



Energy research Centre of the Netherlands

Learning in Times of Change

a dynamical explanation for technological progress

ECN policy studies, Amsterdam & Petten



The Project: Investigating the use of learning curves in energy policy

In this presentation:

- A new look to learning curves: the exponential model
- A simple numerical model for progress
- Conclusions

Authors:

Francesco Ferioli

Bob van der Zwaan



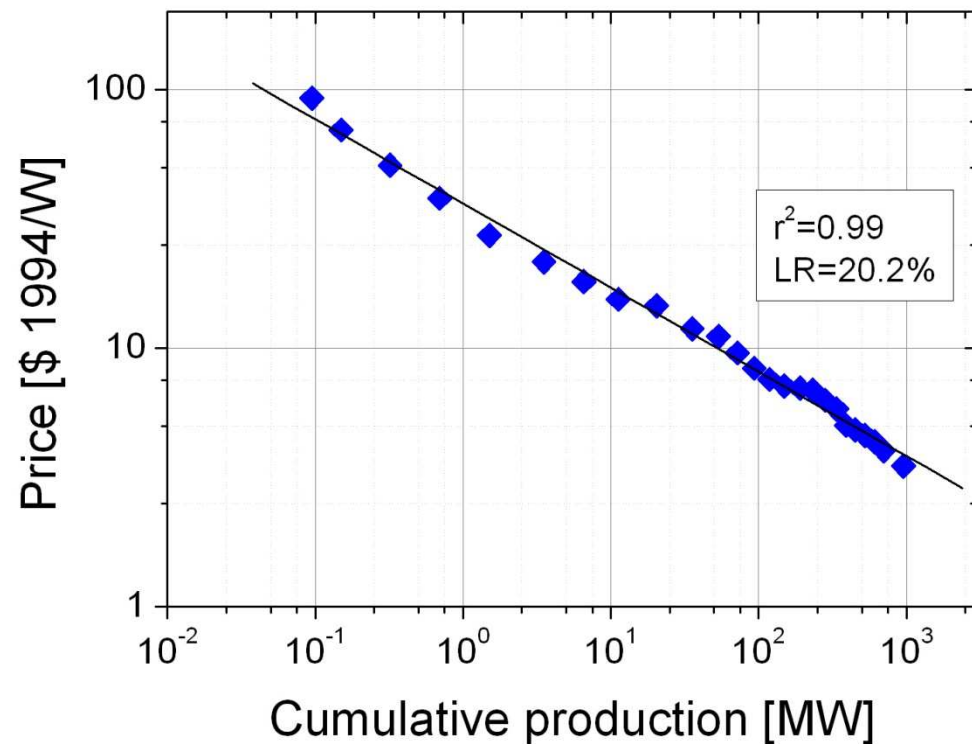
The Learning Curve

The learning curve:

$$C(x) = C_0 \left(\frac{x}{x_0} \right)^{-b}$$

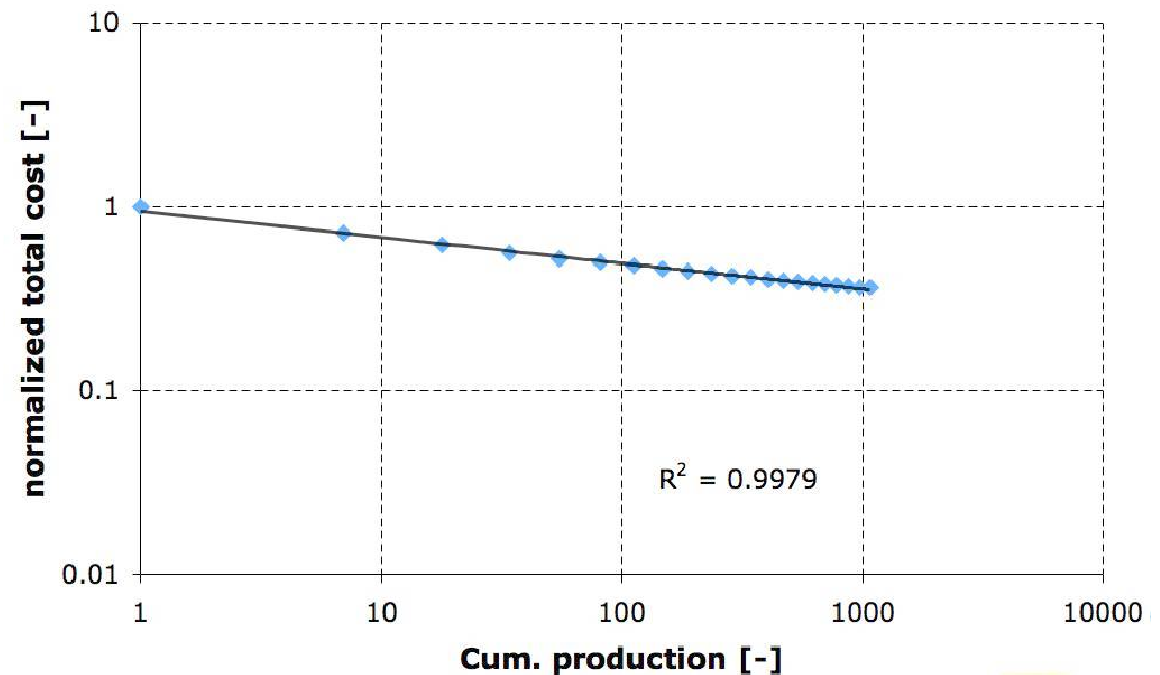
Costs decrease a fix percentage
every time cumulative
production doubles:

$$LR = 1 - 2^{-b}$$



From [Harmon, 2000]

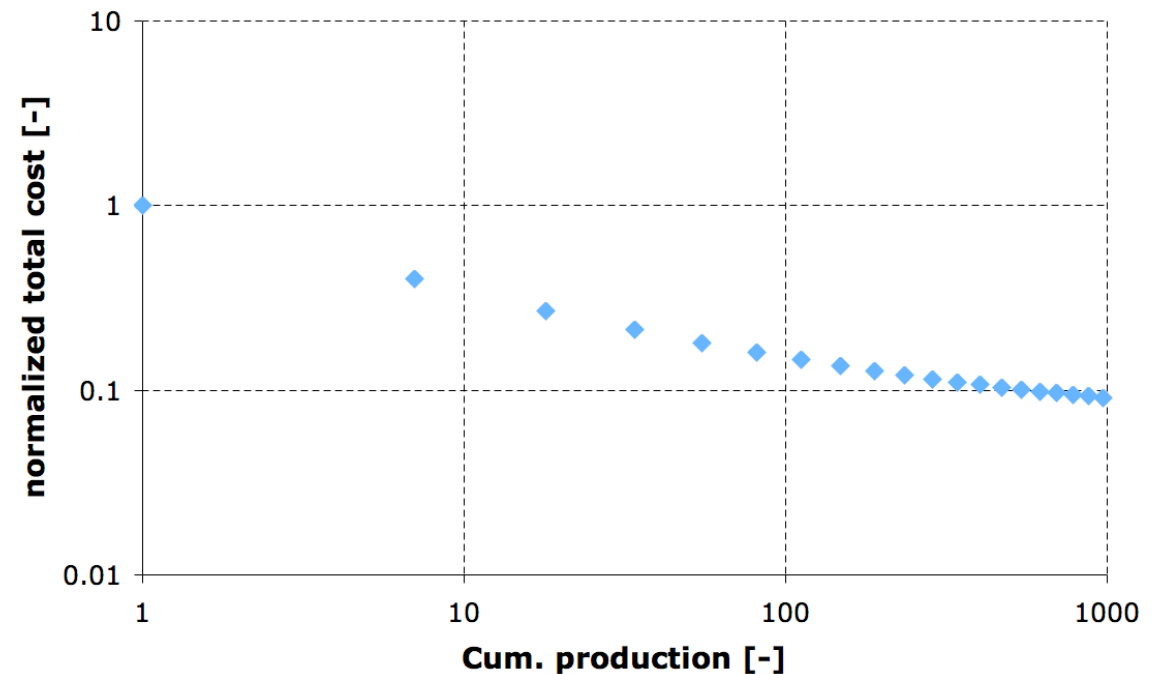
Learning curves for components



$$C_0 \left(\frac{x}{x_0} \right)^{-b} \neq \sum_{i=1}^n C_{0i} \left(\frac{x_i}{x_{0i}} \right)^{-bi}$$

A counterexample:

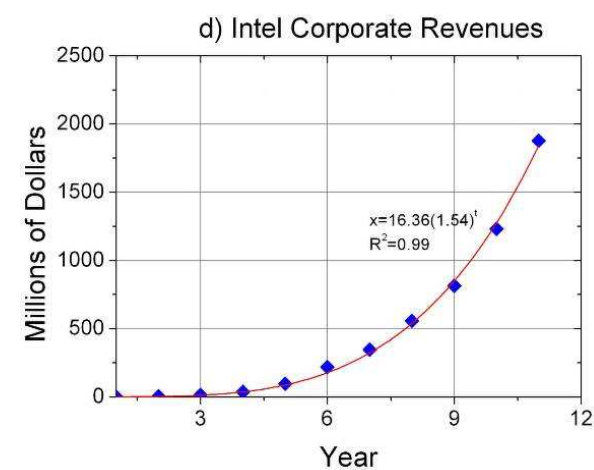
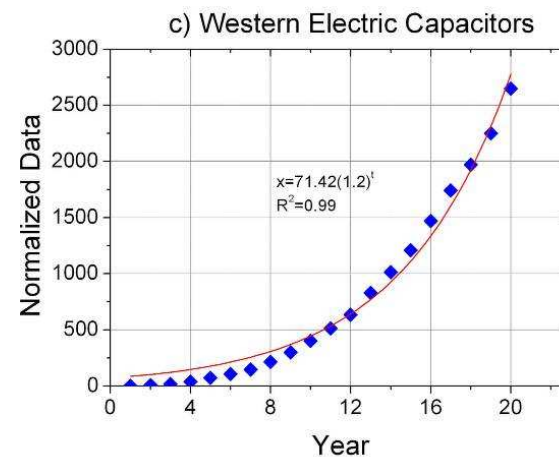
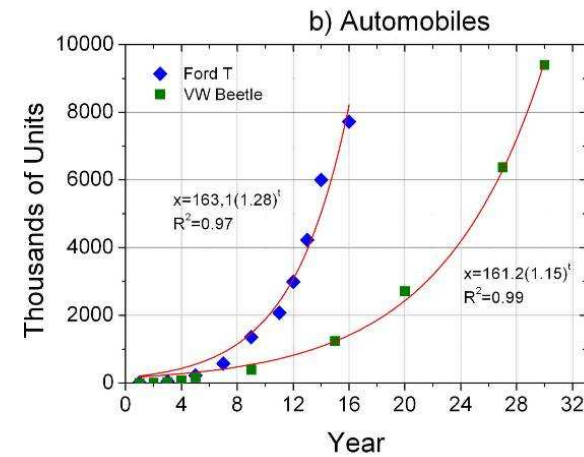
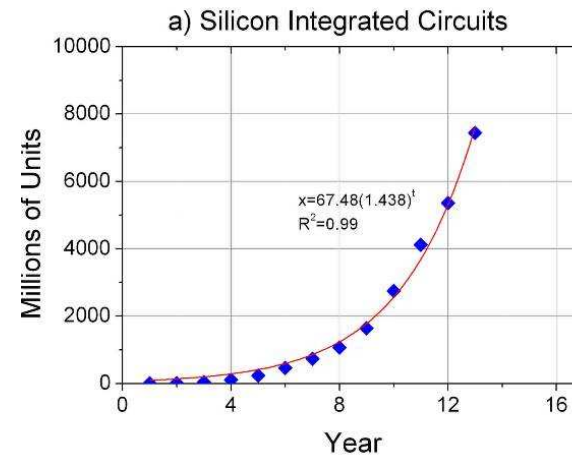
A product
made of a fast
and a slow
learning
component (LR
33% and 6%)



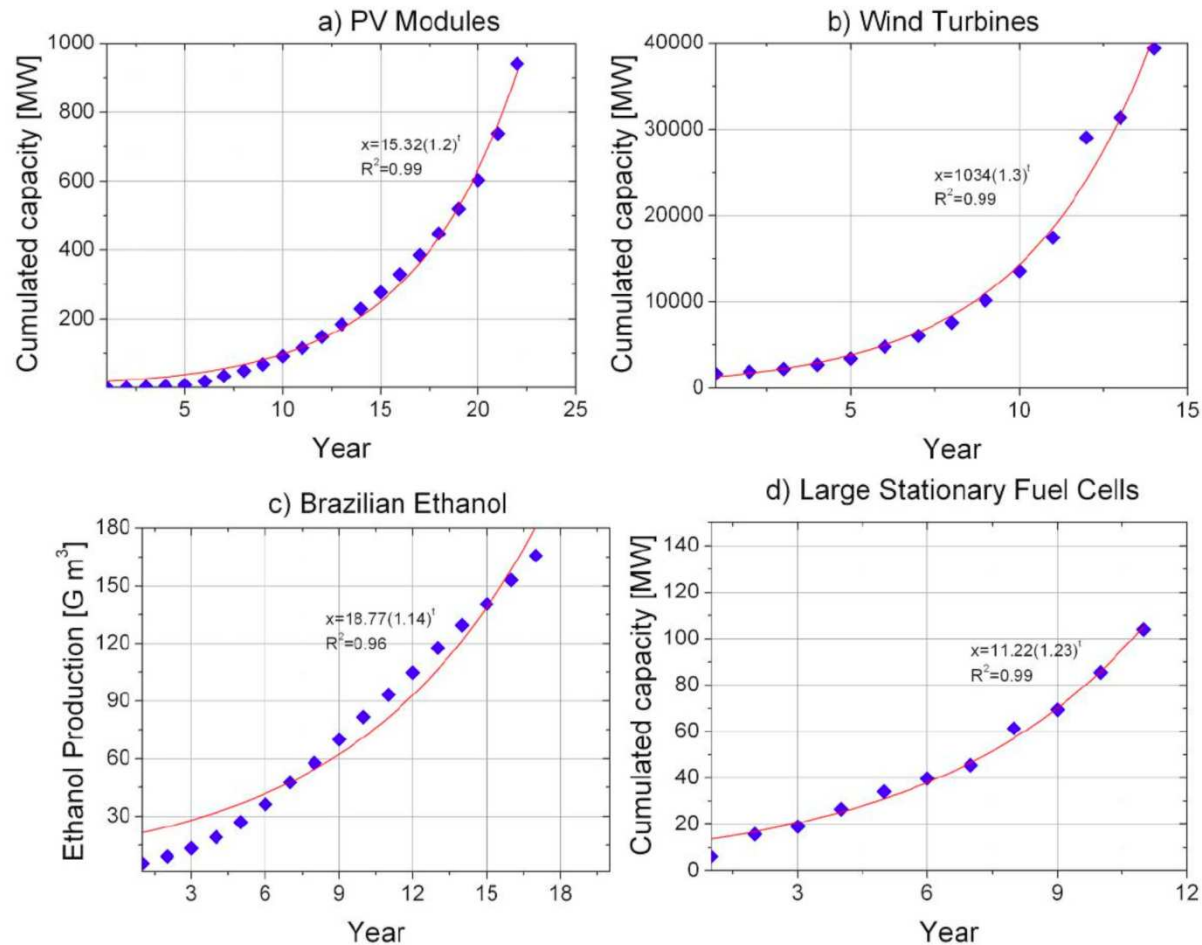
$$C_{tot} = c_1 \left(\frac{x_1}{x_{01}} \right)^{-b_1} + c_2 \left(\frac{x_2}{x_{02}} \right)^{-b_2}$$

Exponential growth

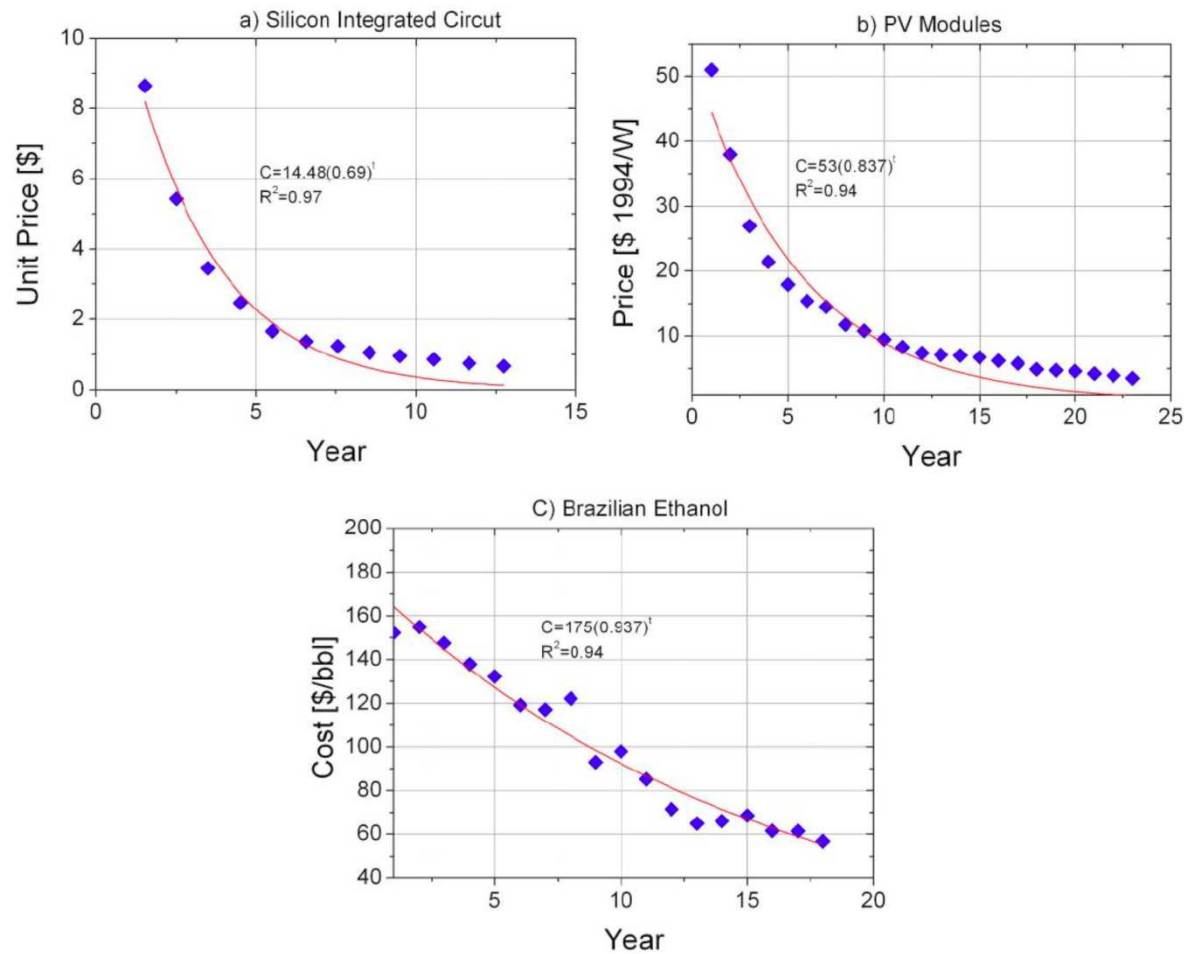
$$x(t) = ab^t$$



Exponential growth



Exponential cost reduction



$$C(t) = df^t$$

A dynamic model for progress

$$x(t) = ab^t \quad ; \quad C(t) = df^t$$

$$\ln(x/a) = t \ln b \implies t = \frac{\ln(x/a)}{\ln b}$$

$$C(x) = d(f)^{\frac{\ln(x/a)}{\ln b}} = d(e^{\ln f})^{\frac{\ln(x/a)}{\ln b}} = d\left(\frac{x}{a}\right)^{\frac{\ln f}{\ln b}}$$

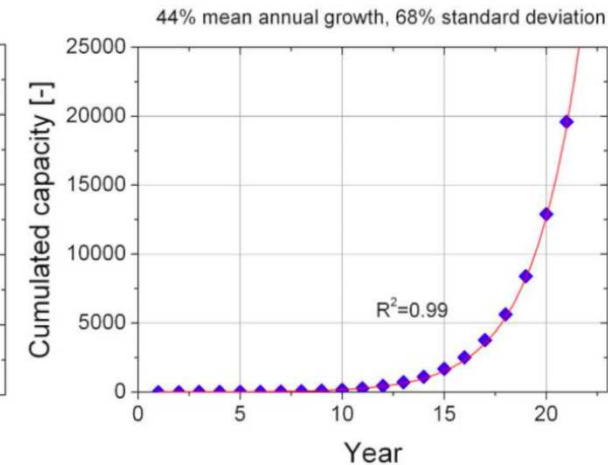
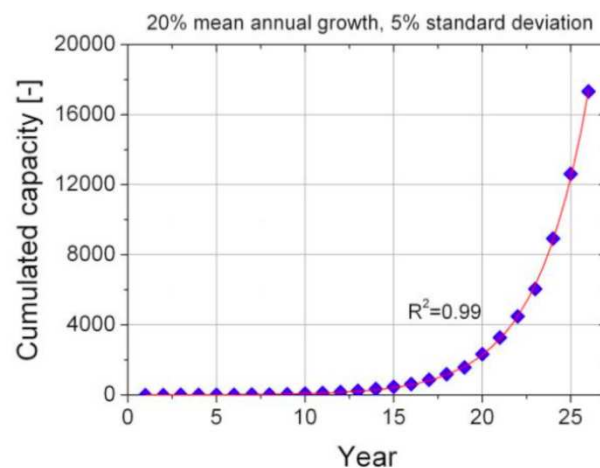
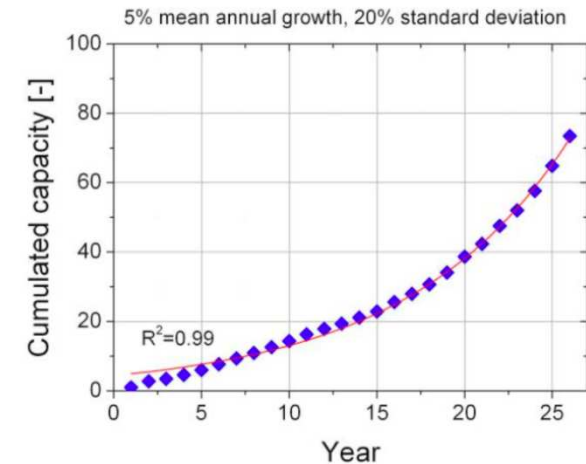
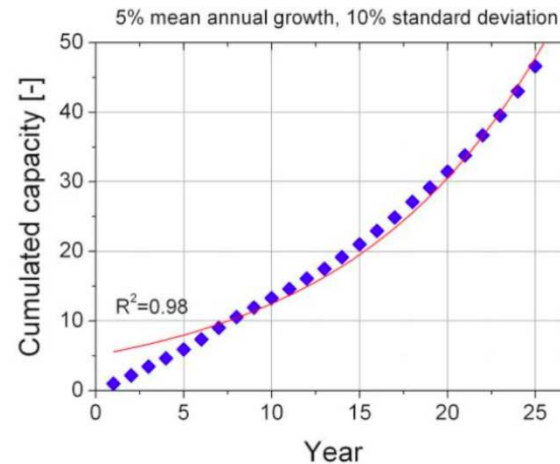
Equivalent to a learning curve with learning rate:

$$LR = 1 - 2^{\ln f / \ln b}$$

A simple numerical model: I) growth

$$y_t = \prod_{i=1}^t \alpha_i$$

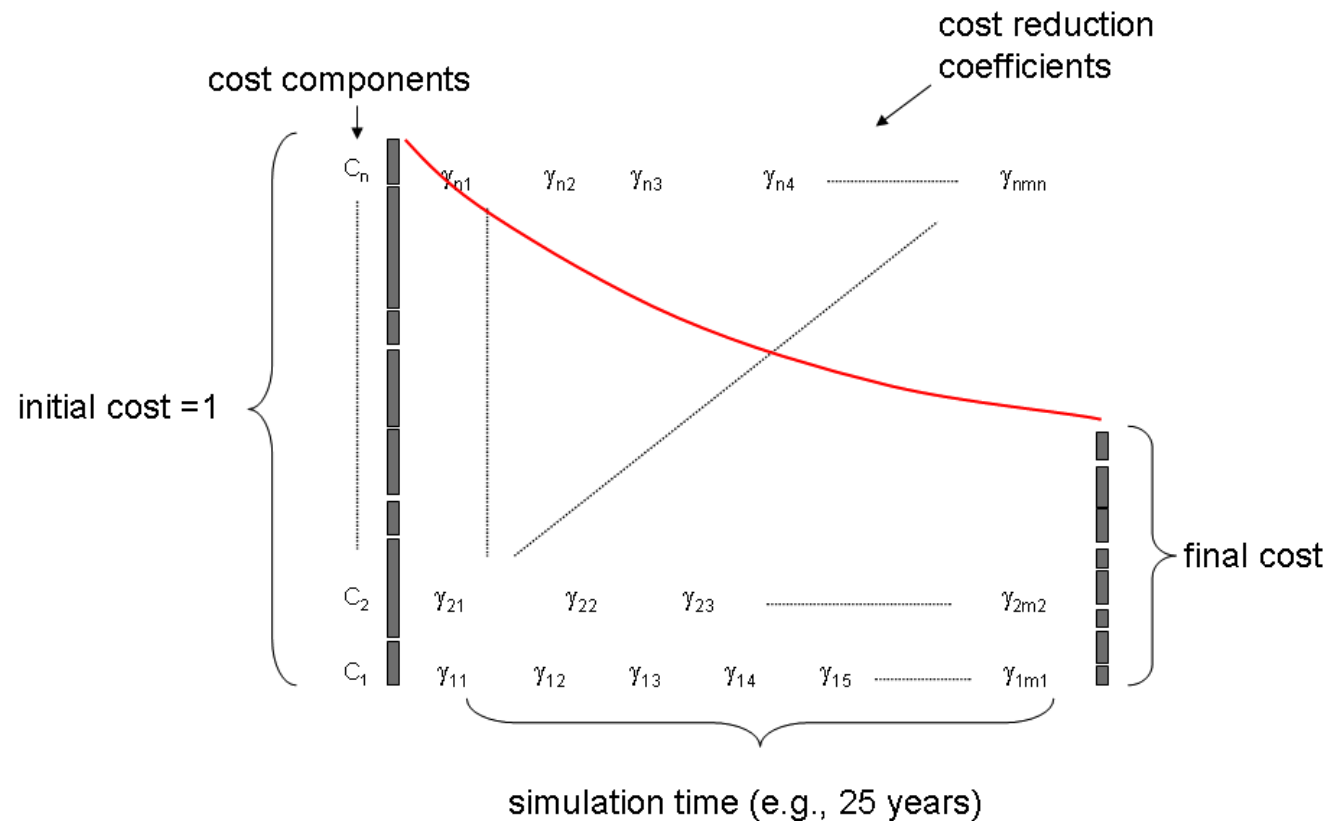
$$x_t = \sum_{i=1}^t y_i$$



A simple numerical model: II) cost reduction

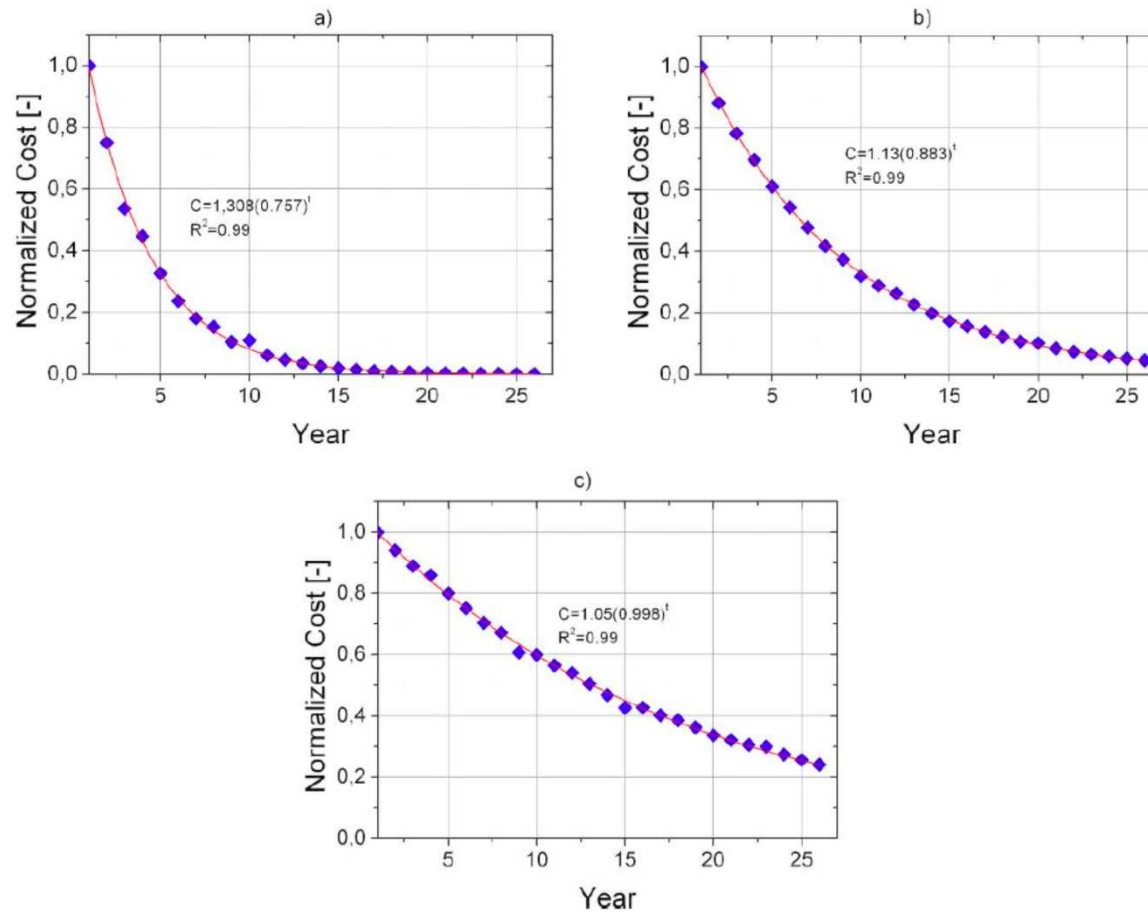
$$\sum_{i=1}^n c_i = 1$$

$$C = \sum_{i=1}^n \prod_{j=1}^{m_i} c_i \gamma_{ij}$$

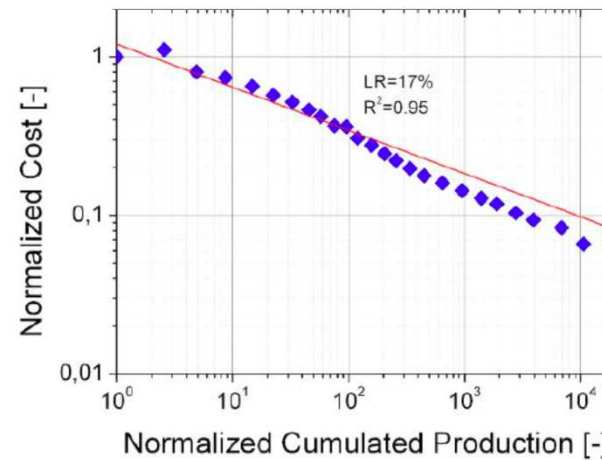
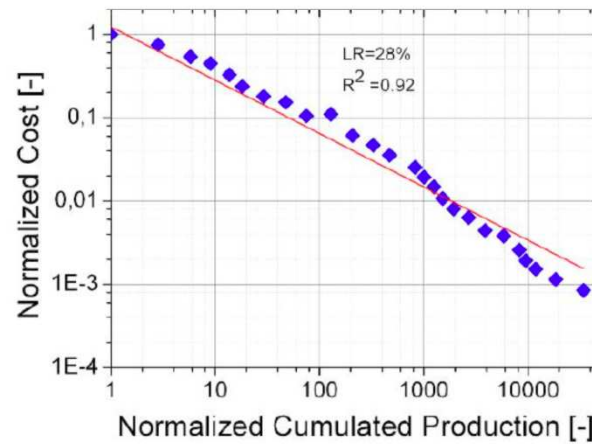
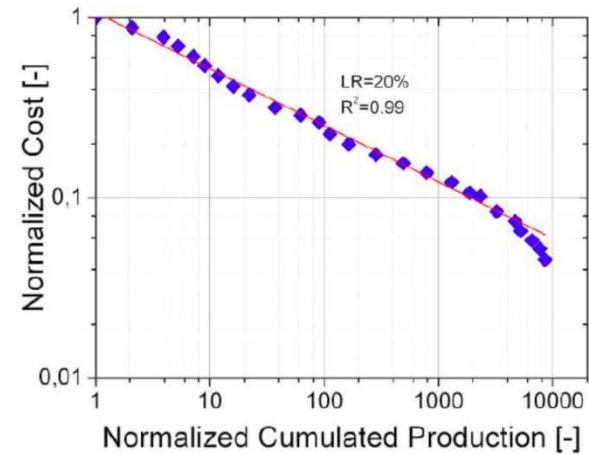
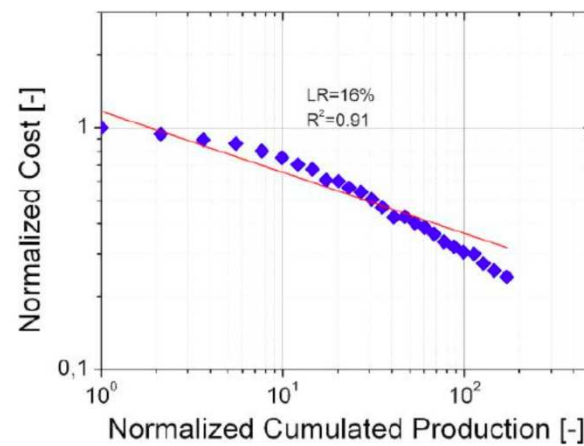


A simple numerical model: II) cost reduction

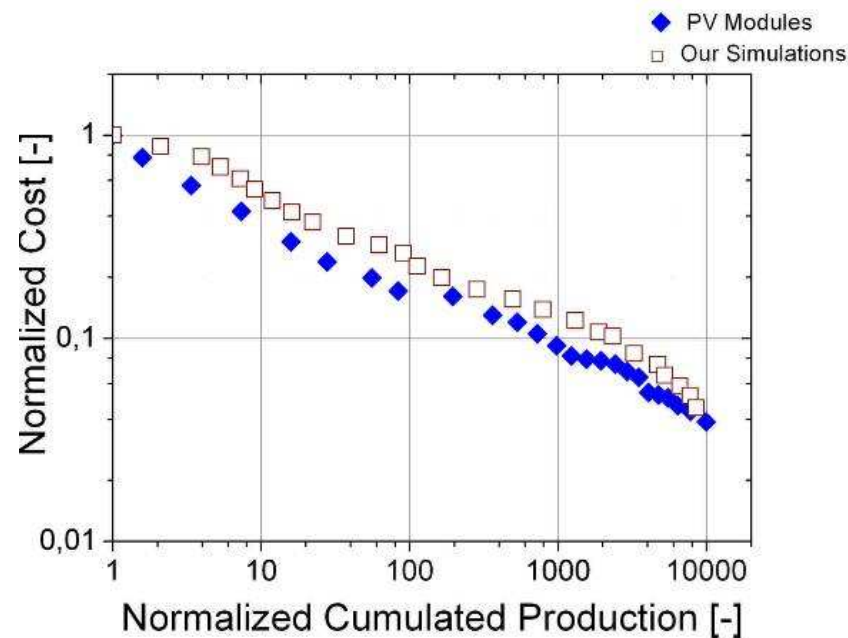
$$C(t) \simeq n\bar{c}_i(\overline{\gamma_{ij}})^{kt}$$



Generated learning curves

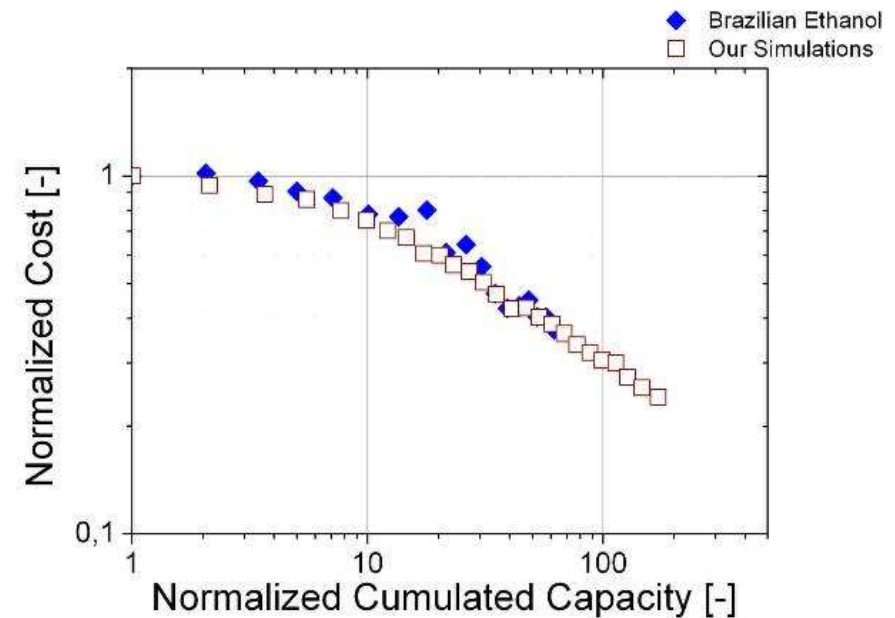


An example using actual data



PV

- 40% annual growth
- 10x cost reduction

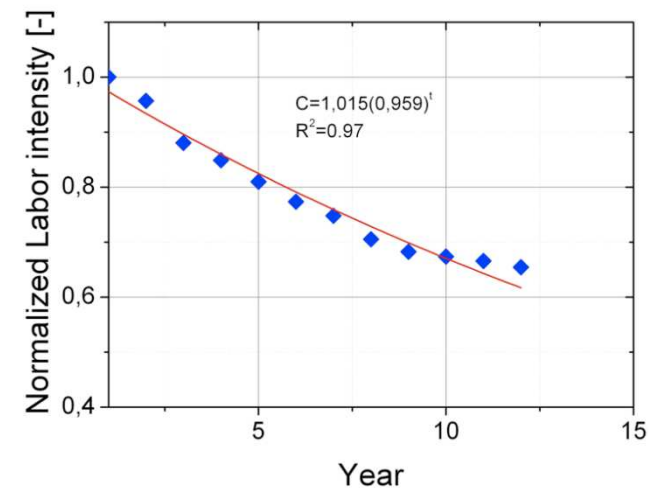
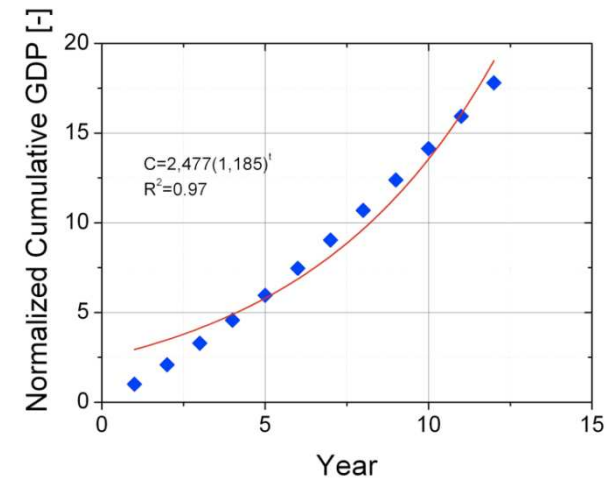


BR Ethanol

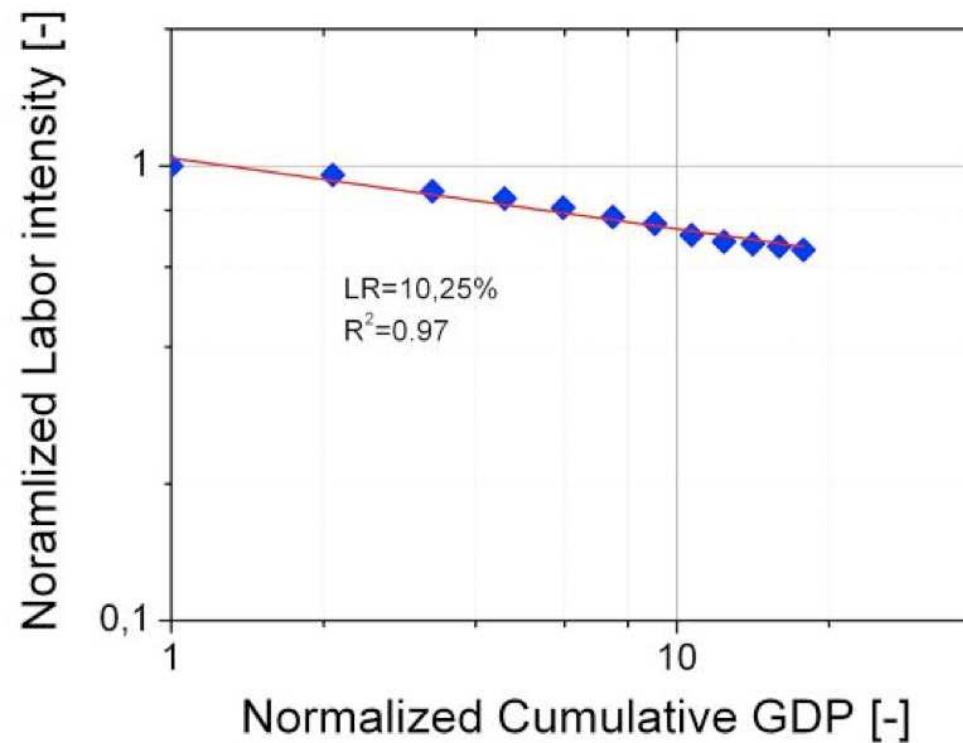
- 10% annual growth
- 3x cost reduction

The learning curve of Ireland

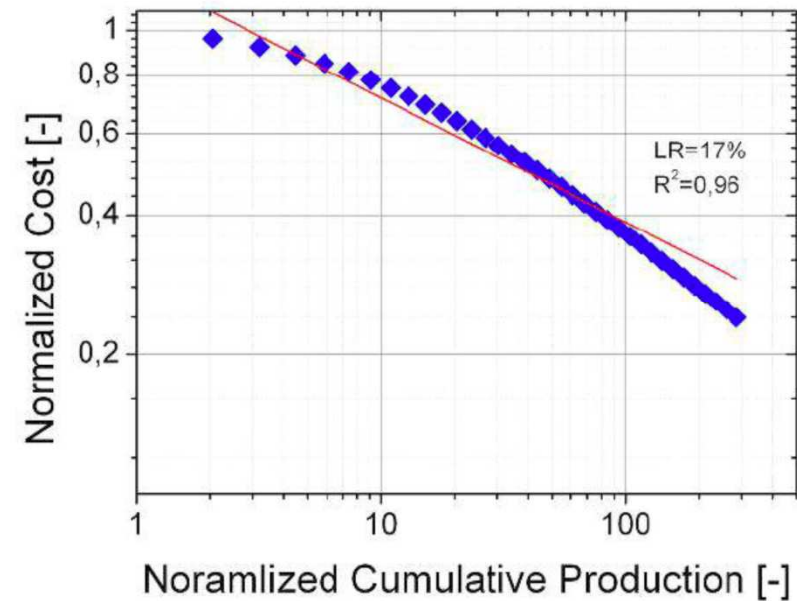
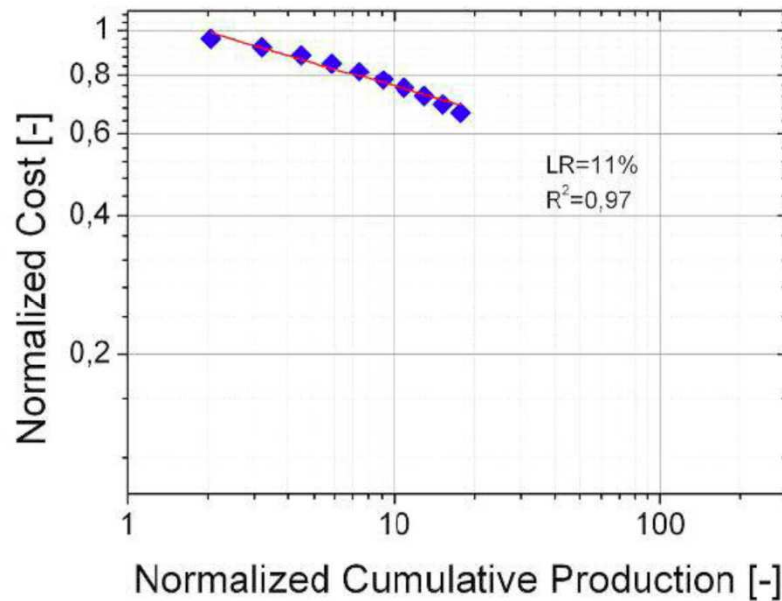
Year	GDP change per capita (%/yr)	Productivity gain (%/yr)
1996	8.7	4.3
1997	10.3	8
1998	6.6	3.6
1999	9.2	4.6
2000	8	4.5
2001	4.5	3.3
2002	4.8	5.7
2003	2.8	3.2
2004	2.6	1.3
2005	3.7	1.2
2006	3.1	1.7



The learning curve of Ireland

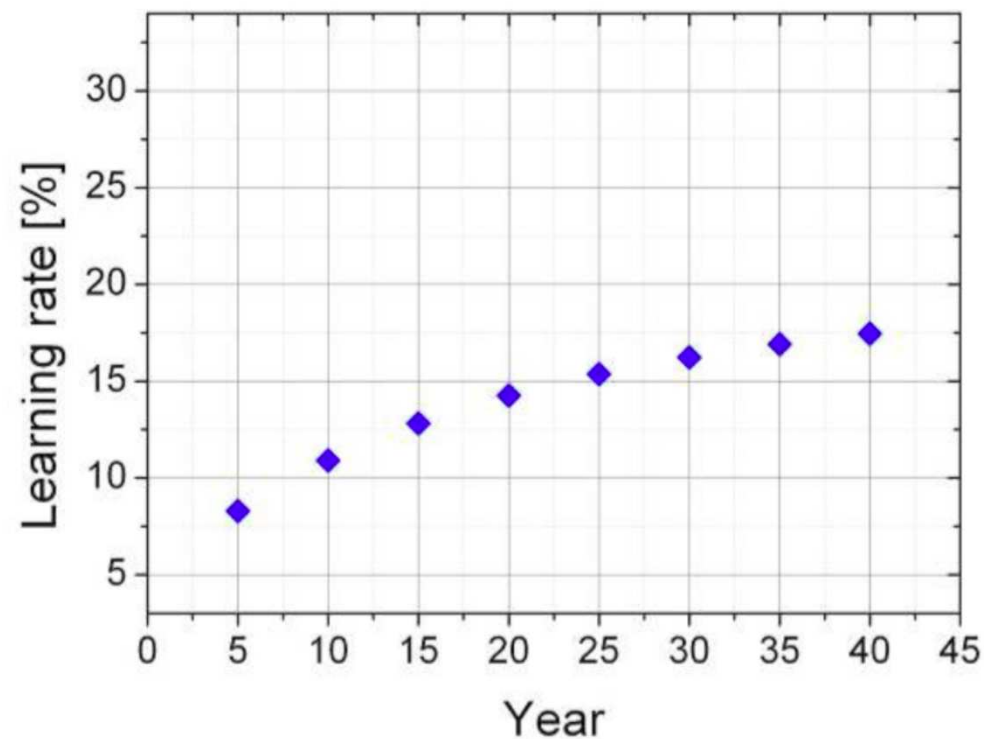


The predictive value of cumulative production



The predictive value of cumulative production

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



Conclusions

- The exponential model is equivalent to the learning curve
- Every investment that reduces costs (R&D, economies of scales, etc.) can be aggregated in a LC
- The LR is not a constant property of a product or technology
- The learning curve depicts an important relation between growth, investments and cost reduction

Thanks for your attention!