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Understanding & Modeling Technology innovation & diffusion

Thanks to:
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Assessing technical change

I believe successful assessment's of technical change are only possible through consideration of characteristics shaped by its human dimensions.

- Policy will change the rate and direction of technology innovation and diffusion -- models treating technical change as an autonomous process are not helpful in evaluating the impact & cost of policy.
- Diffusion of a novel technology is greatly accelerated if it meets existing social goals -- mobility, urban pollution & energy security are the probable determinants of energy technologies we are most likely to get.
- We do not know how to cost a climate policy.

Outline of this talk

The basics

A real example of technology diffusion

Estimating technical change for modeling in assessments

The challenge ahead and (in)adequacy of existing tools

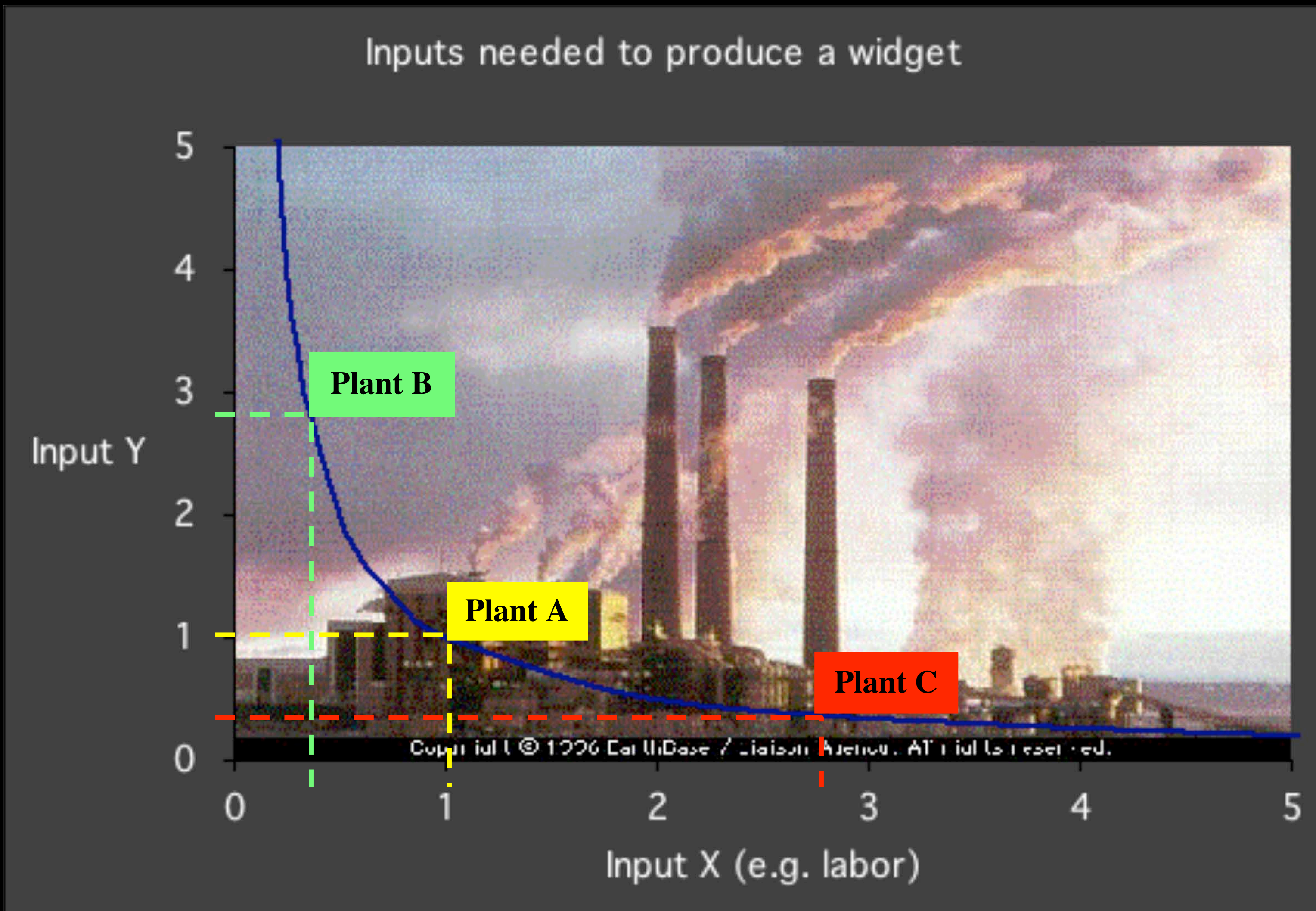
A brief glossary

- Motivations for technical change
  - » Serendipity, Profit and Regulations
- Elements of technical change
  - » Invention and Innovation
  - » Adoption and Diffusion
  - » Process change and Product change
- Models of Technical change
  - » Autonomous, Endogenous and Induced technical change
  - » Economics of scale, learning, ...
- Destruction (obsolescence)

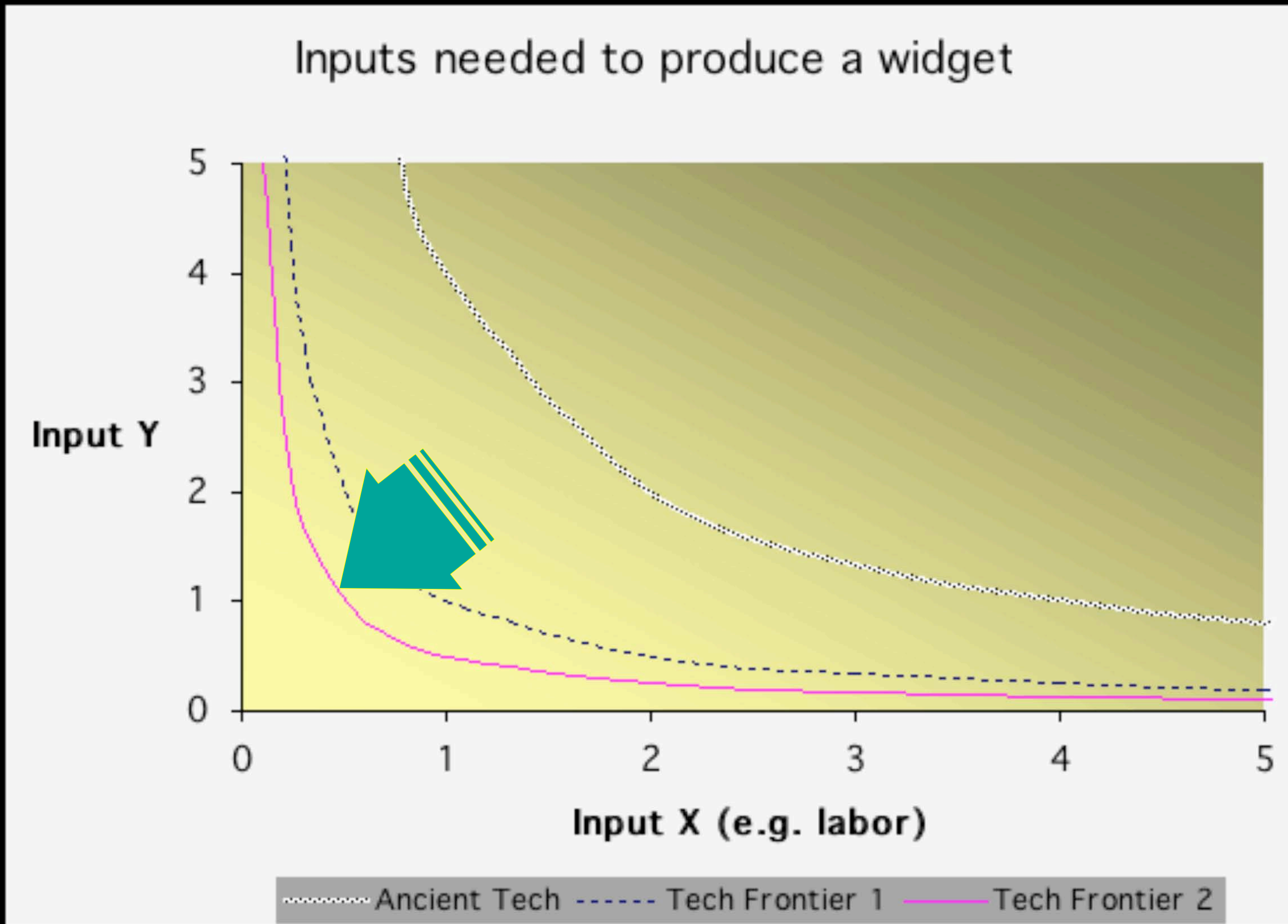
Background

- In economics it is common to equate production to a function of inputs such as labor, capital, and material. When productivity grows significantly faster than the changes in these inputs, "Technological change" is defined as the responsible factor.
- In explanation of US economic growth in the first half of the 20th century:
  - ~ 10% attributed to capital and labor inputs.
  - ~ 40% attributed to a better educated labour force.
  - ~ 50% attributed to technical change embodied in equipment

The Technological Frontier

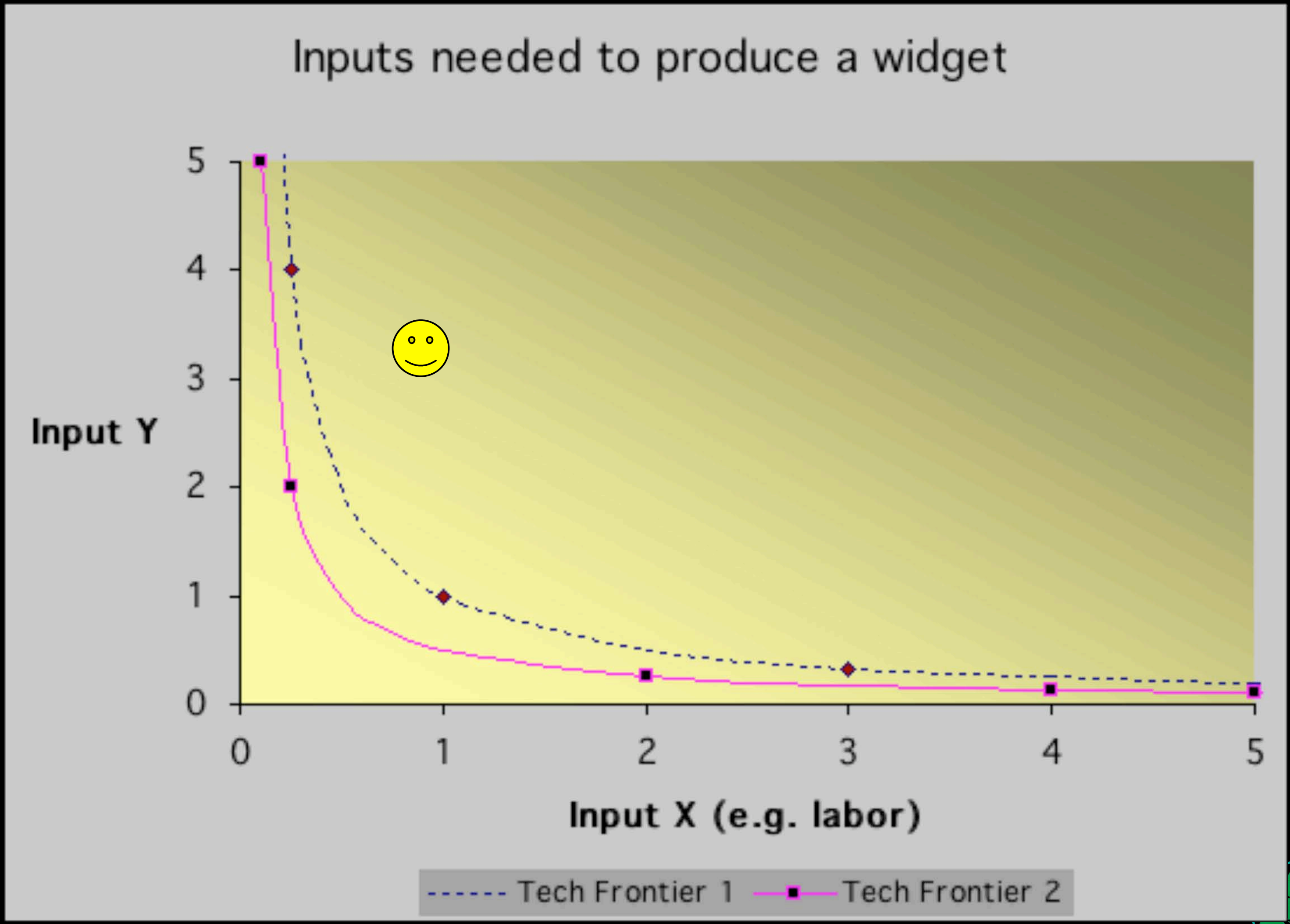


Technological Progress can mean: *less is used to produce the same*



Granularity matters!

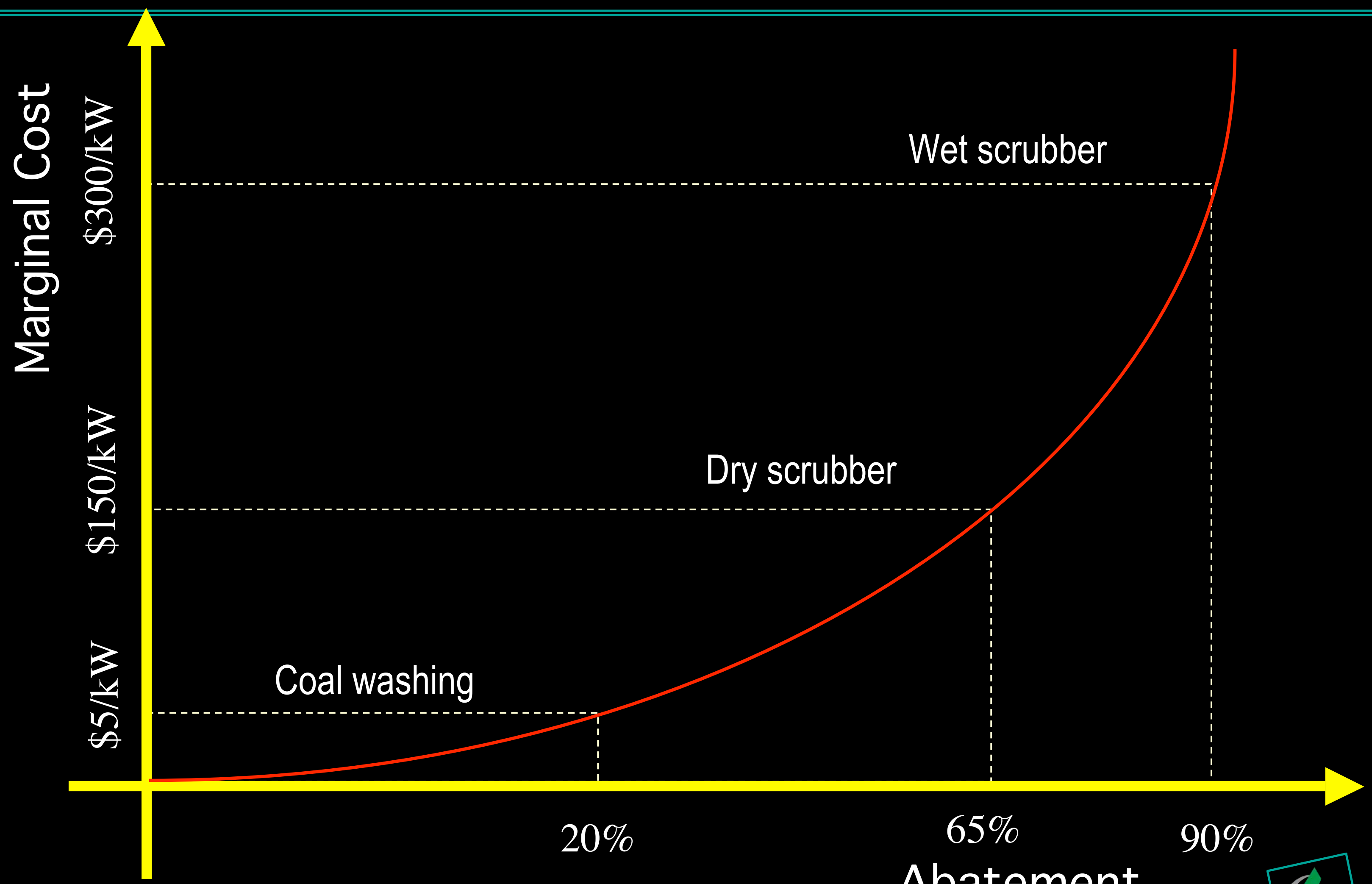
As does doing well enough!



Assertions & Empirical Evidence

- Widely used theory asserts that if we start on the frontier, and need to consider *any* new constraint, it will be costly.
- Porter hypothesized that being forced to consider new constraints lead to a new technology frontier and overall savings.
- Empirical studies of actual control costs in various industries indicate costs average 80% of expected but range from -200% to + 350%.

Consider an abatement cost curve



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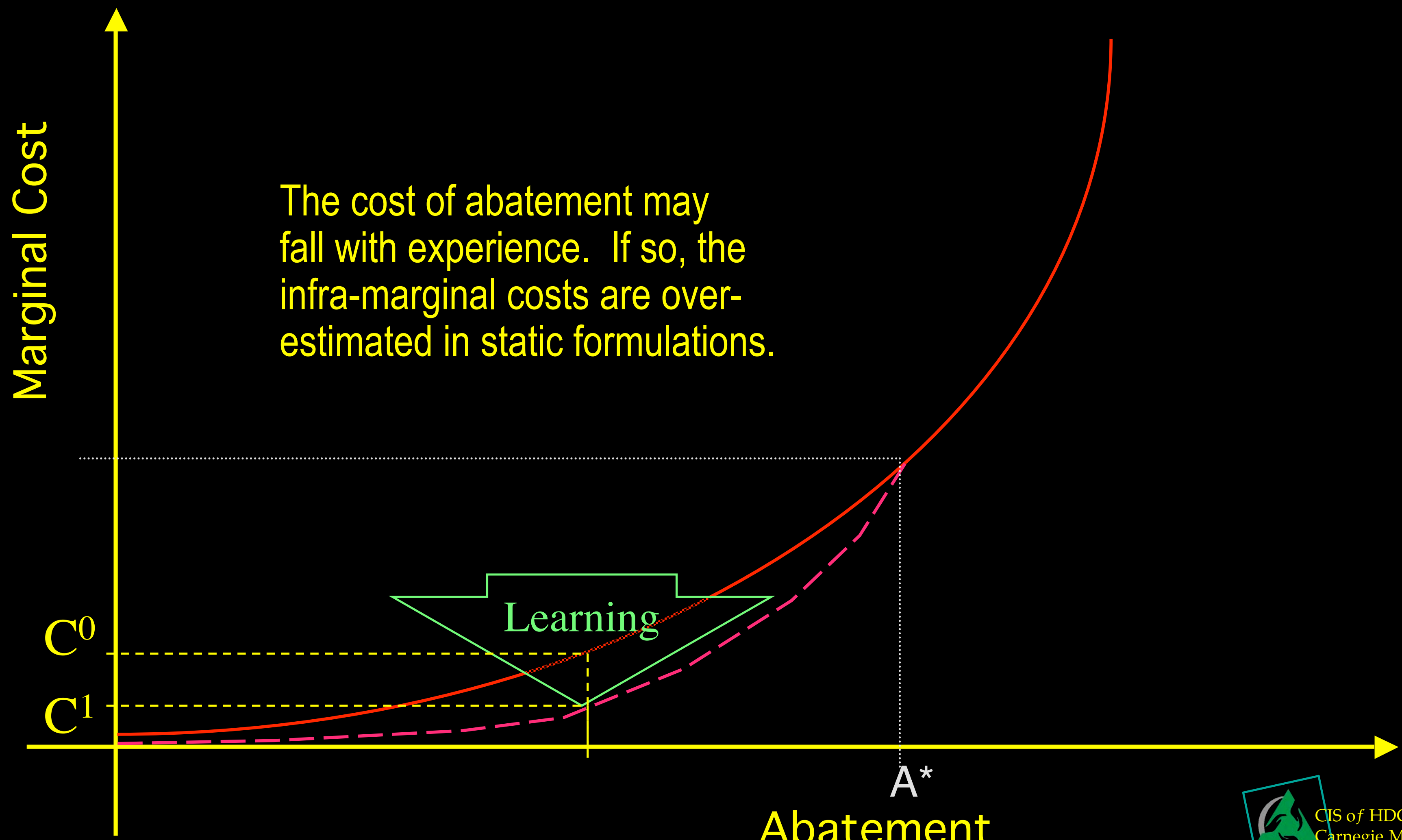
Abatement cost curves: process change

The cost of abatement may fall with experience. If so, the infra-marginal costs are over-estimated in static formulations.



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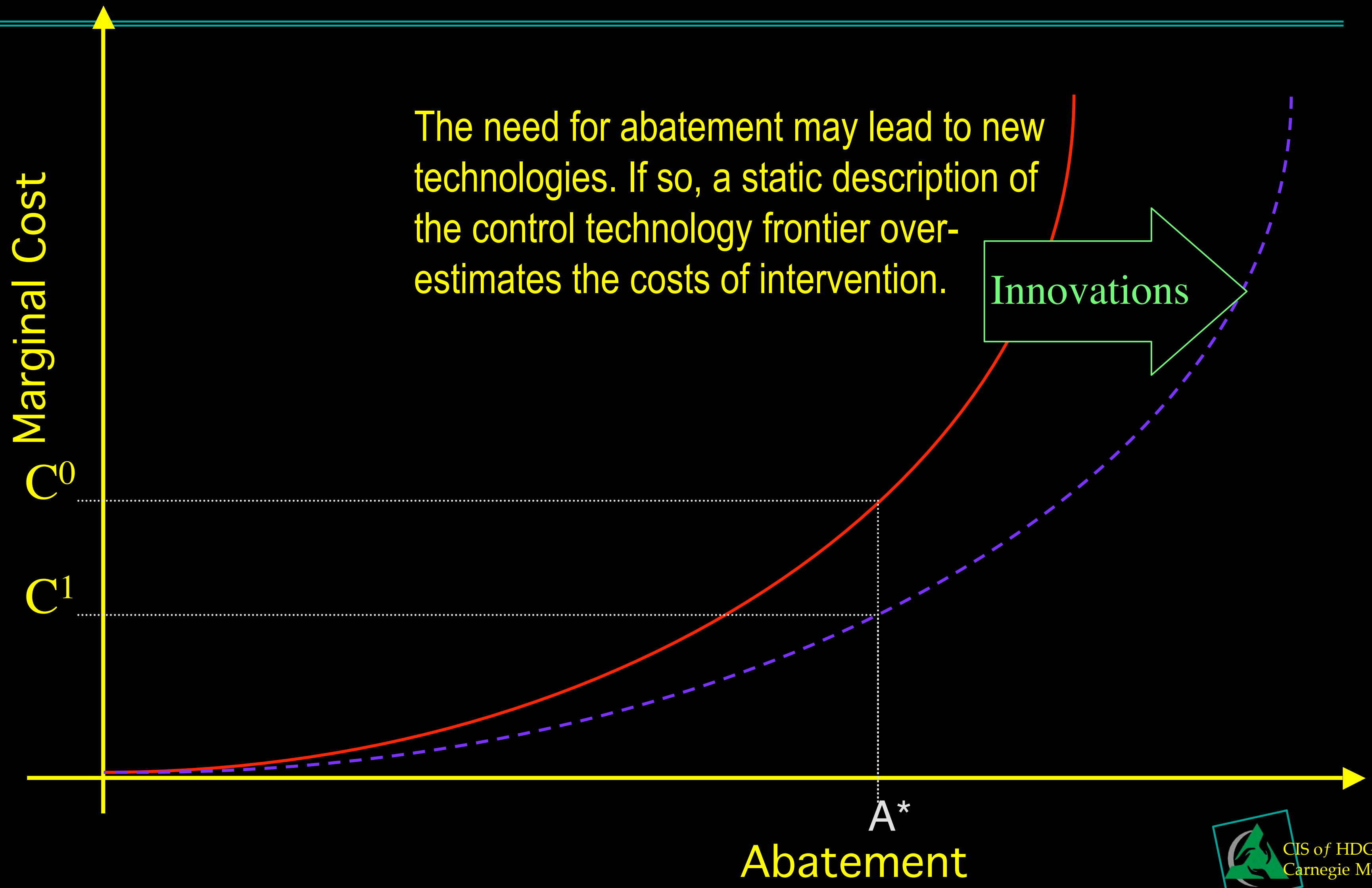
Abatement cost curve: product change

The need for abatement may lead to new technologies. If so, a static description of the control technology frontier over-estimates the costs of intervention.



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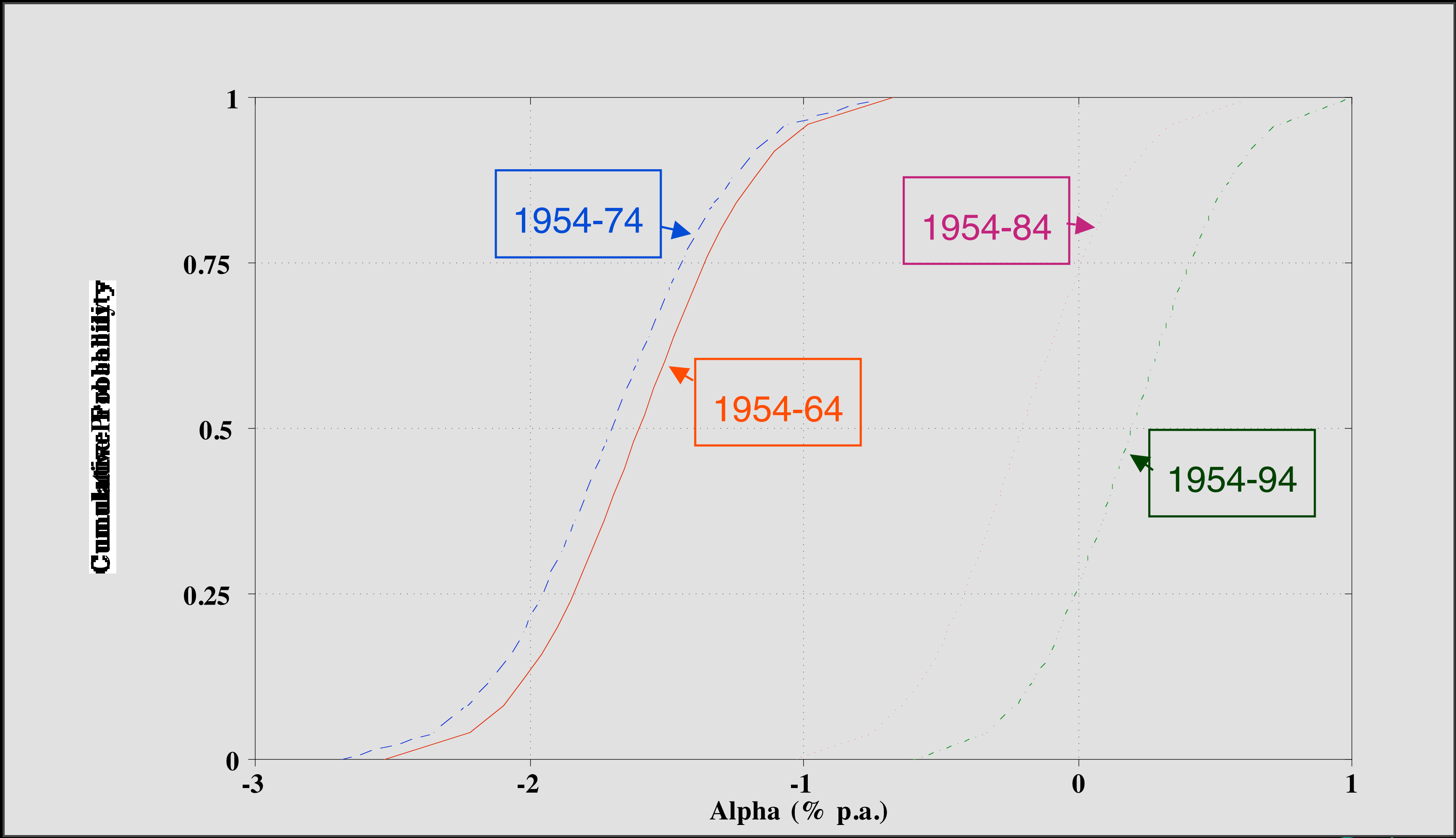
Modeling technical change

- In general, technical change has been limited to cost & efficiency of energy supply (& use).
- Three approaches have been adopted:
  - » Bottom-up models: Detailed specification of technology and the anticipated evolution of their performance and economics.
  - » Top-down models: a) Specification of technological change as an autonomous process.
  - » Top-down models: b) Specification of technological change as a process that responds to other state variables in the model.

Factors affecting energy intensity

- Many factors determine energy intensity, when there are price or policy signals:
  - » The structure of the economy can change, e.g., service sector.
  - » Consumers may choose to use energy services in a different pattern.
  - » The same services would be provided using new technologies.
- Some of these are explicitly included in various models. But more often than not, the trend in the residual of factors affecting energy intensity is an exogenously specified constant, specified to decline by 0.5 to 1.5%p.a. (or as a constant multiplier of GDP growth (2.3x∂GDP).
- We explored the validity of this assumption

Probabilistic estimates of efficiency change through time



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Mean of estimated Energy Price Elasticity

(% change in demand for % change in price)

Period Ending in

Period Beginning in	1964	1974	1984	1994
1954	-0.42	-0.43	-0.42	-0.41
1964		-0.40	-0.41	-0.41
1974			-0.39	-0.39
1984				-0.37

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Mean of estimated residuals
(%p.a. improvement in energy intensity)

Period Ending in

Period Beginning in	1964	1974	1984	1994
1954	-1.6	-1.9	0.3	0.35
1964		-2.7	0.5	0.4
1974			3.8	2.9
1984				2.8

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A dynamic specification of technical change (1954-94)

The dynamic response of the α_t can be estimated from the pseudo-data which best replicates history:

$$\alpha_t = \rho_0 + \rho_1.\ln\left(1+\ln\left(1+\dot{P}_{t-5\to t}\right)\right)$$
$$+\rho_2.\ln\left(1+\ln\left(1+\dot{P}_{t-10\to t-5}\right)\right)$$
$$+\rho_3.\ln\left(1+\ln\left(1+\dot{P}_{t-15\to t-10}\right)\right)$$

$$where:$$

$$\rho_0 = normal(-1.7,\ 0.03)$$
$$\rho_1 = normal(6.3,\ 1.45)$$
$$\rho_2 = normal(5.1,\ 2.40)$$
$$\rho_3 = normal(1.8,\ 0.25)$$
$$n = 652;\ r^2 > 0.95$$

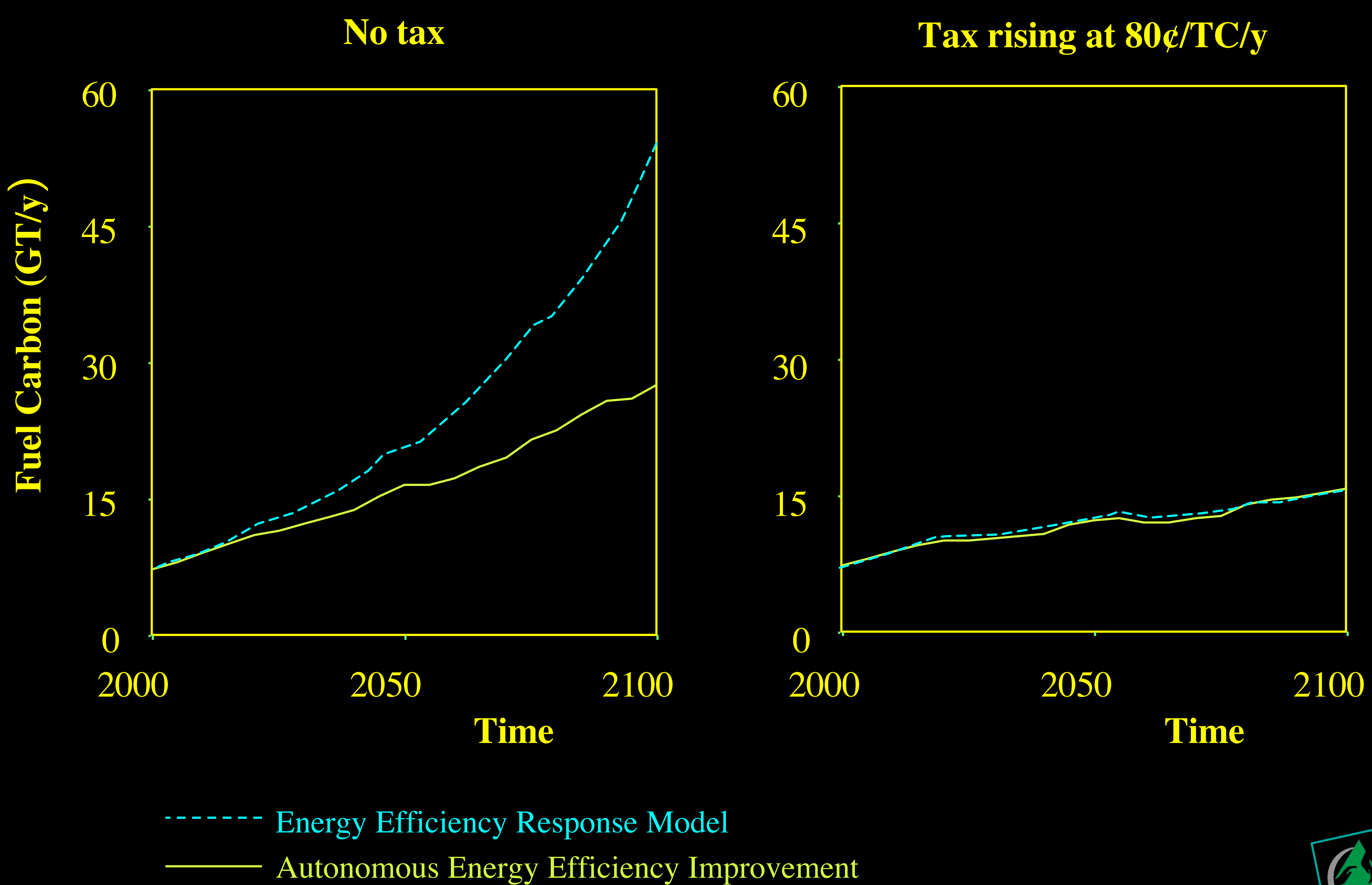
The residuals reflect many phenomena

- The immediate decline of energy intensity after 1974 is too fast to be due to technical change. More likely it is due to structural change in the economy.
- After 5 years, the continued improvement in energy intensity is reflective of continued structural change as well as diffusion of energy efficient (consumer oriented) technologies.
- Given that the RD&D of many technologies takes longer than 10 years, and rate of turnover of large capital is slow, it takes 10+ years for the innovations spurred by price and policy signals of 1974 to make their mark.

Bringing these findings into the main stream

- Theory is based on the notion that the economy is efficient in allocation of resources. Hence, if resources are *deviated* to improve energy efficiency, there *must* be a *loss* of economic productivity.
  - » Evidence: the post oil-shock economic debacle!
  - » Rebuttal: how much of that was due to macro-economic errors?
- The work of Nakicenovic and Schmalensee shows learning curves for energy technologies.
  - » Implication: the findings here are probably specific to the US which has a well developed industry and a powerful energy lobby. We have begun to estimate α for other countries.
  - » Next challenge: how might α evolve through time?

Implications of a revised α for projection of CO_2 emissions



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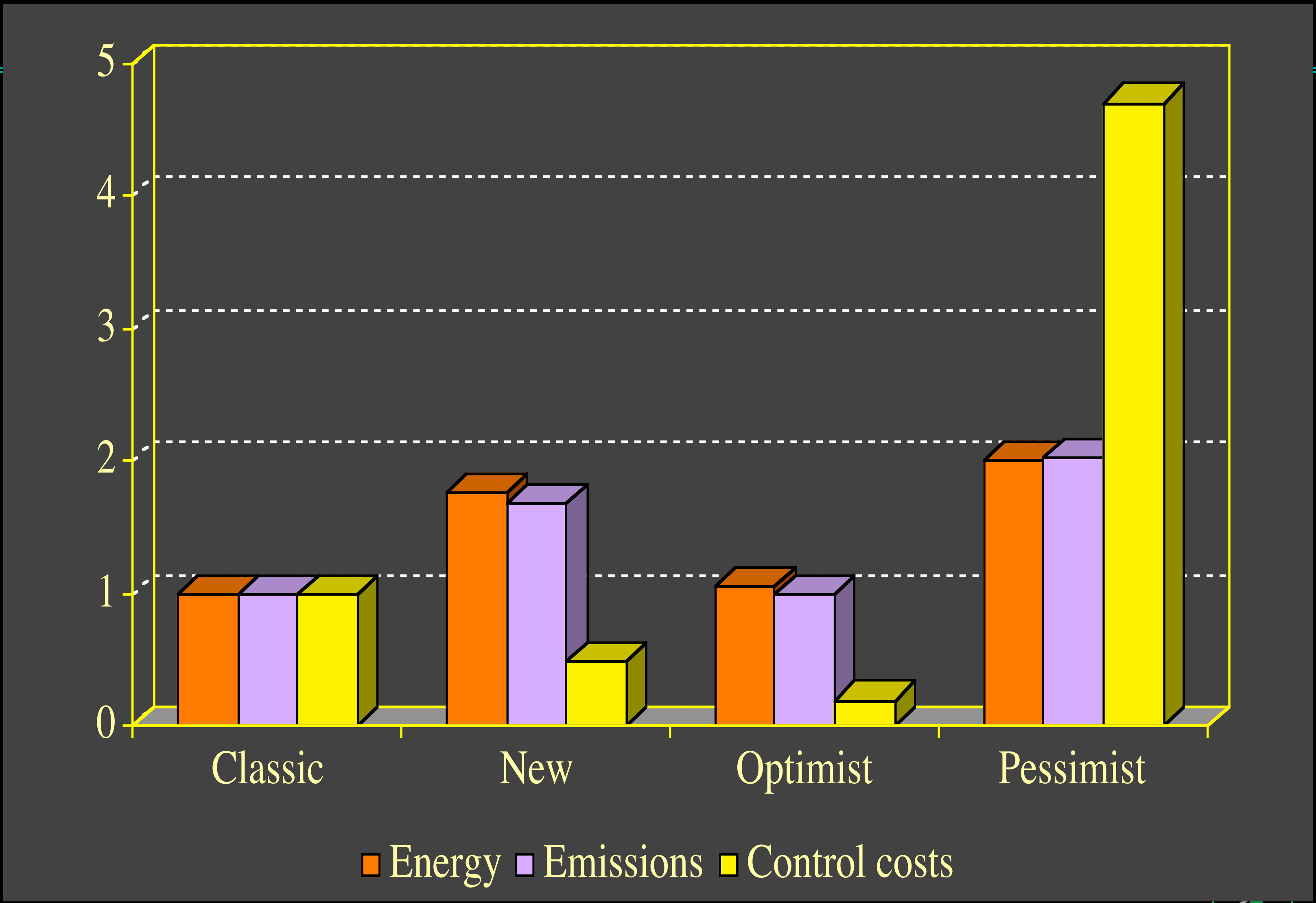
Modeling Climate Policy & Technical Change

- What is the purpose of policy and its form?
- What are the Implications of policy for pace and direction of technical change?
- What is the capacity for innovation and technical progress in energy production and consumption?

Issues Reflected In ICAM-3

	Expectations (price, regulations)	Experience
End use technologies & economic structure	√	
Fossil Fuel Discovery & Production	√	
Renewable Energy Production	√	√
Pollution control technologies (S, C)	√	√

Climate Policy & Technology Change



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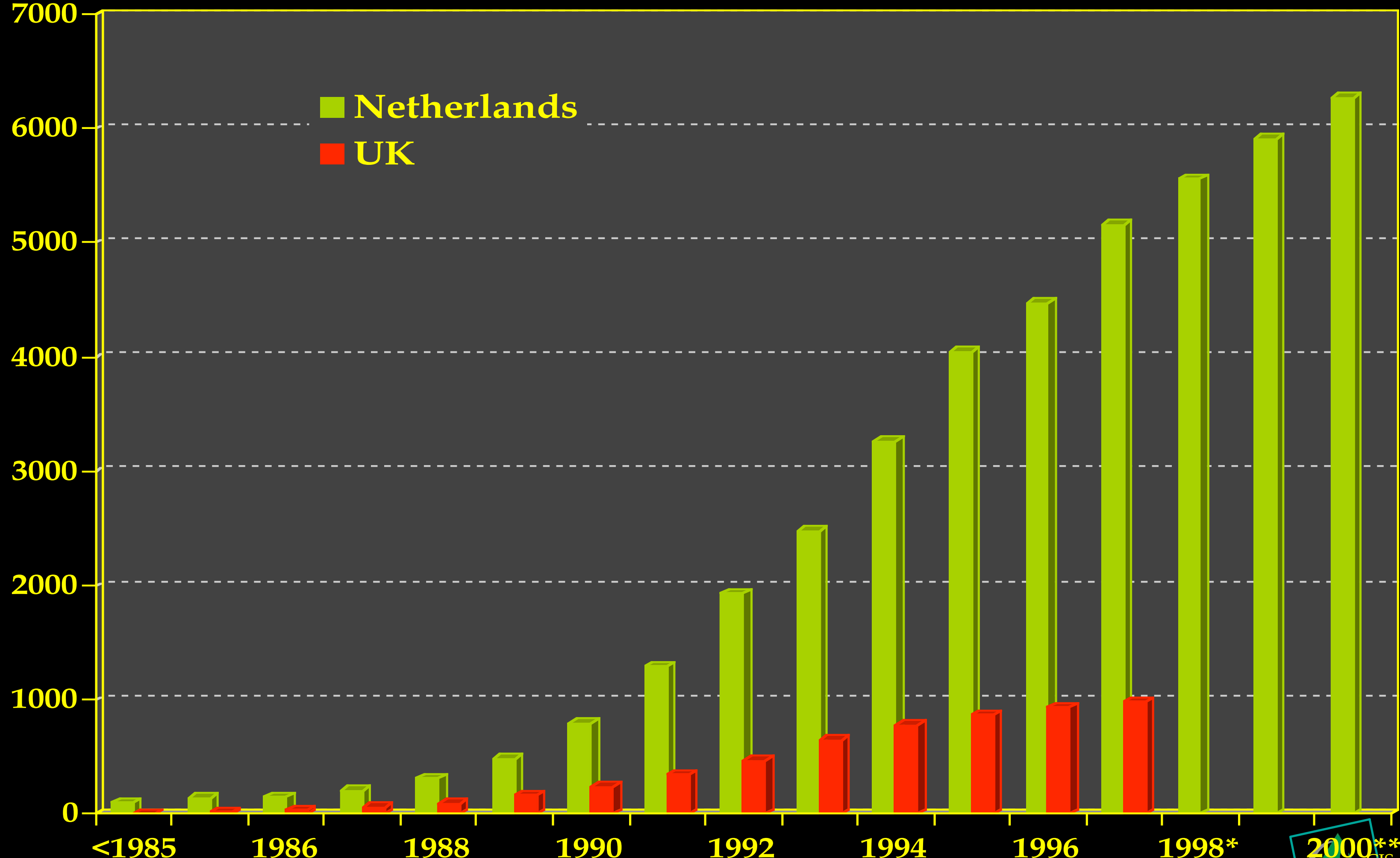
Estimating technical change for modeling in assessments	The challenge ahead and (in)adequacy of existing tools

Why did distributed cogeneration take off in the Netherlands and not the UK?



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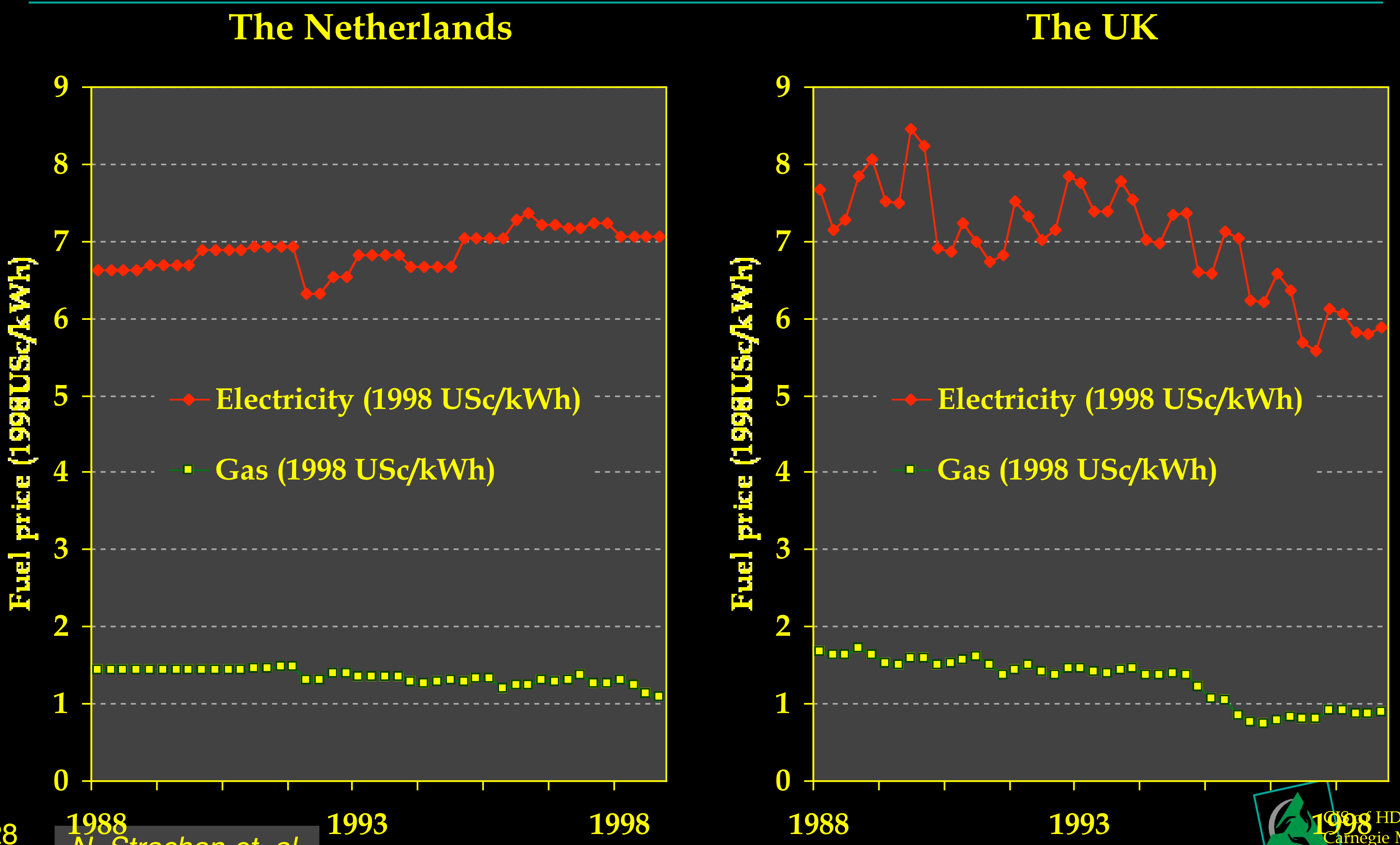
A focus on investor uncertainties pointed up fuel *price volatility*



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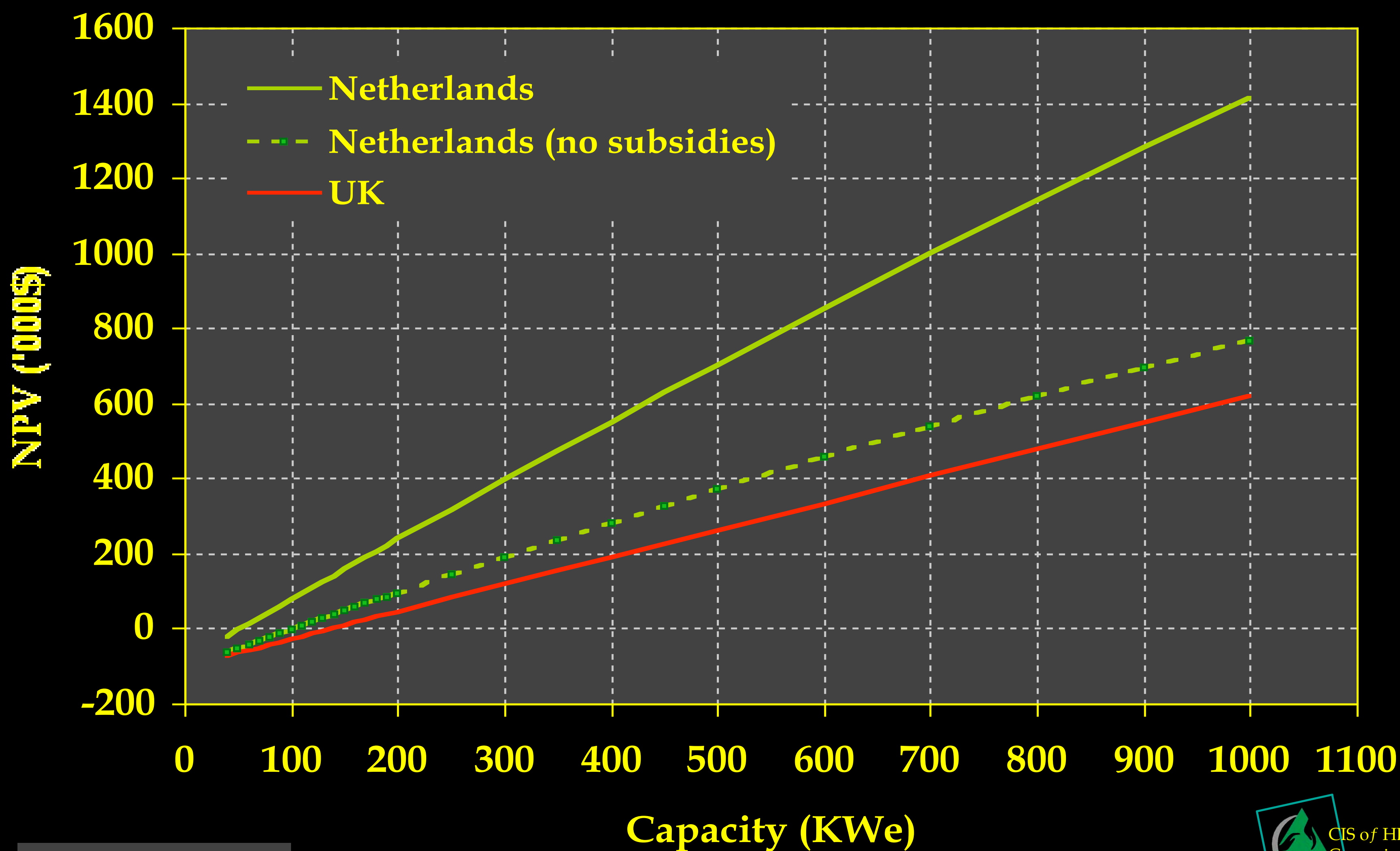
A focus on national programs pointed up *subsidies*

- Netherlands (1986-1998)
  - 167M capital subsidy,
  - + 137M fuel subsidy,
  - + 3.9M energy tax exemption,
  - + 17.7M to establish Cogen Information Center.
  - Also the utilities were allowed to raise up to 525M in electricity and gas levy to pay for their CO_2 reduction plans
  - 1500 MWe
  - i.e. 220$/kWe (570$/kWe if we include the levy)

- UK (1986-1998)
  - ≈ 10M capital subsidy
  - + 0
  - + 0
  - + 9.5M to establish Cogen Information Center.
  - 110MWe
  - i.e. 180$/kWe

A focus on engineering economics pointed up economies of scale & *NPV*



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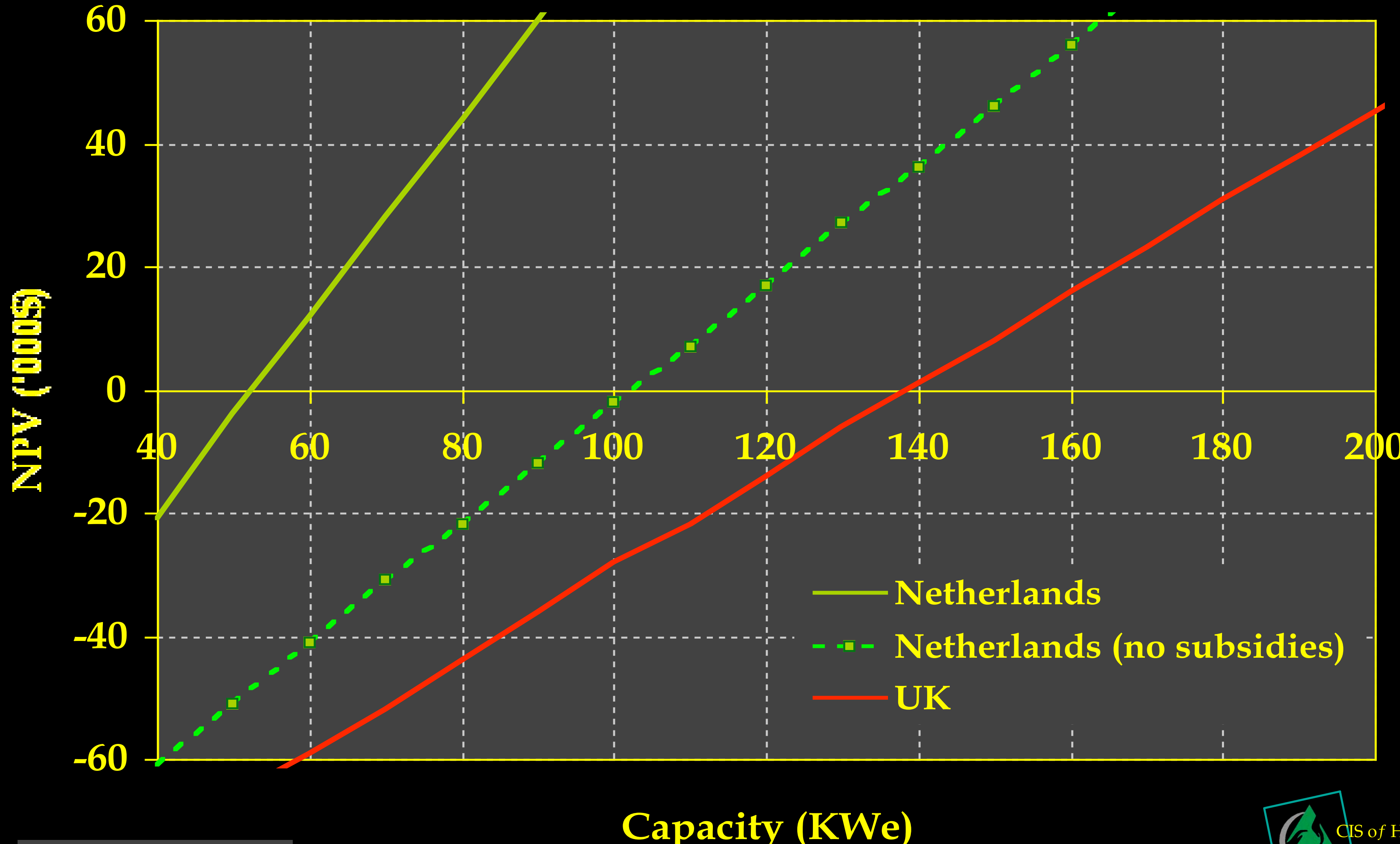
Cost-effectiveness in more detail



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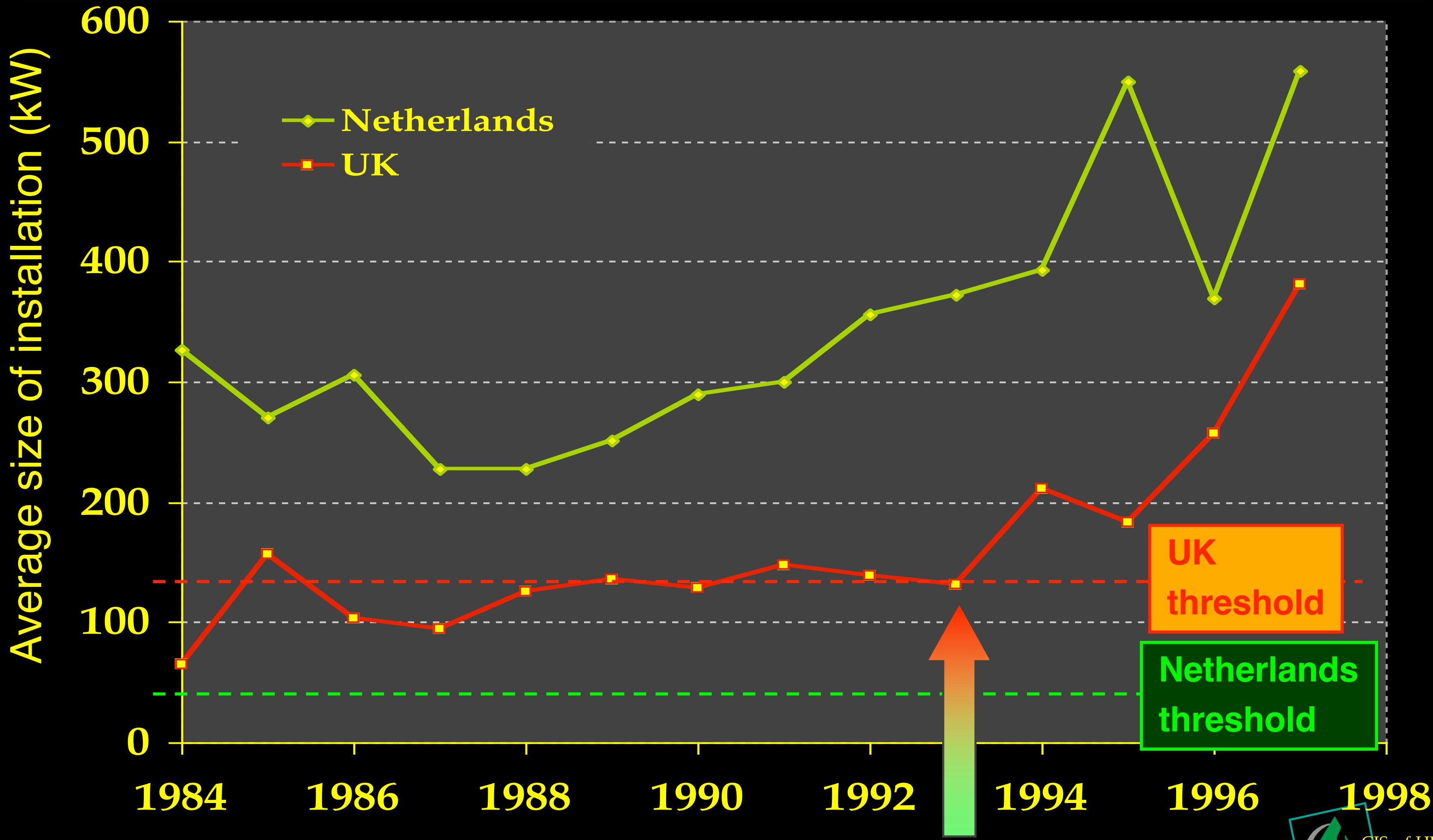
A focus on installation scales points up the role of *supply firms*



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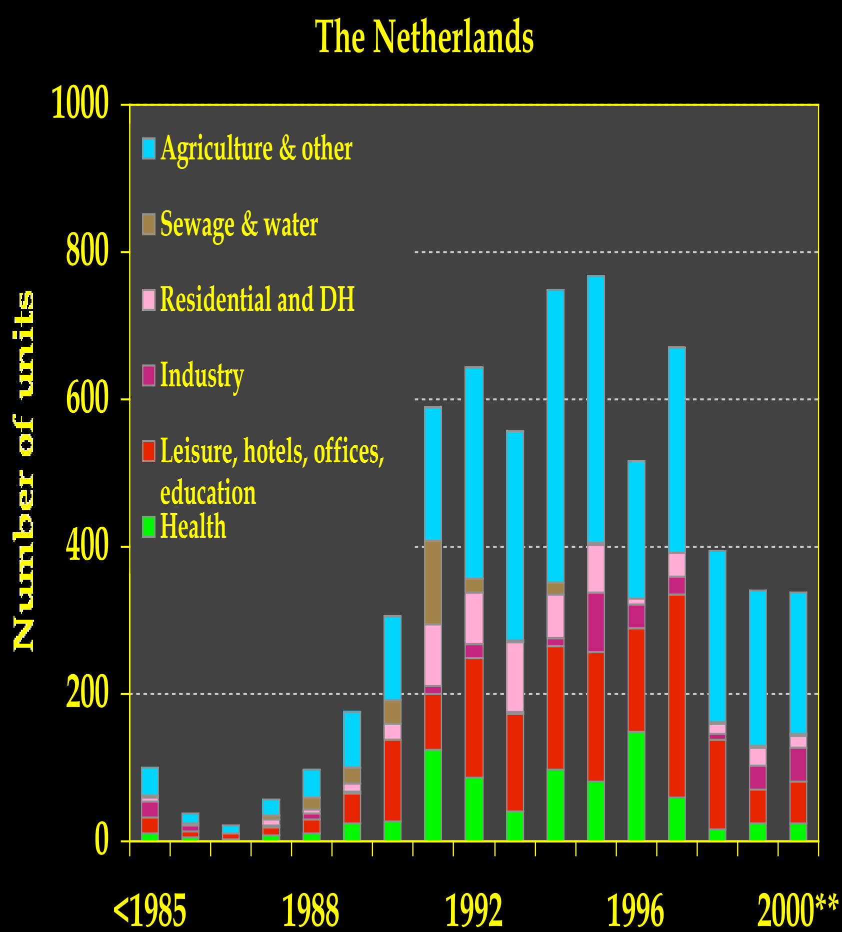
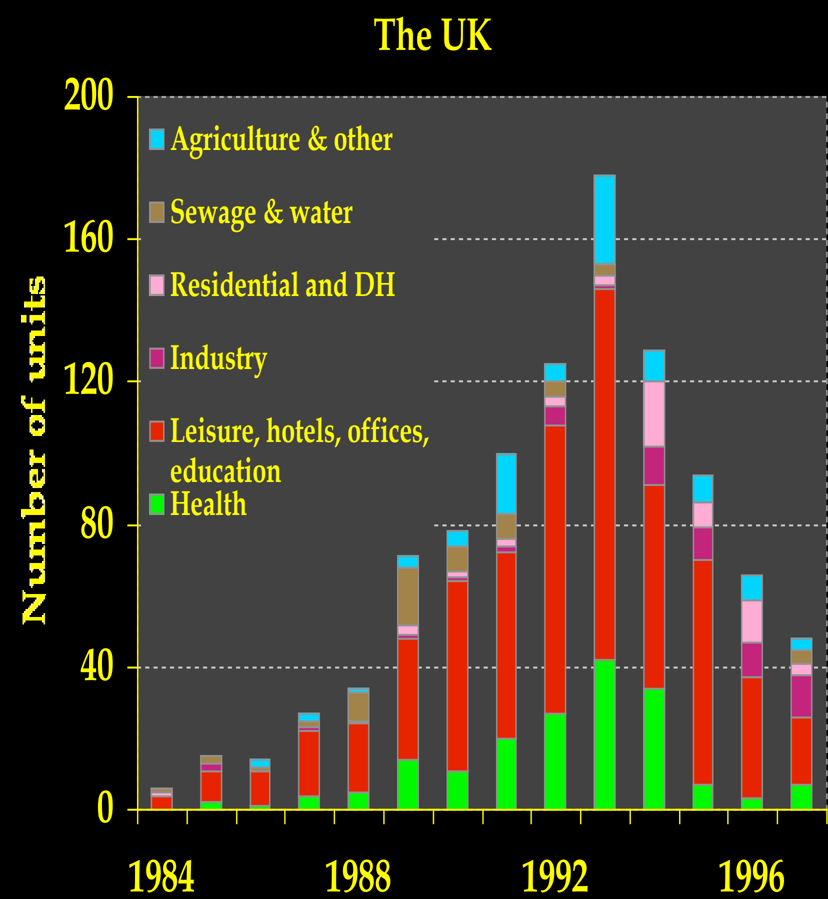
A focus on installations points up the role of *end-users*





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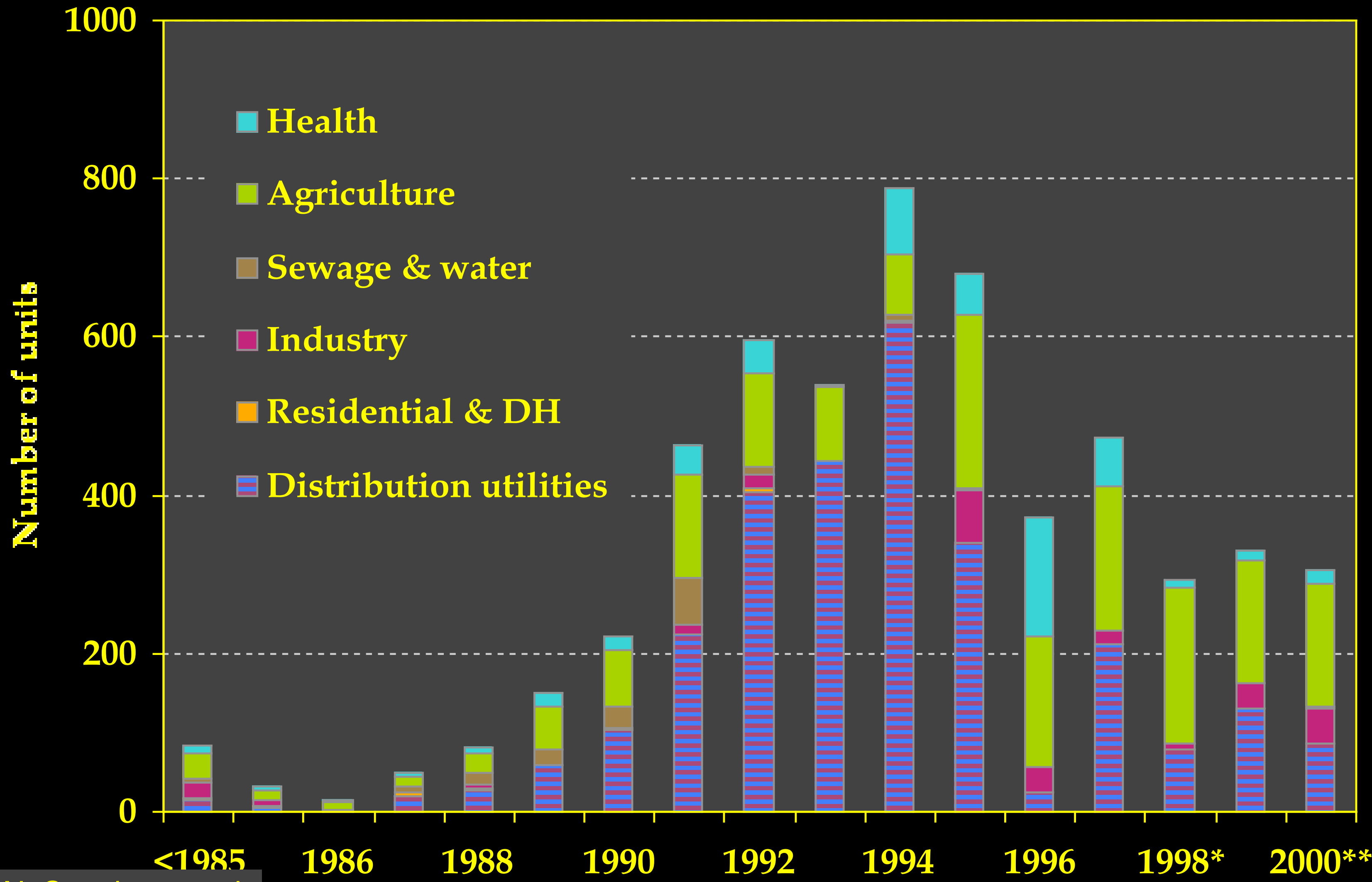
More careful analysis still points up the role of the *Utilities*



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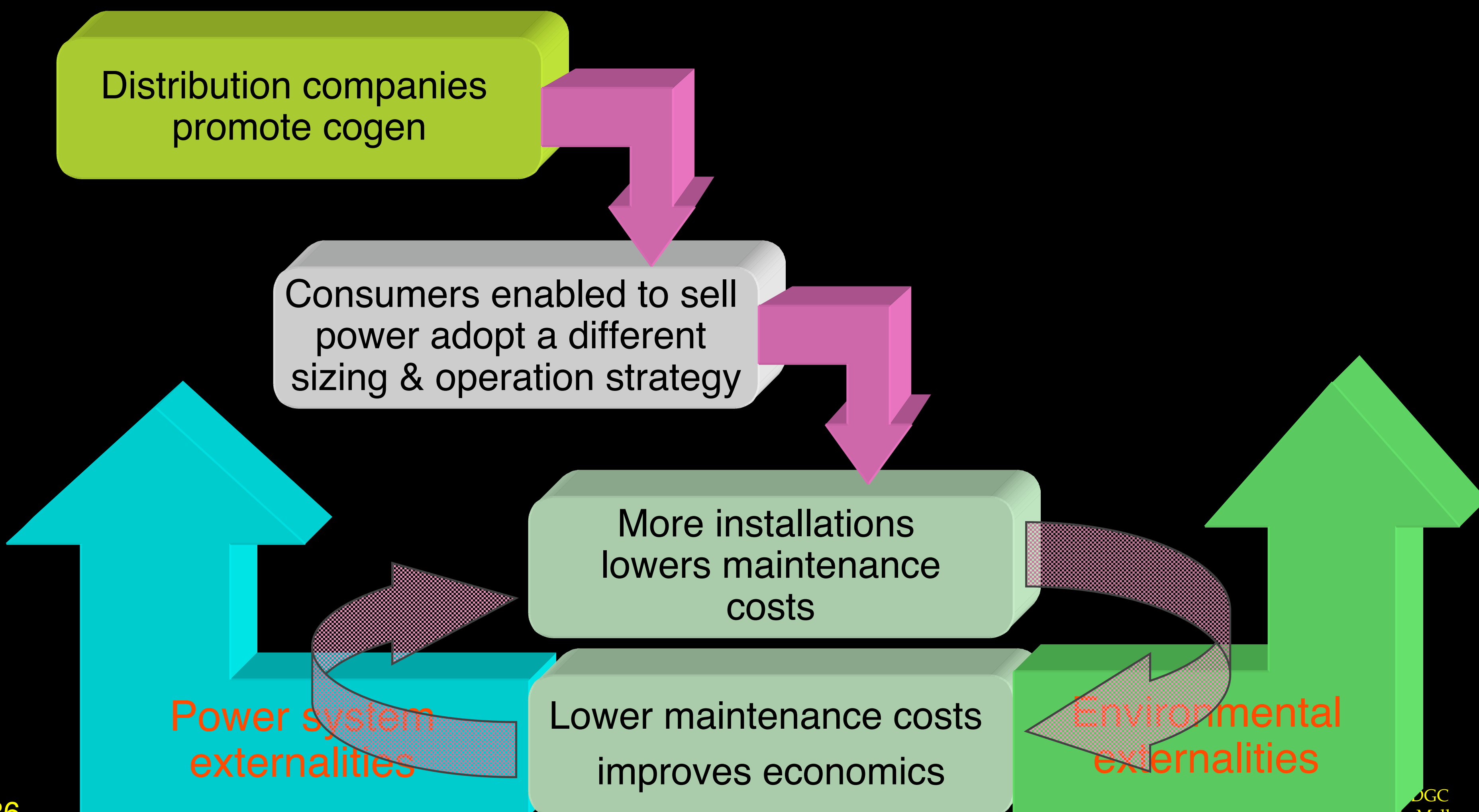
The distribution utilities have affected how the units are sized and operated!

- The Netherlands
  - » Size the unit to meet all but extreme heat loads.
  - » Sell excess electricity to the grid.
  - » Often do not need a backup boiler.
  - » Rarely need to buy power
- The UK
  - » Size the unit to meet base heat requirements.
  - » + no excess electricity is for off-site sale.
  - » Always need to invest in peaking boiler.
  - » Always need to purchase some power.

Cross-scale interactions in the Dutch co-generation market



R_x for Assessments

- Analyses should differentiate between the rhetoric of informed decision-making and the reality of boundedly rational decision-making.
- Analyses should recognize the importance of:
  - » path dependency,
  - » institutional setting,
  - » firm level issues,
  - » nature of information networks and learning.

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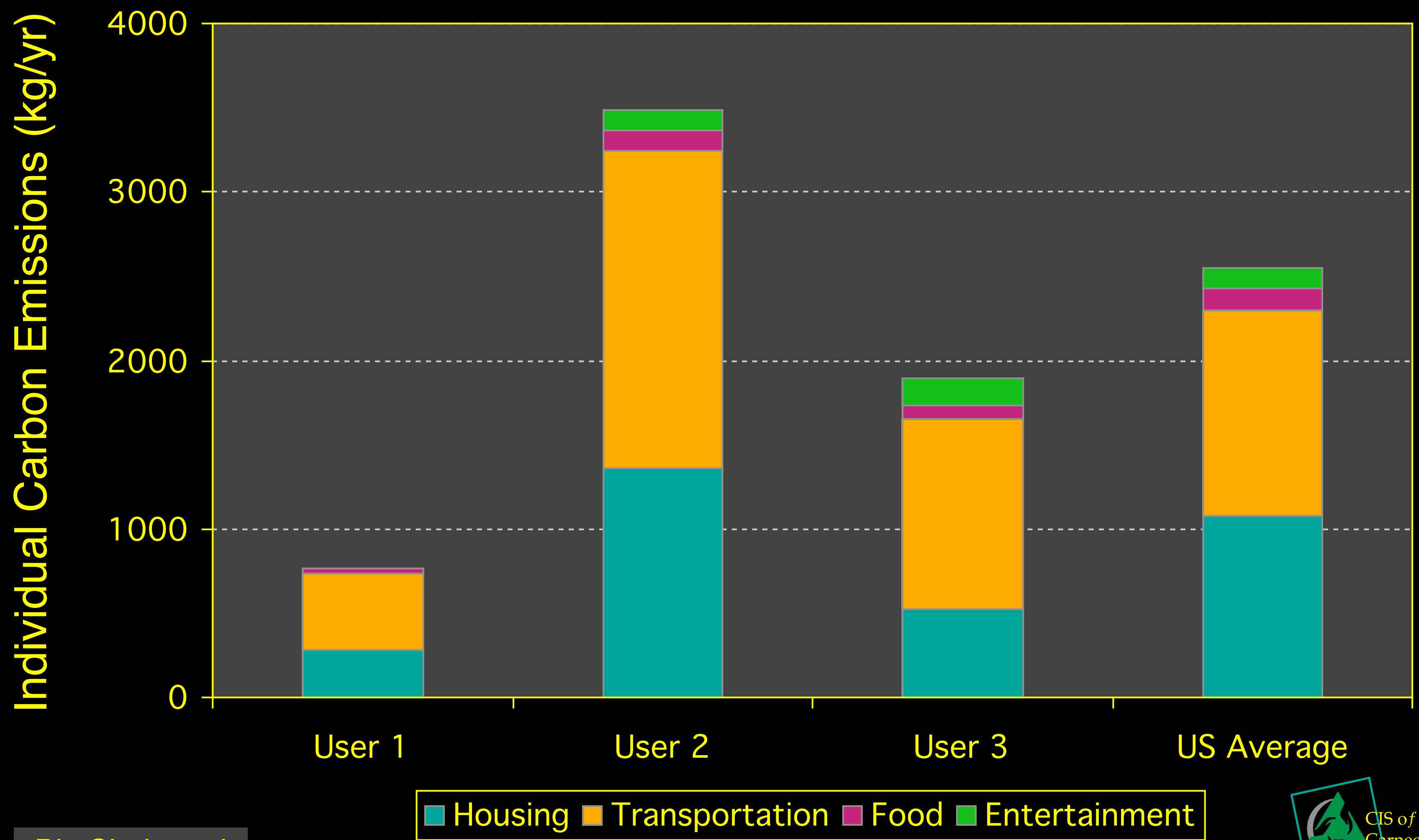
The pixels that make up the nation, &



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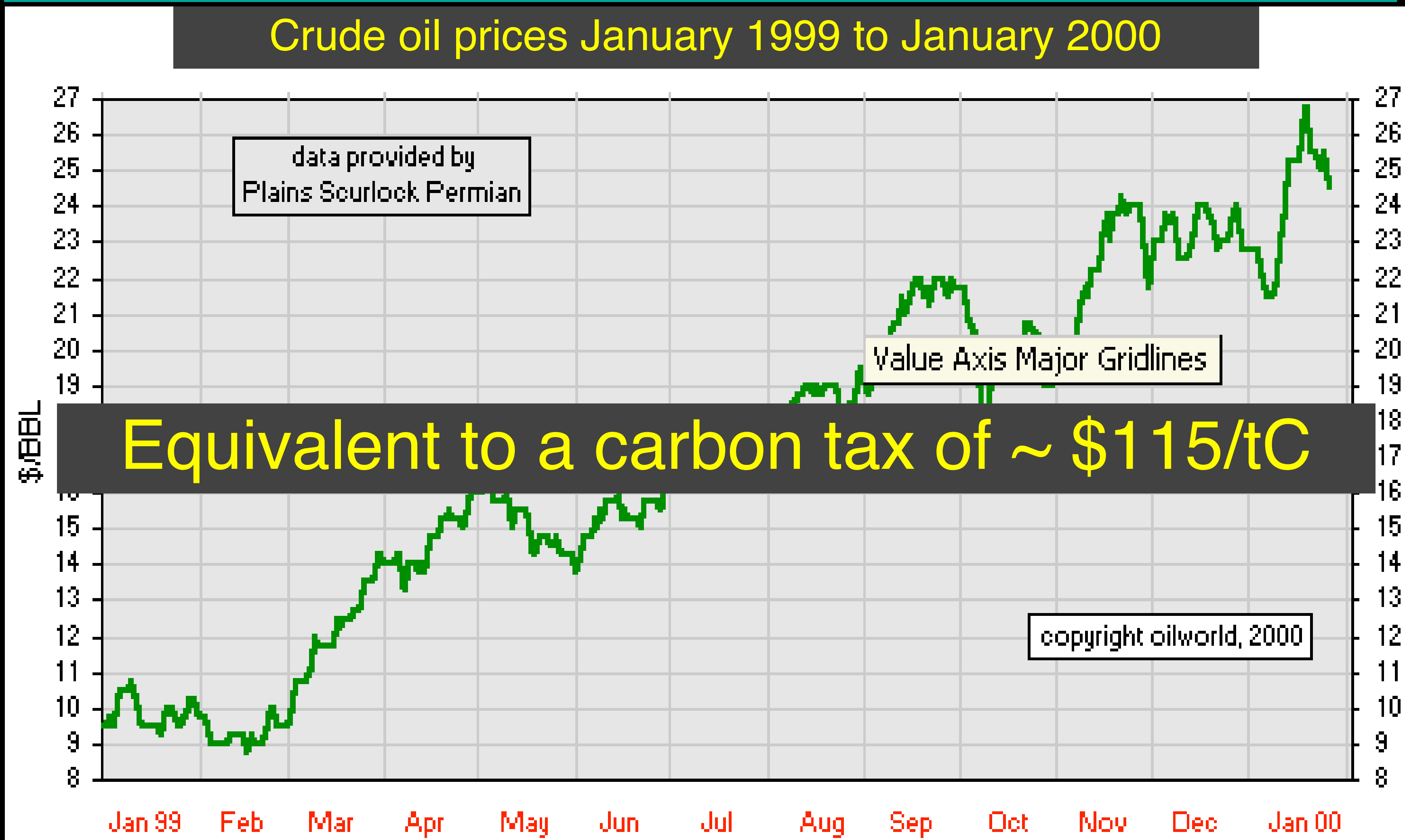
Helping them paint a different picture

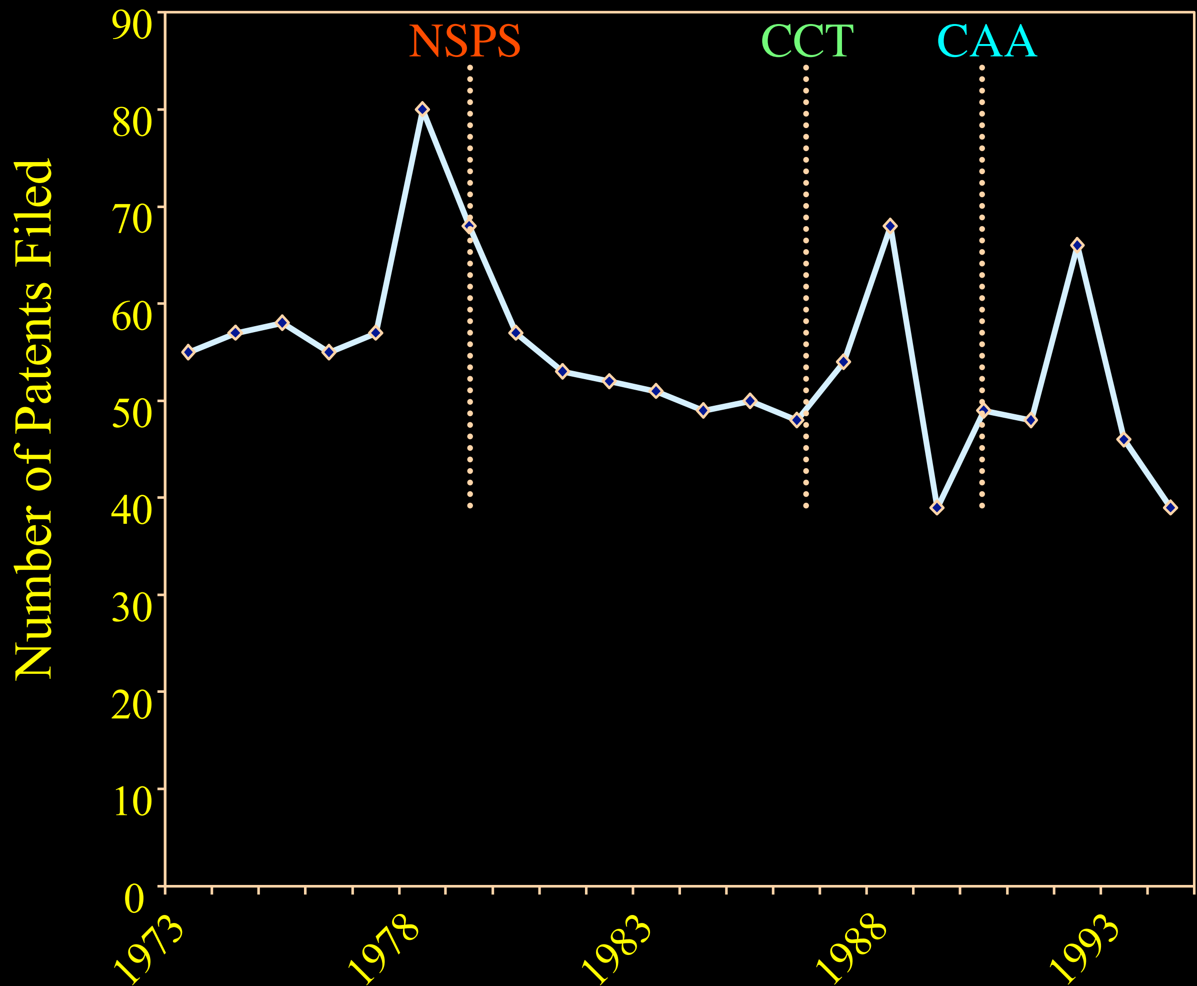
- They had no clue what their emissions levels were but felt they were below the US average.
- No user knew which aspect of their lifestyle led to most CO_2 emissions.
- After their interaction with ICEE:
  - User 1: thought he was doing so well he did not need to consider any further energy efficiencies.
  - User 2: was distraught at learning that she was a gross emitter of CO_2. She started crying when none of the strategies she tried to lower the emissions made much difference to her emissions.
  - User 3: felt to do more there would have to be technological breakthroughs.

Do we need CO_2 controls to trigger technical change?



Equivalent to a carbon tax of ~ $115/tC

Patents seem to respond to: regulations, R&D funding and markets



Key

NSPS: New Source Performance Standard promised in 1977 Clean Air Act Amendments (CAA)

CCT: Clean Coal Technology Demonstration Program

CAA: Clean Air Act Amendments of 1990

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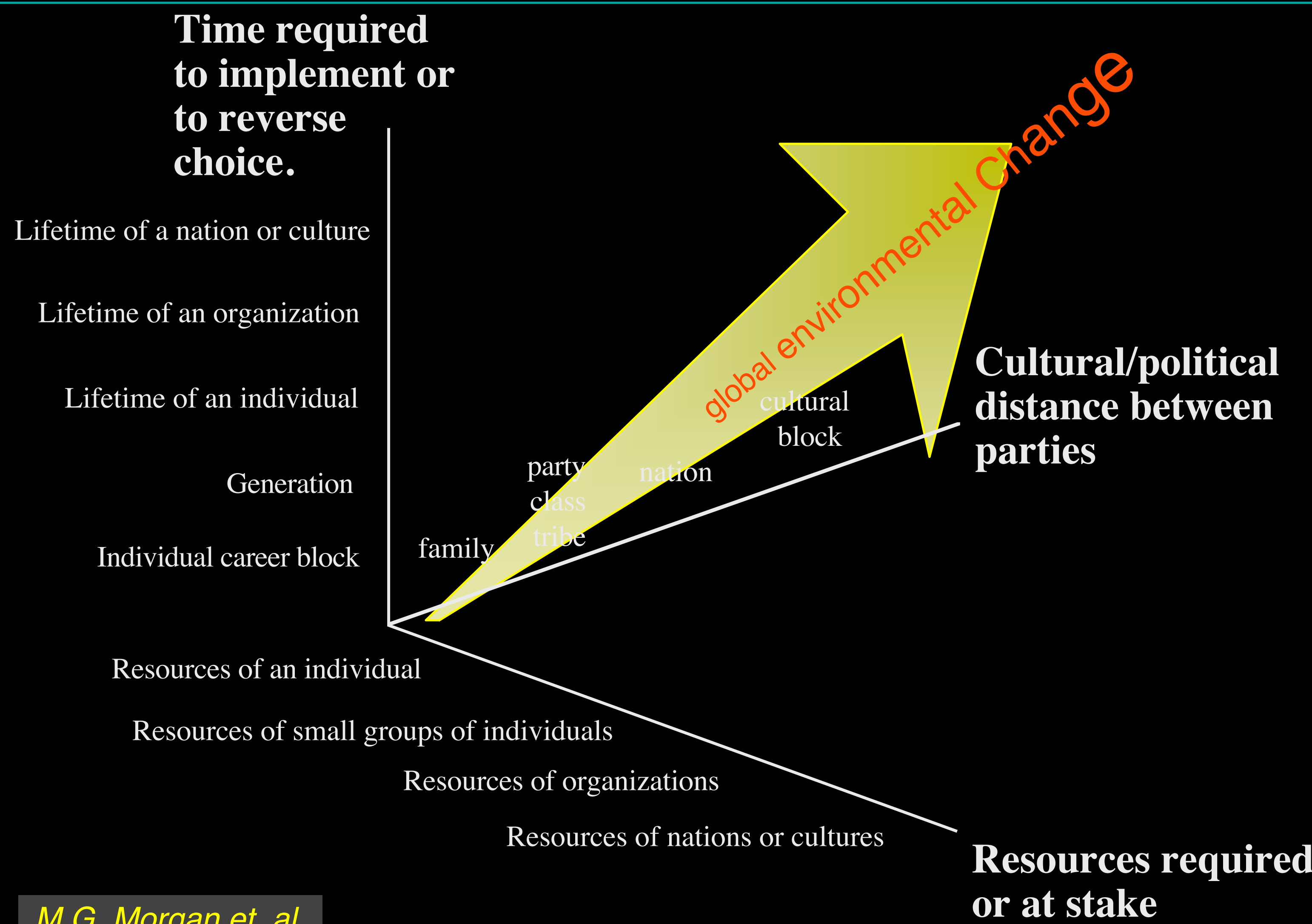
Will *any* policy do *good*?

- If carbon prices are raised globally:
  - » Richer countries will be able to buy energy at the higher price.
  - » Poorer countries may revert to more traditional biomass burning.
- If carbon controls are limited to Annex 1:
  - » It will slow down the economies of richer nations, but it is most likely that commodity exporters in lower income countries who suffer most!

How do we act when the scale of change is unprecedented?

- Climate stabilization requires global emissions of CO_2 to be no higher than ~30% of today's level.
- Now imagine the world in 2100:
  - » Hopefully with no more than twice as many people.
  - » Hopefully with no less than twice as well off as today.
- How can climate stabilization be achieved?
  - » Carbon intensity of the economy needs to fall by 3%p.a. or more and maintained for a century.
  - » The is no historic precedent.
  - » The OPEC oil crisis is an inappropriate analogue.

How can we conduct assessment when the tools are inadequate?



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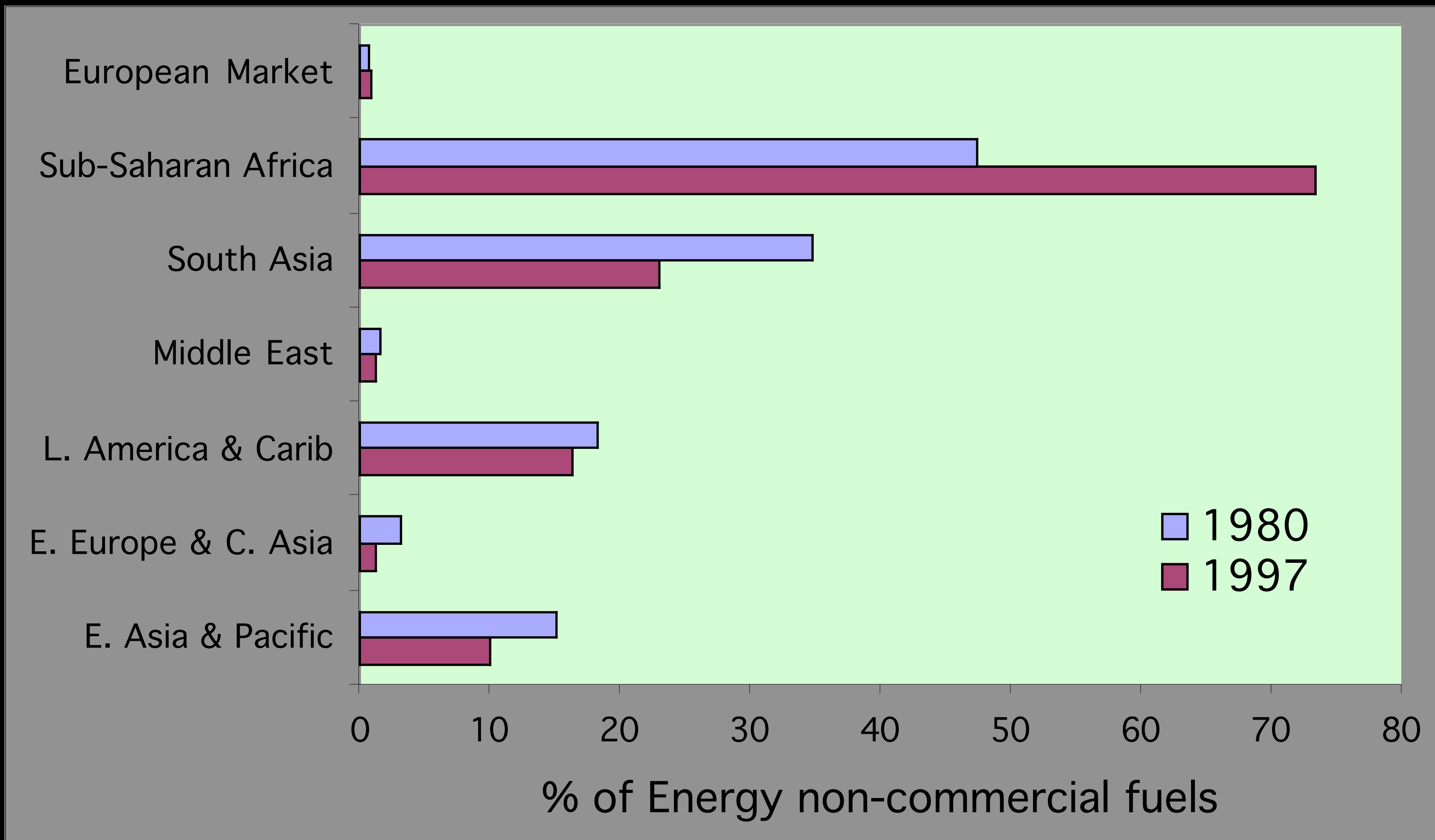
D_x for IA

- We often conduct analyses at scales obscuring heterogeneity of actors and environmental conditions that actually determine the path and pace of change.
- We often fail to learn lessons from the past.
- We often apply past lessons inappropriately.

Summary

- Technological change is a critical yet poorly understood aspect of our lives.
- Theoretical assertions and empirical evidence about technological change are contradictory.
- Current technocratic and economic models are both at sea in predictive and explanatory skill.

Non-commercial fuel
(%of energy use)



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