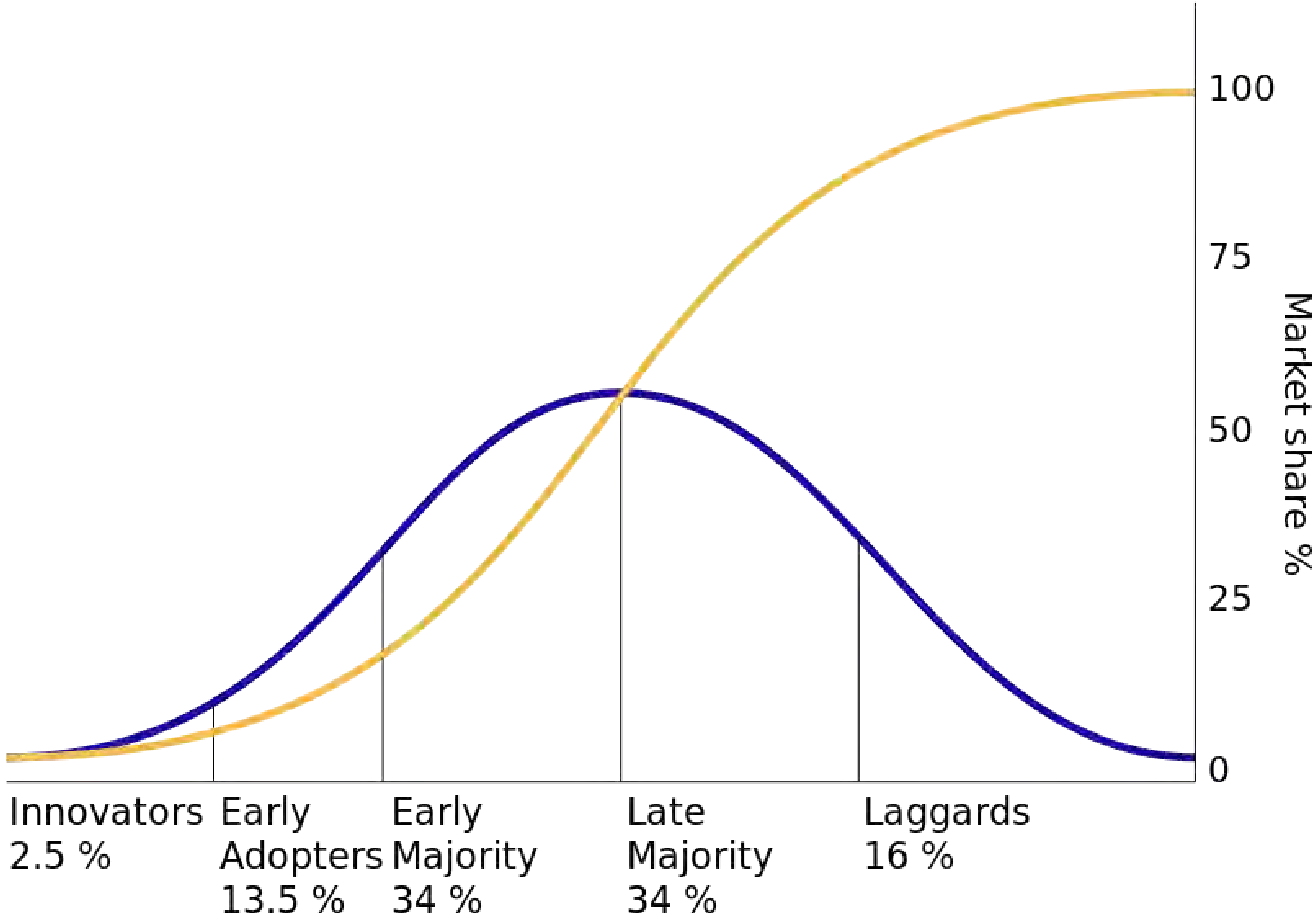
- Why do people adopt?
- What kind of people adopt?
- How do they use it?

Dominant design

- Definition: the key technological features that become a de facto standard. A dominant design is the one that wins the allegiance of the marketplace, the one that competitors and innovators must adhere to if they hope to command significant market following (Utterback and Abernathy, 1975)

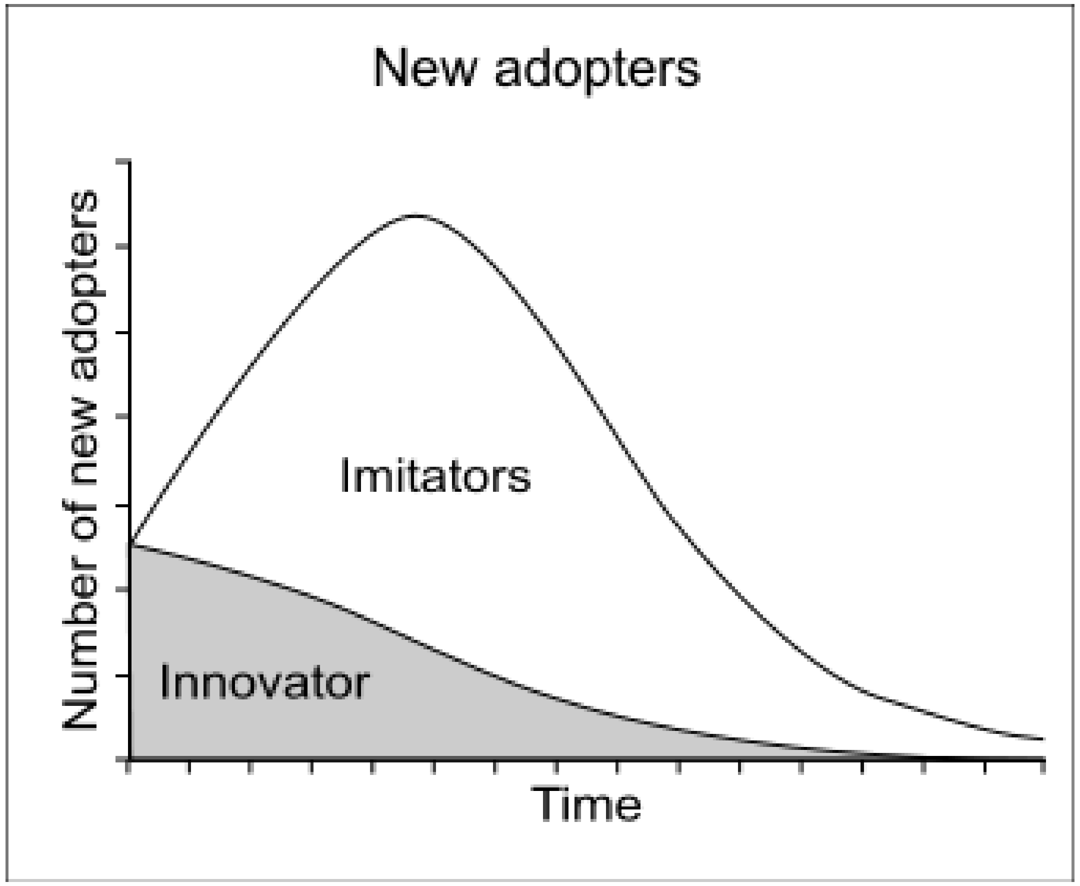
- Dominant design: cars
- Dominant design: energy
- Infrastructure?
- Natural monopoly?

Rogers: the diffusion of innovations



But can we predict the S-curve for EV

The Bass model



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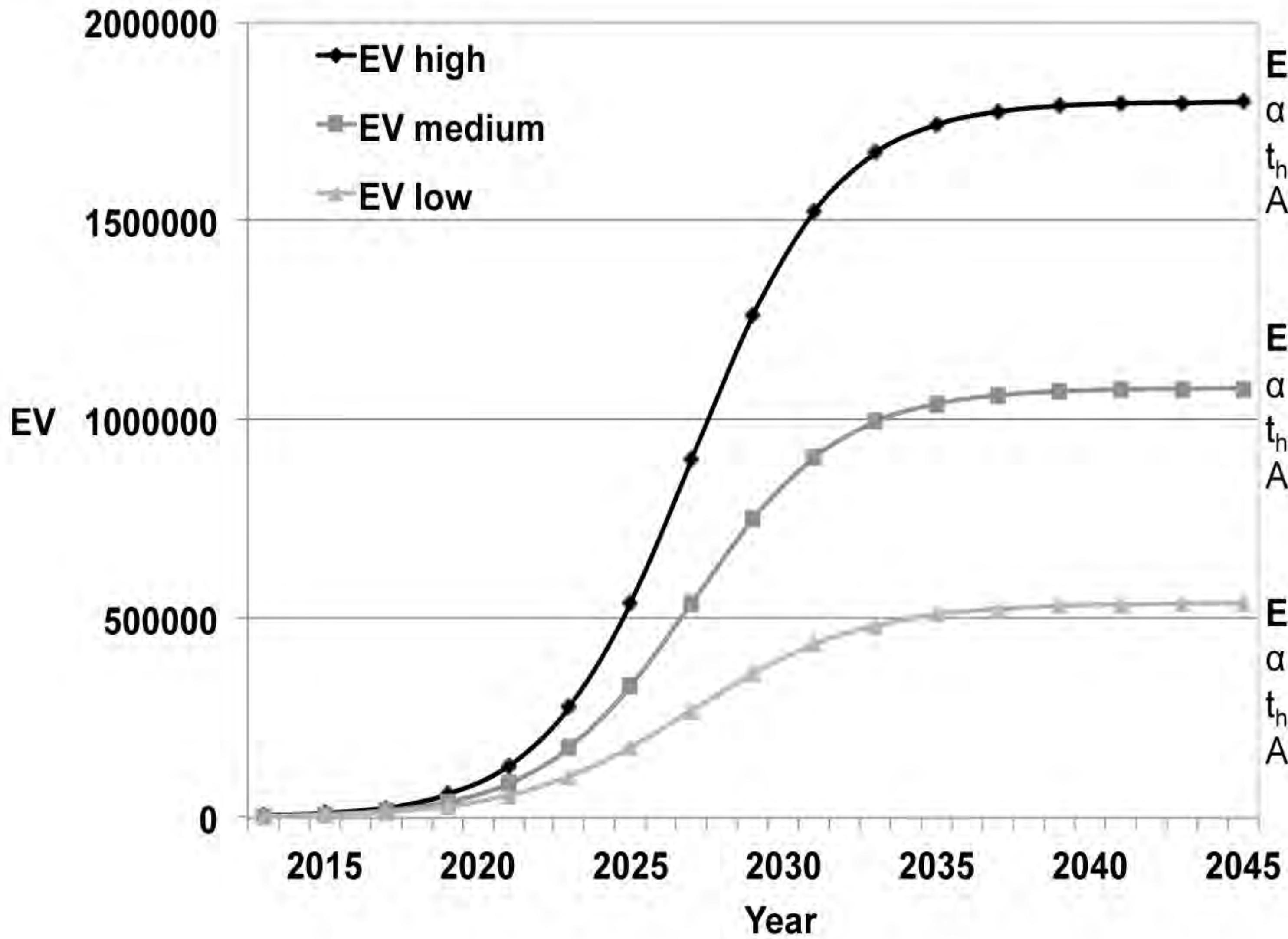
Methode

- RDW data on plug-in electric vehicles
- Data on charging stations
- Data on consumers (income, voting behaviour, etc)
- Data on adoption of solar panels
- Data about the grid

- Methodology: estimate diffusion using simulation, Bass model and Fisher Pry estimates.

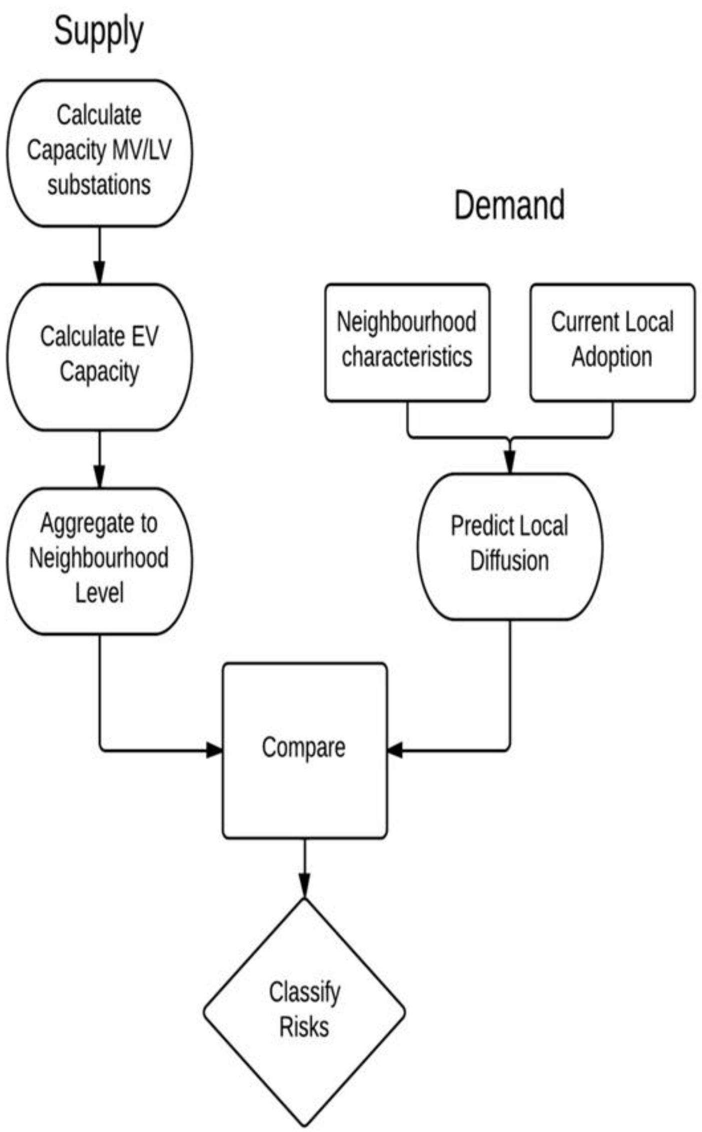
But if the technology is radically new?

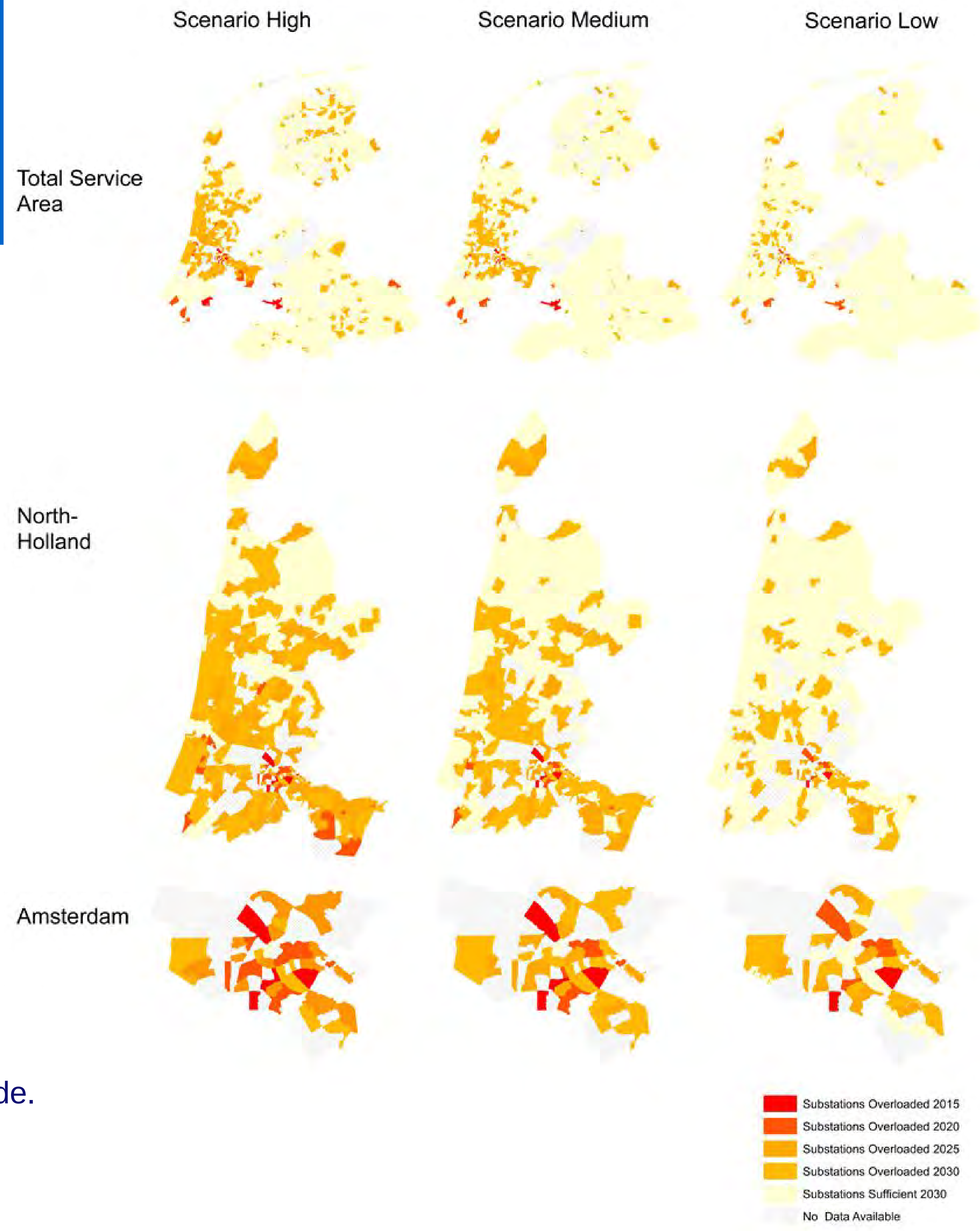


EV High:
α = 0,2
t_h = 2027
$Adoption_{max}$= 1.8 million

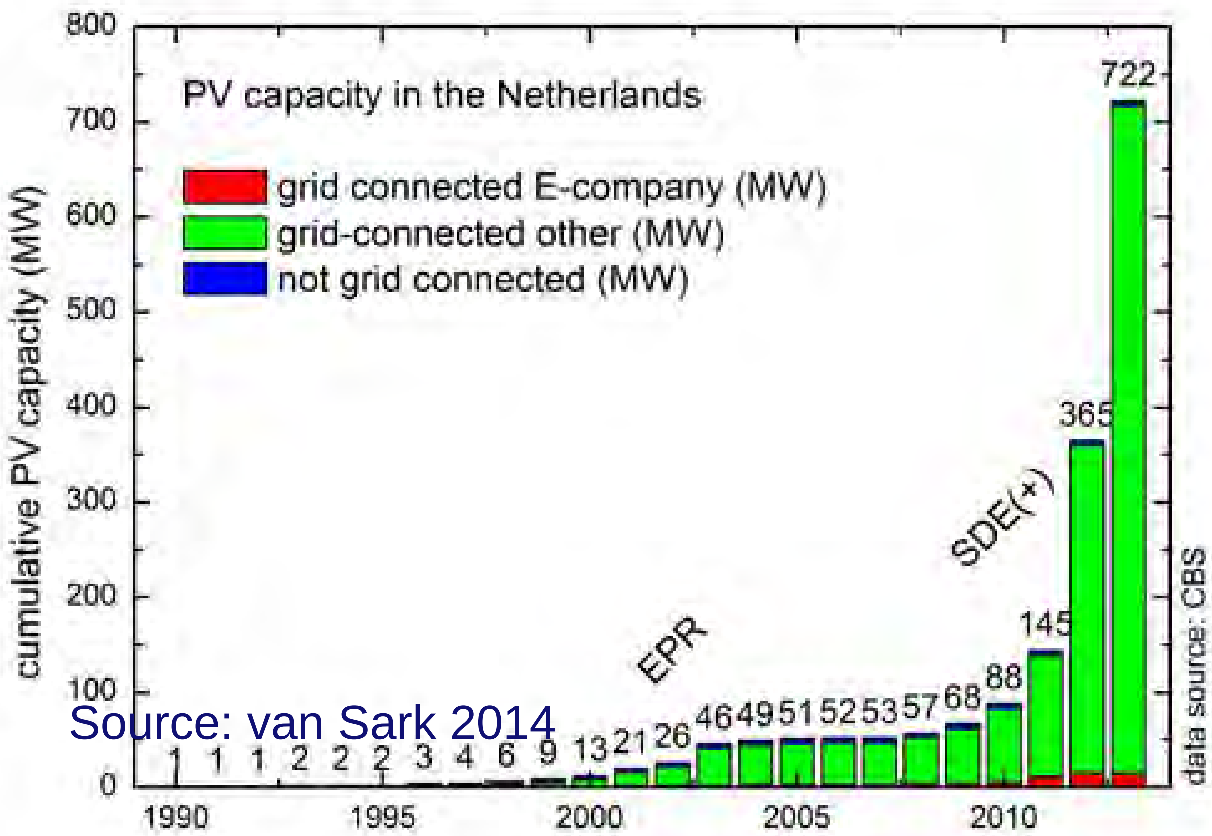
EV Medium:
α = 0,2
t_h = 2027
$Adoption_{max}$= 1.1 million

EV low:
α = 0,2
t_h = 2027
$Adoption_{max}$= 0.55 million

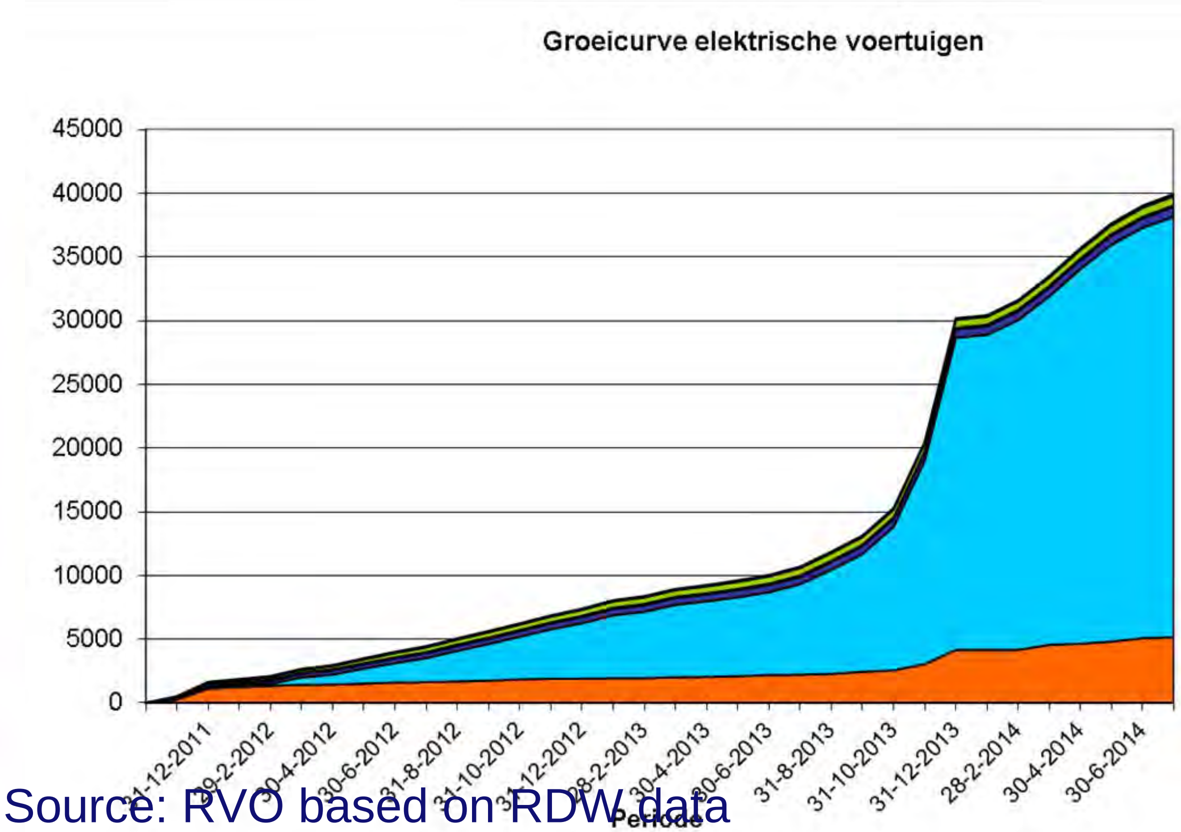

Supply
Calculate Capacity MV/LV substations
Calculate EV Capacity
Aggregate to Neighbourhood Level
Demand
Neighbourhood characteristics
Current Local Adoption
Predict Local Diffusion
Compare
Classify Risks



Eising, J., T. van Onna, and F. Alkemade.
Applied Energy, 123: 448-455, 2014

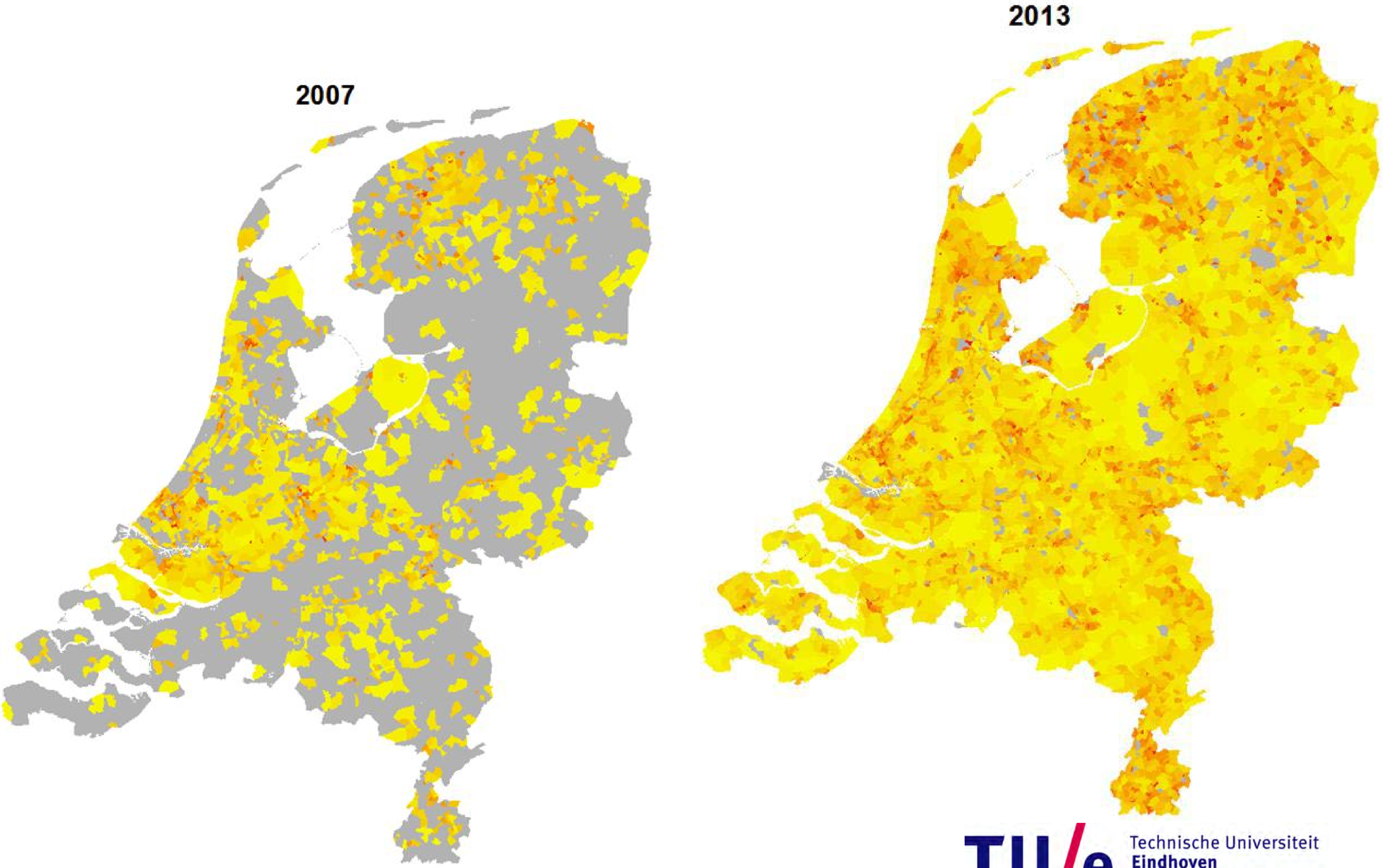


Source: van Sark 2014



Source: RVO based on RDW data

PV per inwoner



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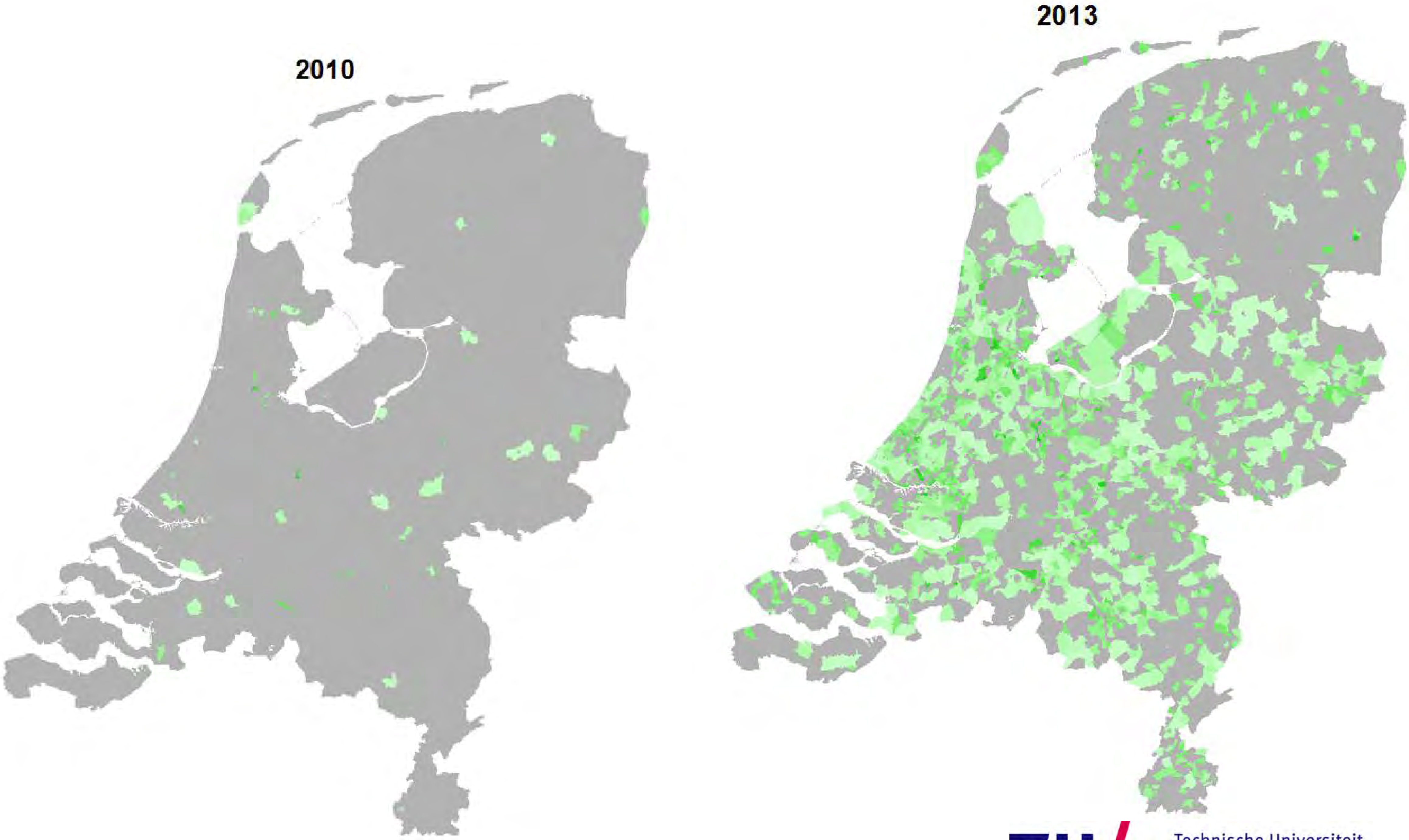
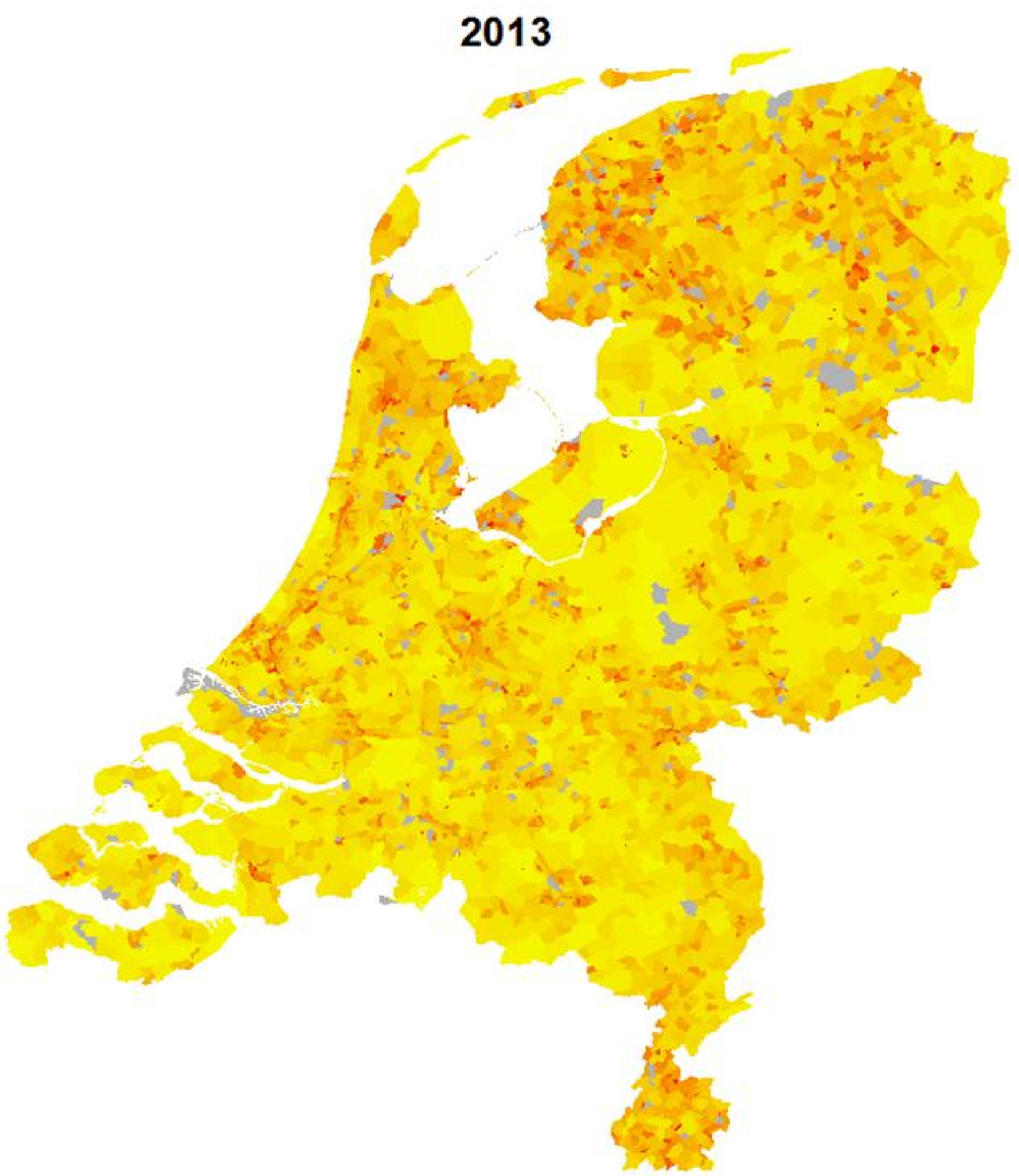
EV per inwoner



EV/PV



Exercise 2

- Try for yourself
- Try to fit the data in excel file using the Bass and Fisher Pry models

- Which parameter values do you find?
- What is your prediction for 2020?

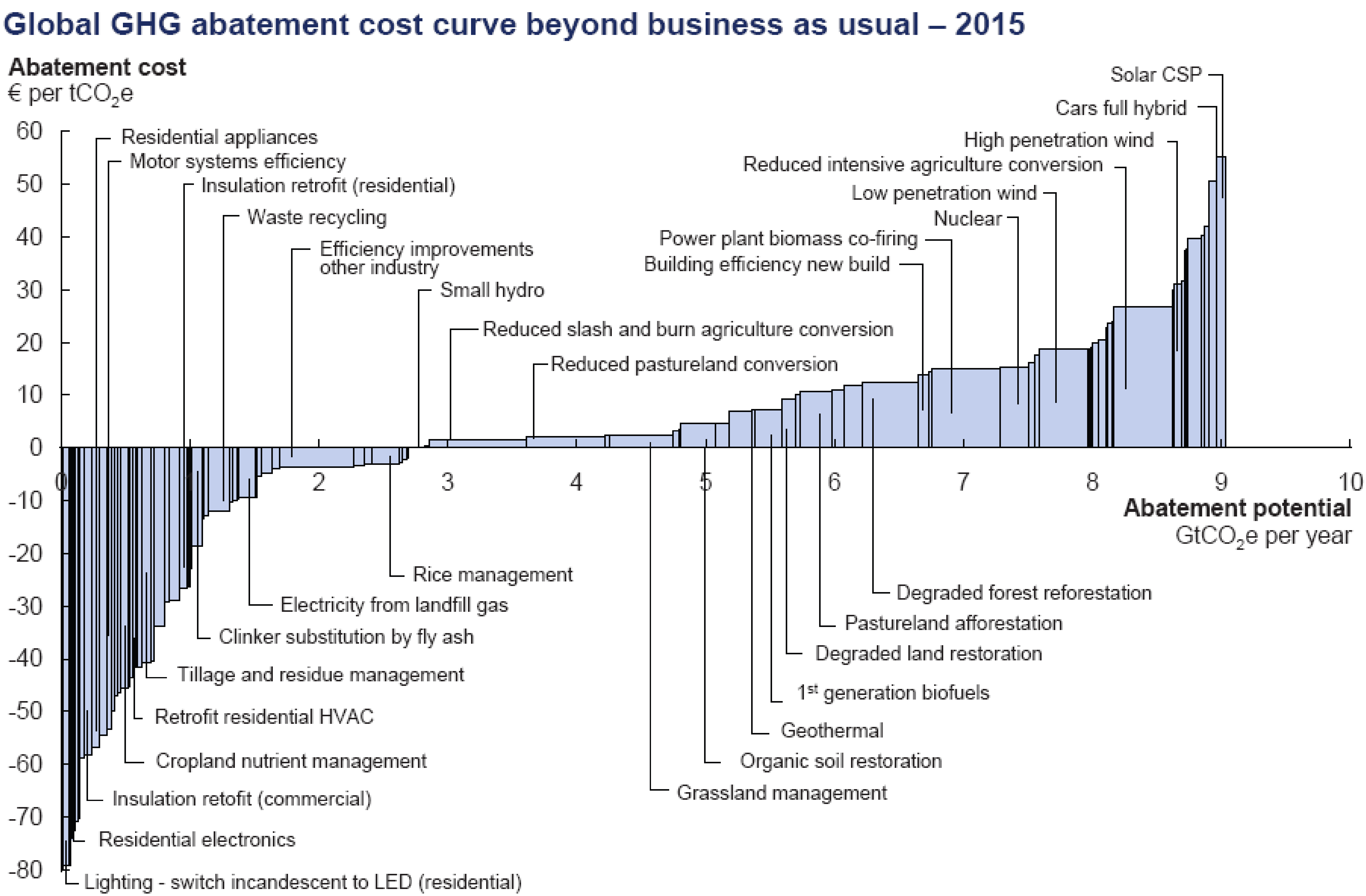
Conclusion

Combining models, data, and simulation provides new insights!

Learning curves

- What is it?
- Why is it interesting?

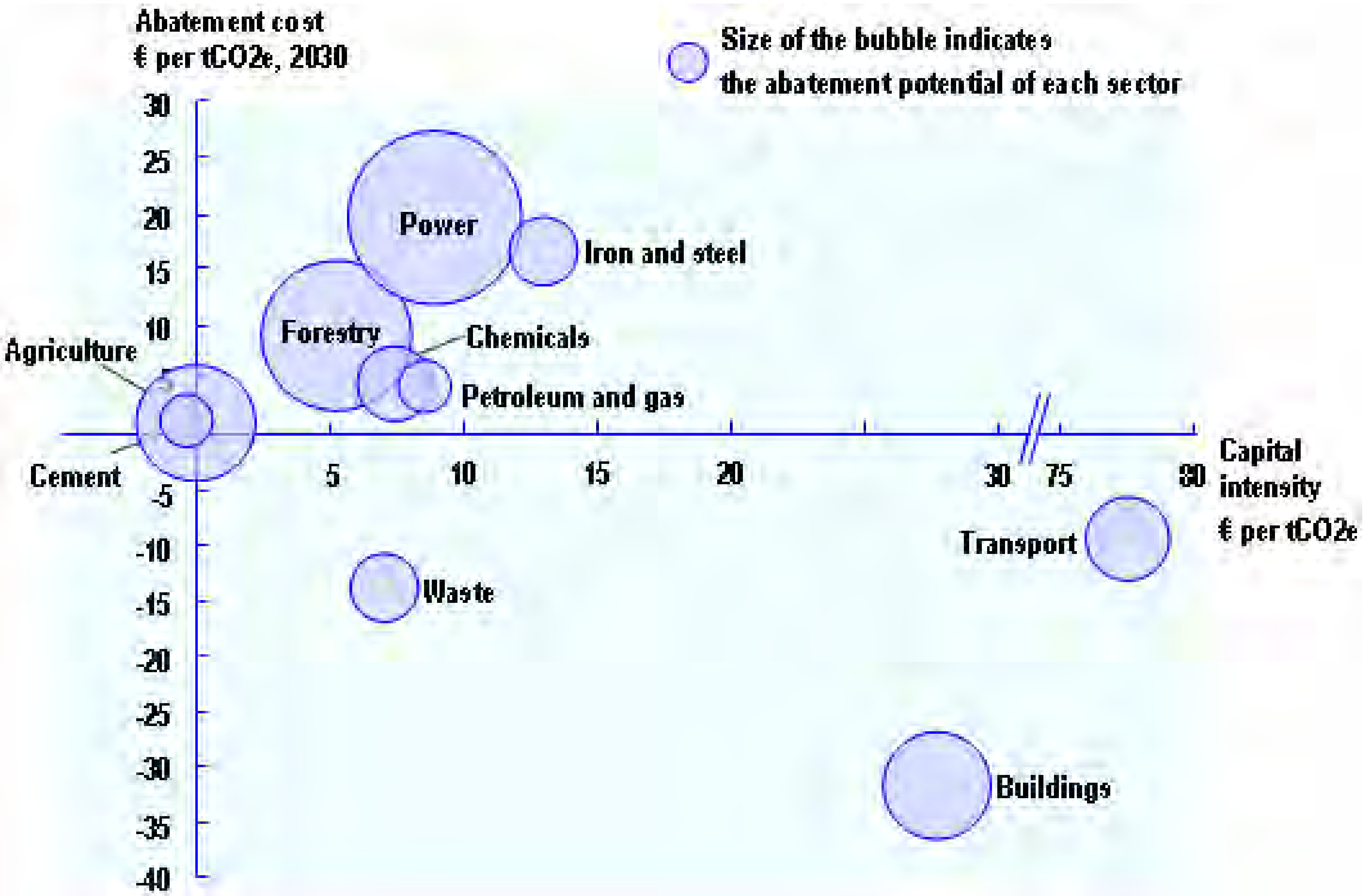
The McKinsey abatement curve



Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.

Source: Global GHG Abatement Cost Curve v2.0

Provides opportunities



The learning curve

The concept of learning curves (experience curves) was first introduced by Wright (1936). By way of empirical evidence, he found that unit costs for different inputs when compared to the cumulative production of airplanes exponentially declines with the cumulative level of production as a result of “learning-by-doing".

*7.6 DYNAMIC CHANGES IN COSTS—THE LEARNING CURVE

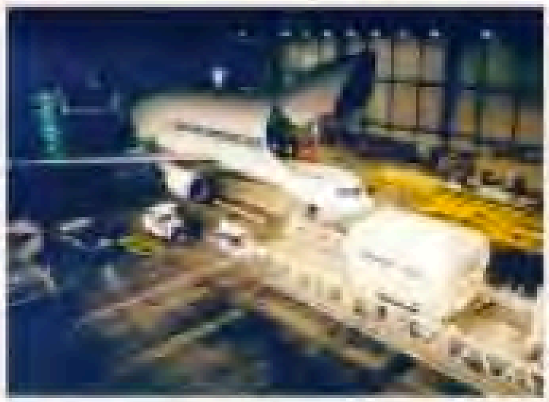
EXAMPLE 7.6 The Learning Curve in Practice

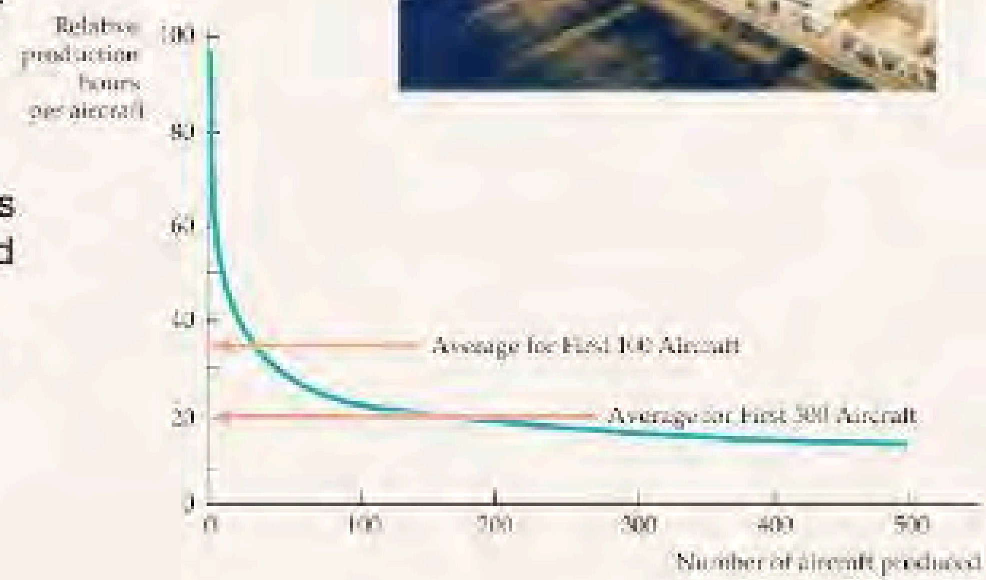
Figure 7.13

Learning Curve for Airbus Industrie

The learning curve relates the labor requirement per aircraft to the cumulative number of aircraft produced.

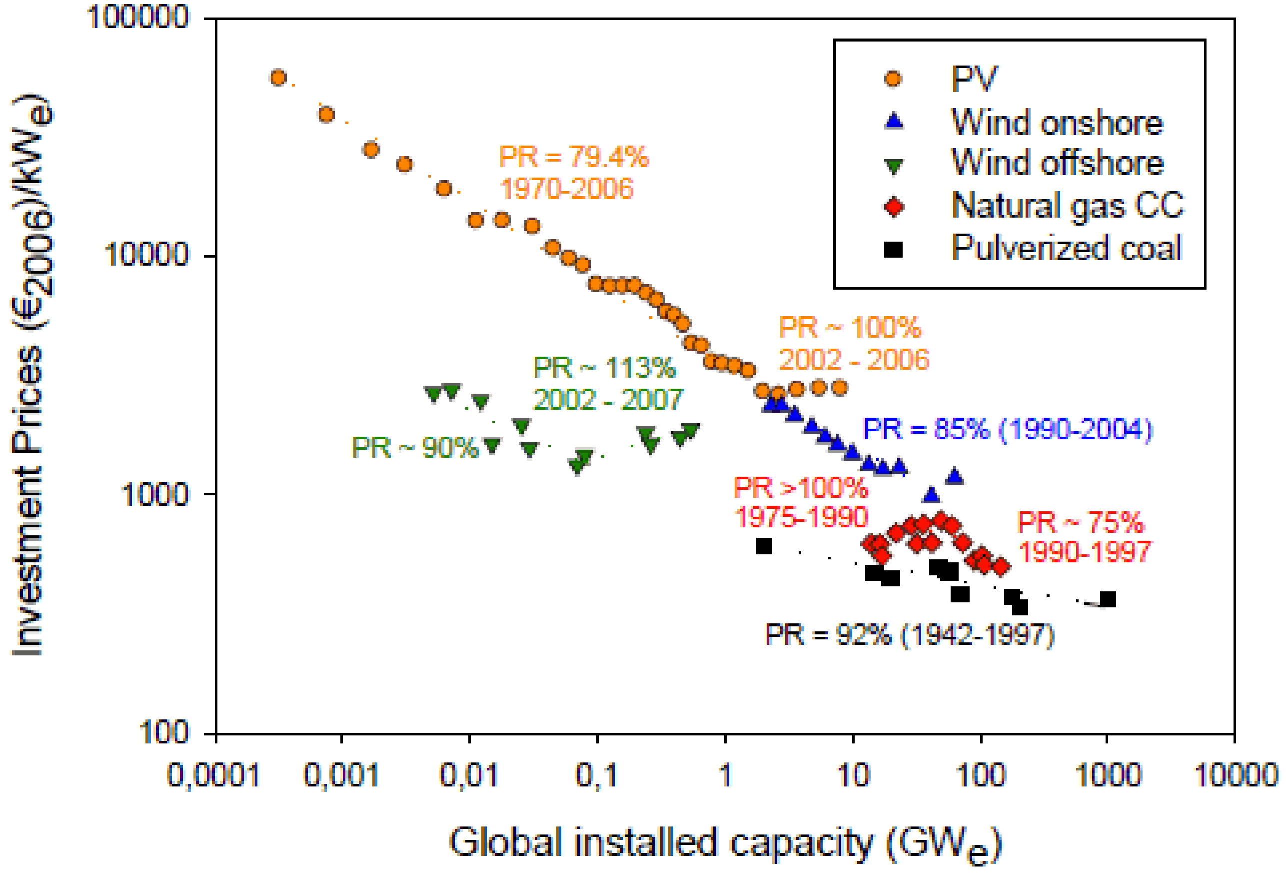
As the production process becomes better organized and workers gain familiarity with their jobs, labor requirements fall dramatically.



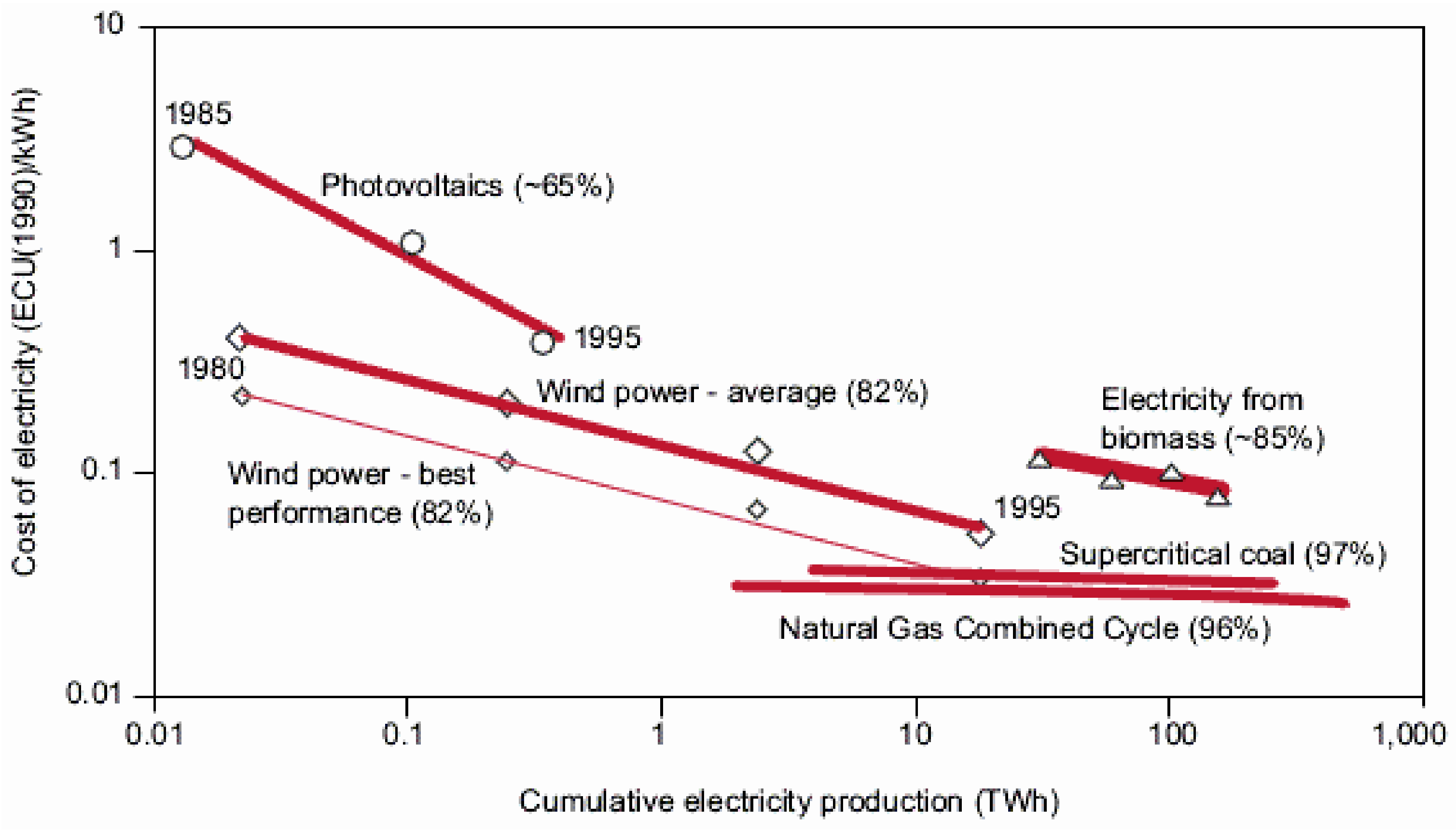


The learning curve

The unit cost of production is measured to fall by x per cent with each doubling of the cumulative volume of production of the product.



Source, Junginger, Sark et. al. 2010


10
1
0.1
0.01
Cost of electricity (ECU(1990)/kWh)
1985
Photovoltaics (~65%)
1995
1980
Wind power - average (82%)
Electricity from
biomass (~85%)
Wind power - best
performance (82%)
1995
Supercritical coal (97%)
Natural Gas Combined Cycle (96%)
0.01
0.1
1
10
100
1,000
Cumulative electricity production (TWh)

Source IEA

$$P_t = P_0 \cdot X^{-E}$$

- P_0 is a constant equal to the price of one unit of cumulative production or sales.
- E is the (positive) experience parameter, which characterizes the inclination of the curve.
- Large values of E indicate a steep curve with a high learning rate.

- **Can you think of processes that generate the learning curve?**

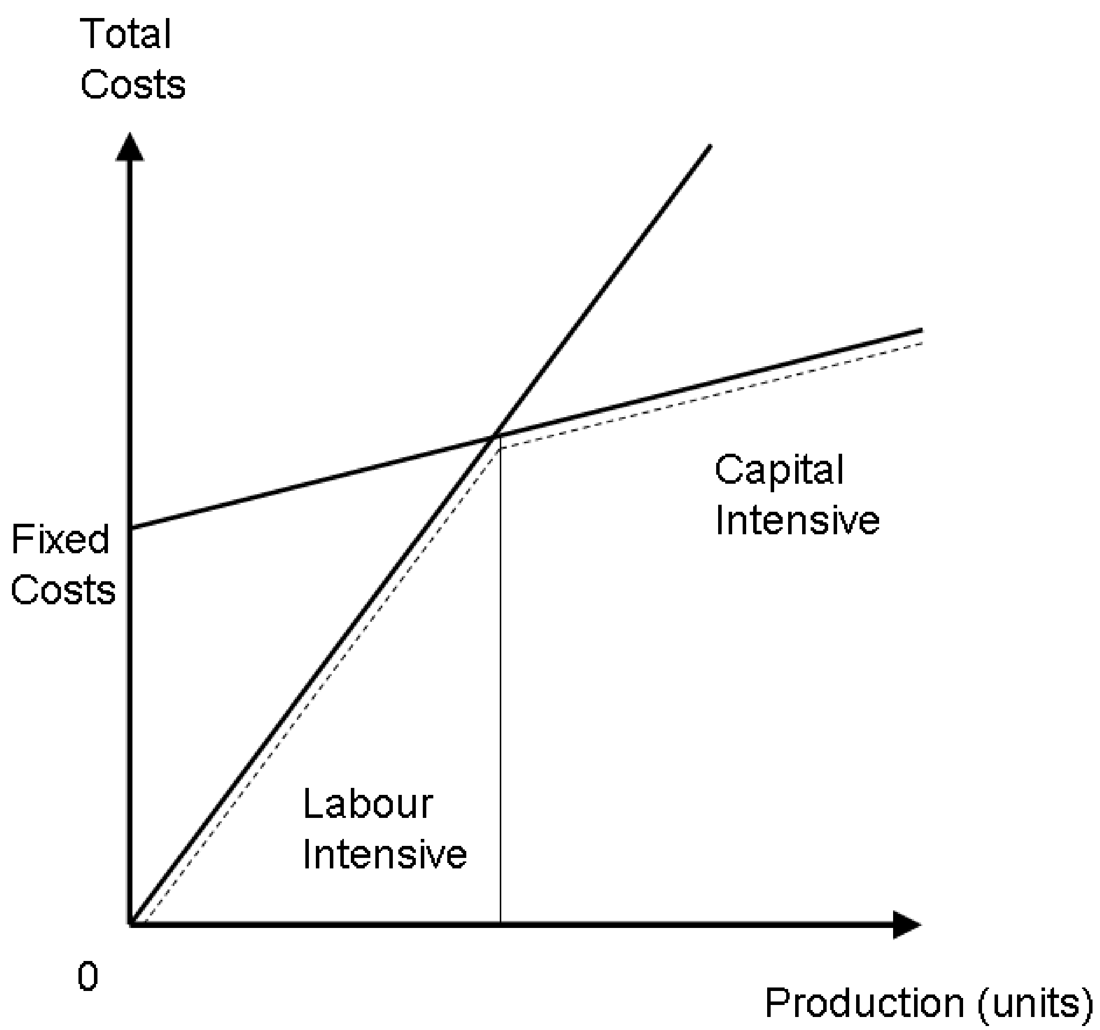
Learning by doing

- Workers often take longer to accomplish a given task the first few times they do it. As they become more adept, their speed increases.
- Managers learn to schedule the production process more effectively, from the flow of materials to the organization of the manufacturing itself.
- Engineers who are initially cautious in their product designs may gain enough experience to be able to allow for tolerances in design that save costs without increasing defects. Better and more specialized tools and plant organization may also lower cost.
- Suppliers may learn how to process required materials more effectively and pass on some of this advantage in the form of lower costs.

Example: the effect of process innovation

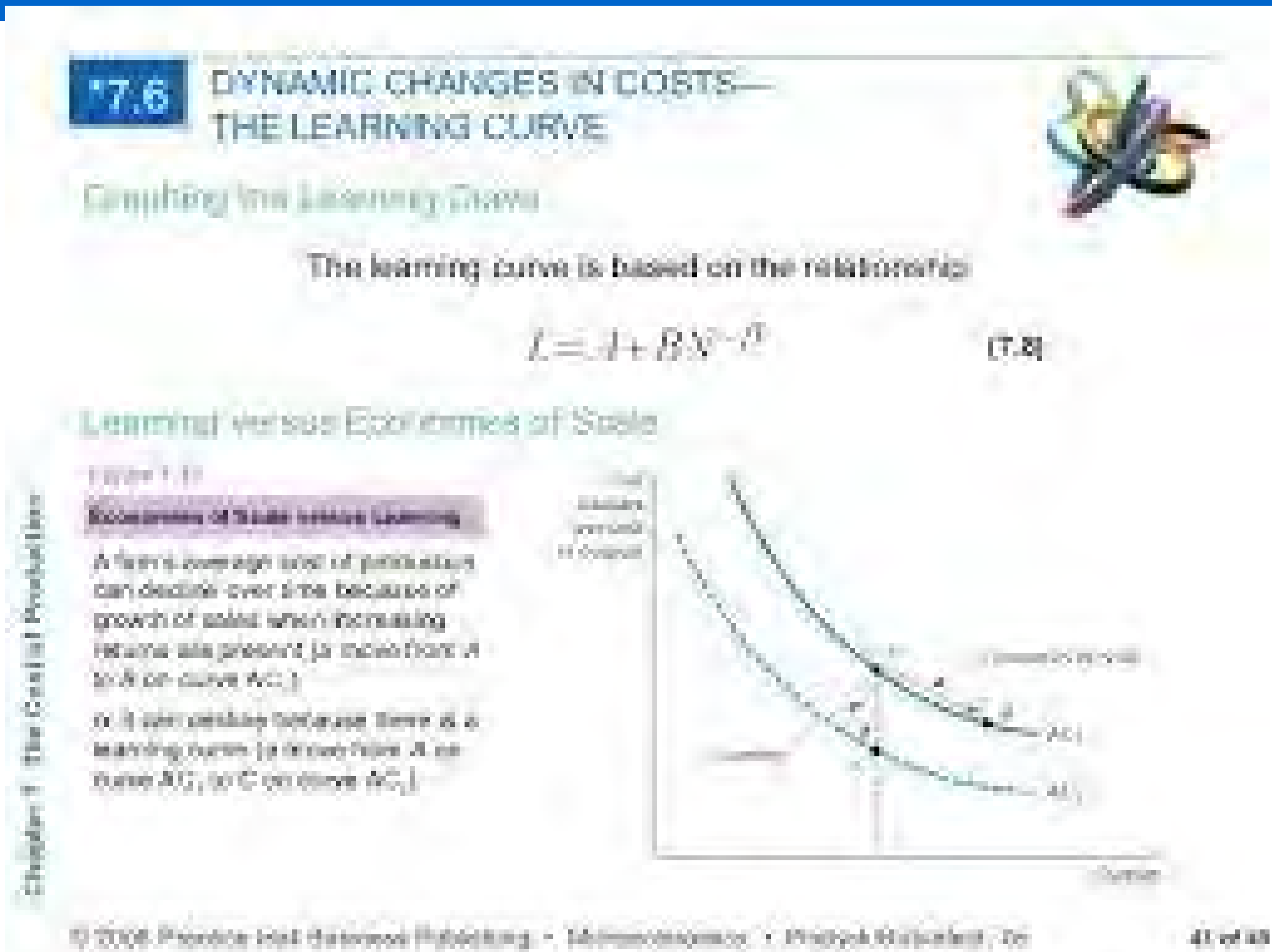
A reduction in marginal costs accompanied by an increase in fixed costs.

Examples of such innovations include the replacement of a labour-intensive production process with a more capital intensive form of production.


Total
Costs
Fixed
Costs
Capital
Intensive
Labour
Intensive
0
Production (units)

Young technologies learn faster from market experience than old technologies with the same progress ratios. The same absolute increase in cumulative production will have more dramatic effects at the beginning of a technology's deployment than it will later on.

Not the same as economies of scale!



Exercise

- Go to http://pcdb.santafe.edu/process_view.php

- Download learning curve data into your excel
- How long will it take before your technology comes "into the market"

- Pick two technologies
- Does the more complex one have the lower learning rate?