Small is Better:
The Benefits of *Granularity* in Energy Technologies

Charlie Wilson

(with Arnulf Grubler, Nuno Bento, Caroline Zimm ...)

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Tyndall Centre for Climate Change Research

SILCI Social Influence and *disruptive* Low Carbon Innovations

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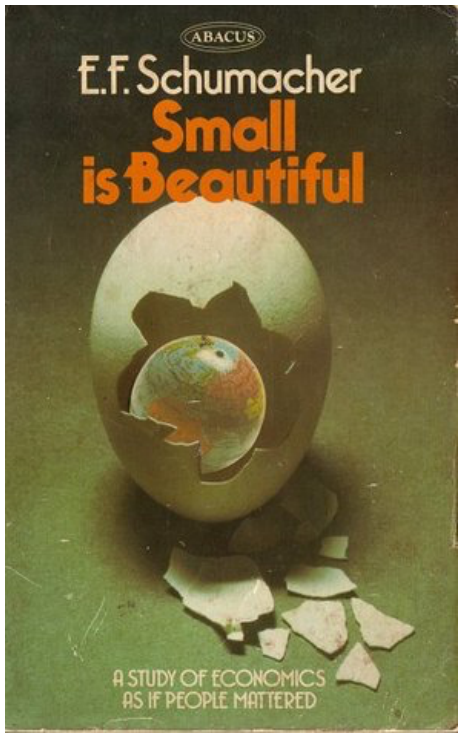
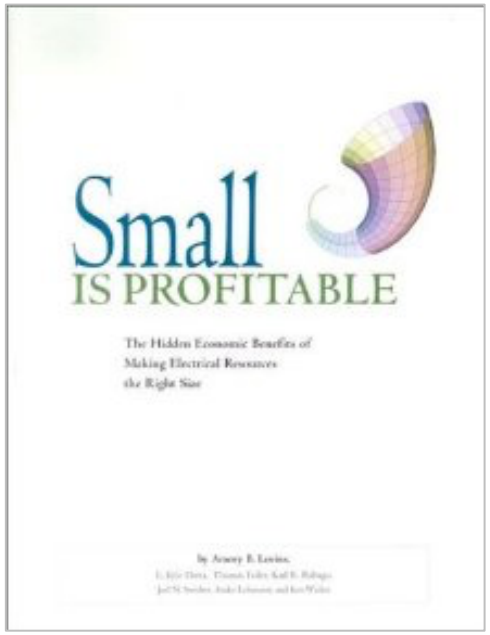
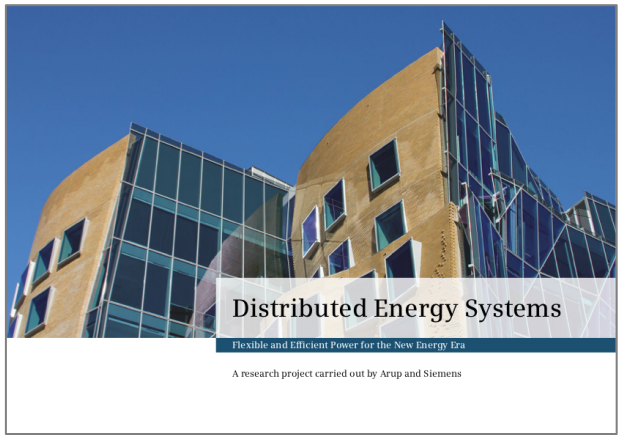
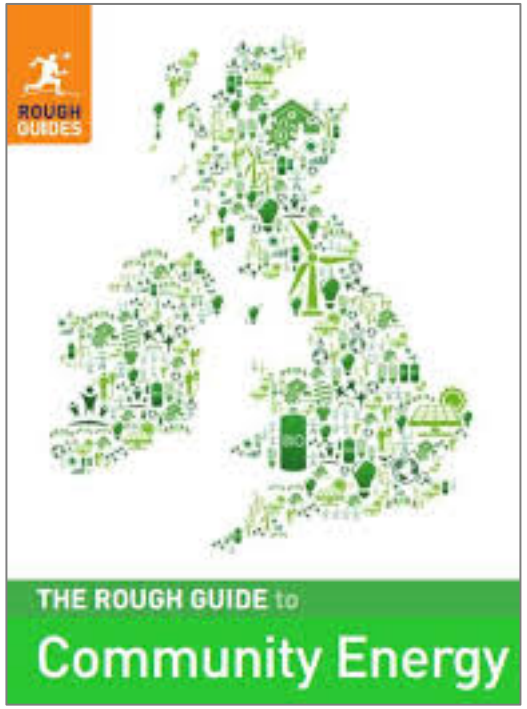
"Small is ..." has a long tradition in technology studies, particularly for **distributed energy-supply** systems









‘granular’

small unit size

low unit cost

modular

replication

‘lumpy’

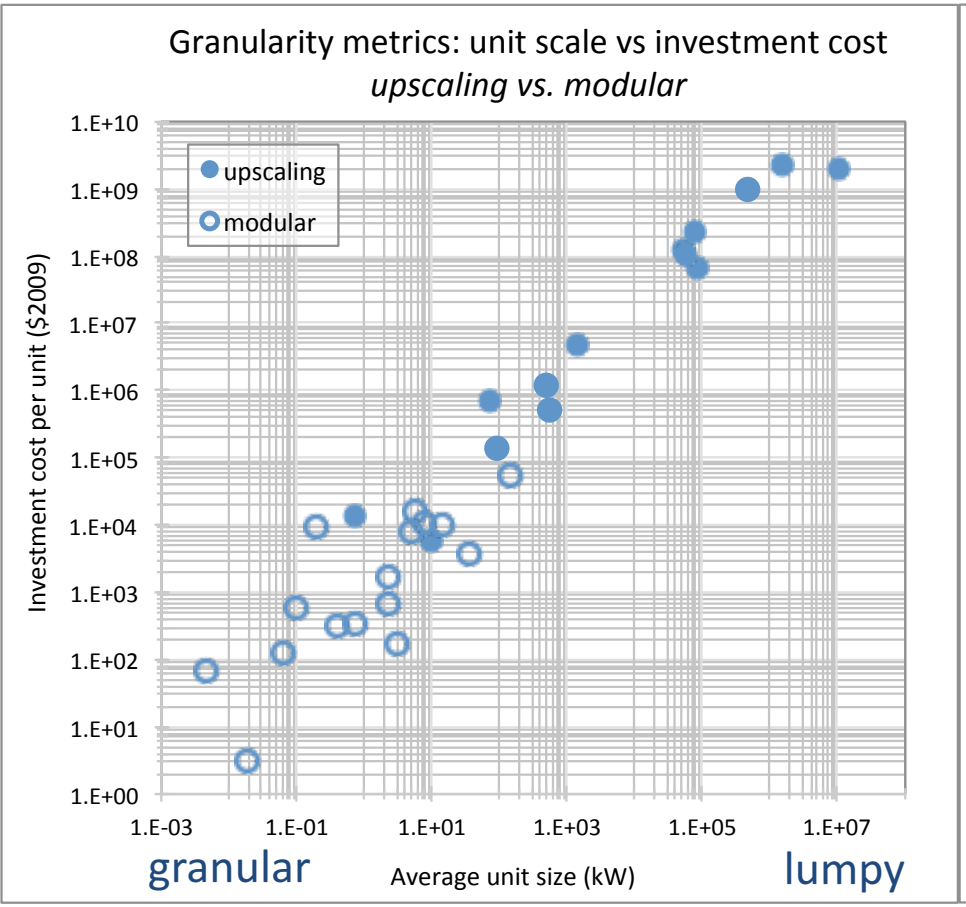
large unit size

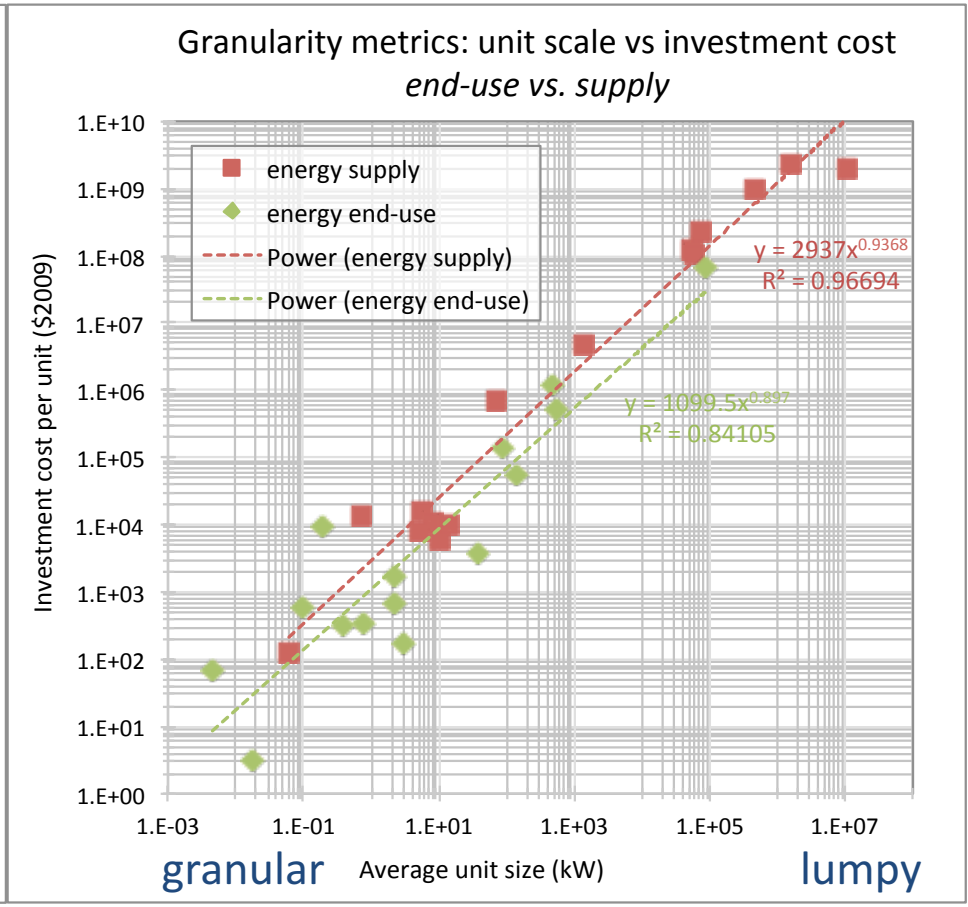
high unit cost

indivisible

up-scaling

Unit size and **unit cost** strongly **correlate** in diverse samples of energy supply *and* end-use technologies





end-use *tends* to be more granular

supply *tends* to be more lumpy

Are granular energy technologies 'better'?

… lower **adoption risks?**

… more rapid **learning rates?**

… faster **diffusion times**?

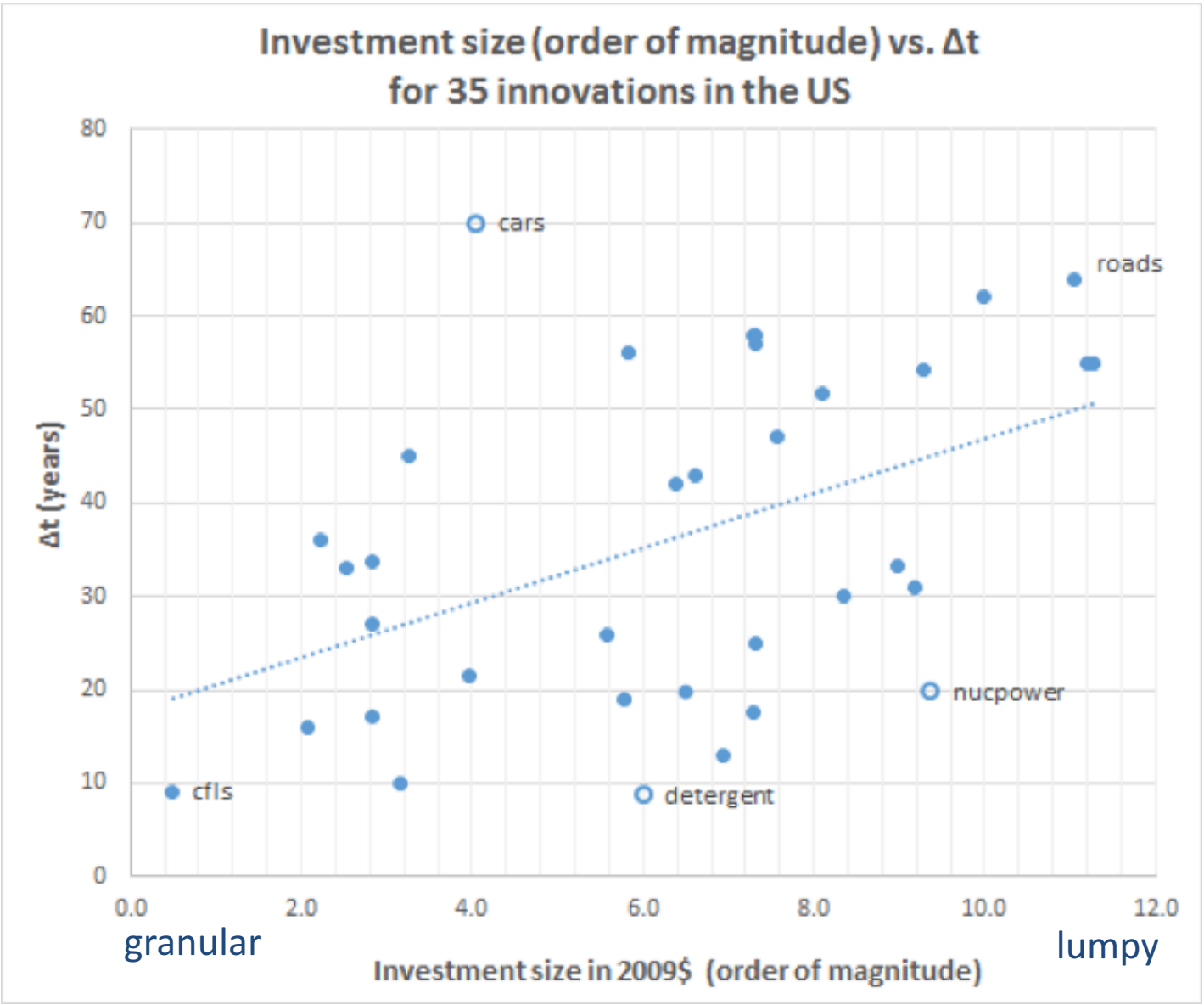
… lower risks of **lock-in?**

… more **equitably** distributed?

innovation and diffusion processes

system outcomes

Granularity (1): **lower adoption effort** (investment per unit) results in **faster diffusion** (Δt)



diffusion of 35 industrial, energy, transport, and consumer good innovations (US)

35% of variance in *Δt* explained by investment size

*NB. two outliers exclude: cars + 2 * WW2*

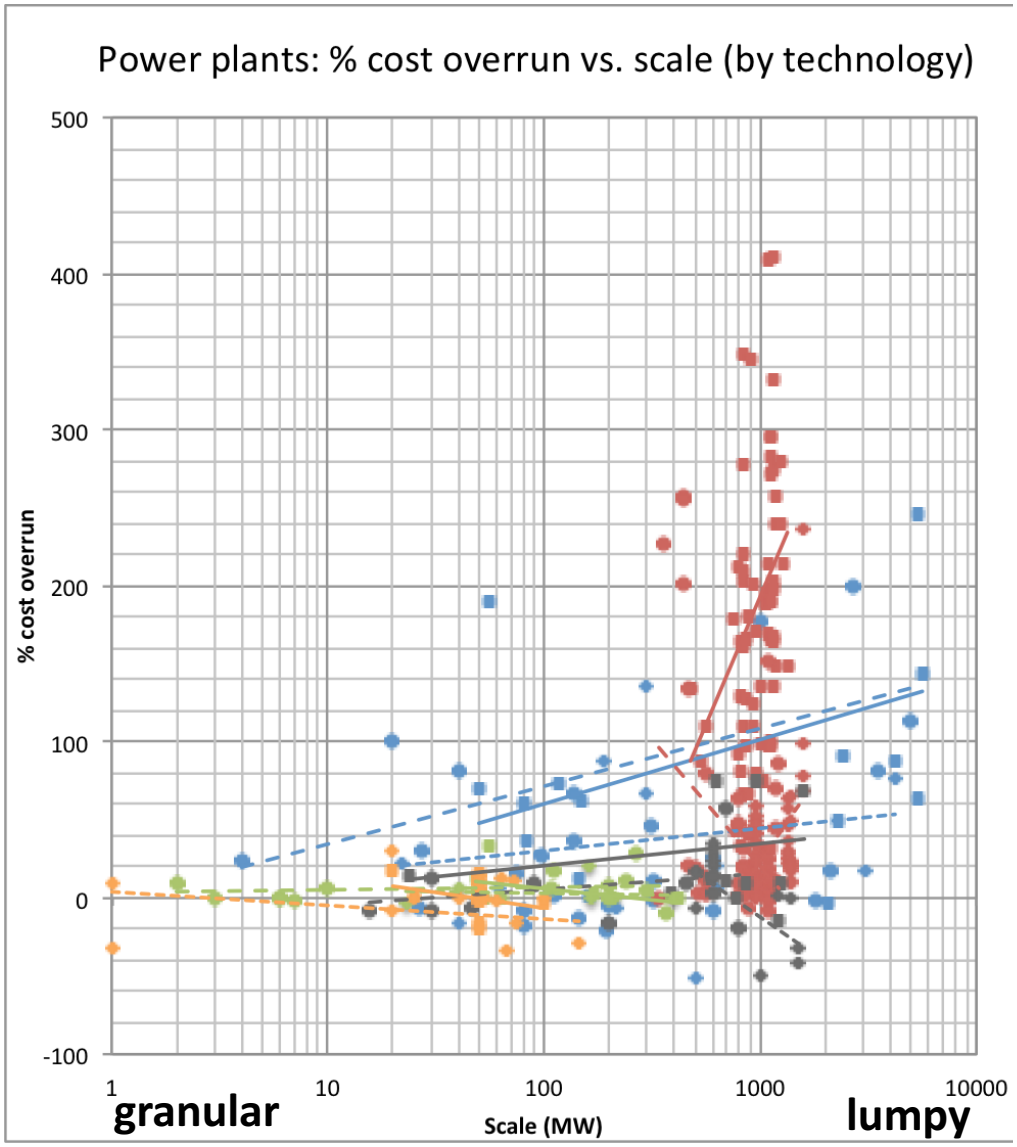
Size matters. Megaprojects carry large risks associated with complexity, one-off designs, and long lead times

The iron law of megaprojects [Flyvberg 2014]:
"they run over budget, over time, over and over again"

Adoption risks with lumpy technologies:
(i) **bespoke** (non-standard) **design** limits learning;
(ii) complexity, **interdependencies**, interoperability challenges;
(iii) long planning horizons create exposure to **exogenous change**;
(iv) involvement of diverse actors with **competing interests.**

"*policymakers should prefer energy alternatives that require less upfront outlays and that can be built very quickly*" [Ansar et al. 2013].

Granularity (2): smaller unit sizes & **modularity** result in **lower adoption risk** (% cost overrun)



size positively correlated with cost overruns in 7 of 9 samples for **up-scaling** technologies

nuclear **thermal** hydro

size negatively correlated with cost overruns in 4 of 5 samples for **modular** technologies

wind **solar**

Reanalysis of data from: Sovacool et al. (2014). *Energy Research & Social Science* 3: 152-160.

x 1

x 1,000

x 1,000,000

"Some technologies are more open to improvement than others. Compact, modular systems, such as photovoltaics and electronics, are easily experimented on ..."

Trancik (2014). *Nature* 507: 300-302.

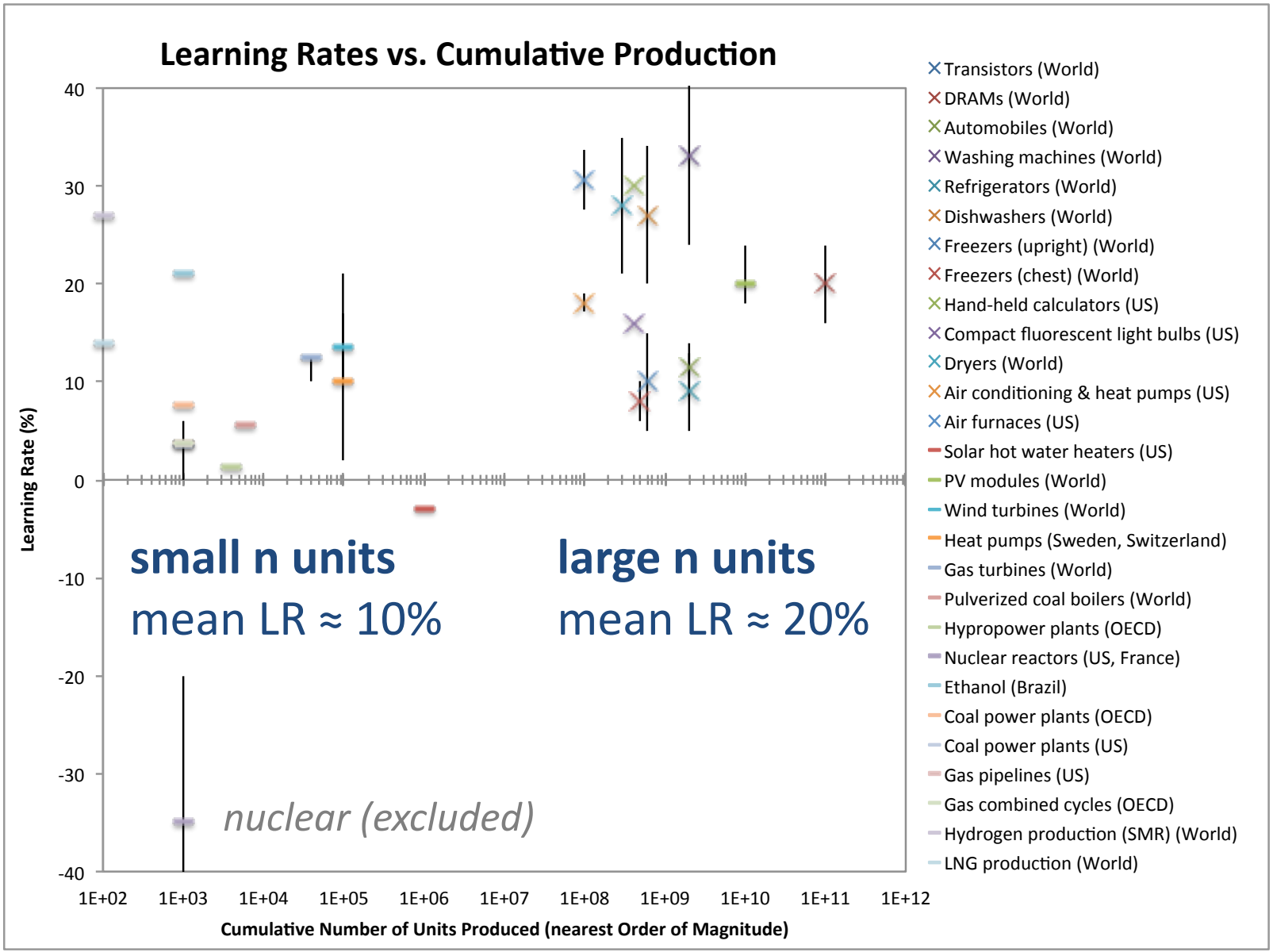
smaller units
-> more units

-> more opportunities to experiment & learn

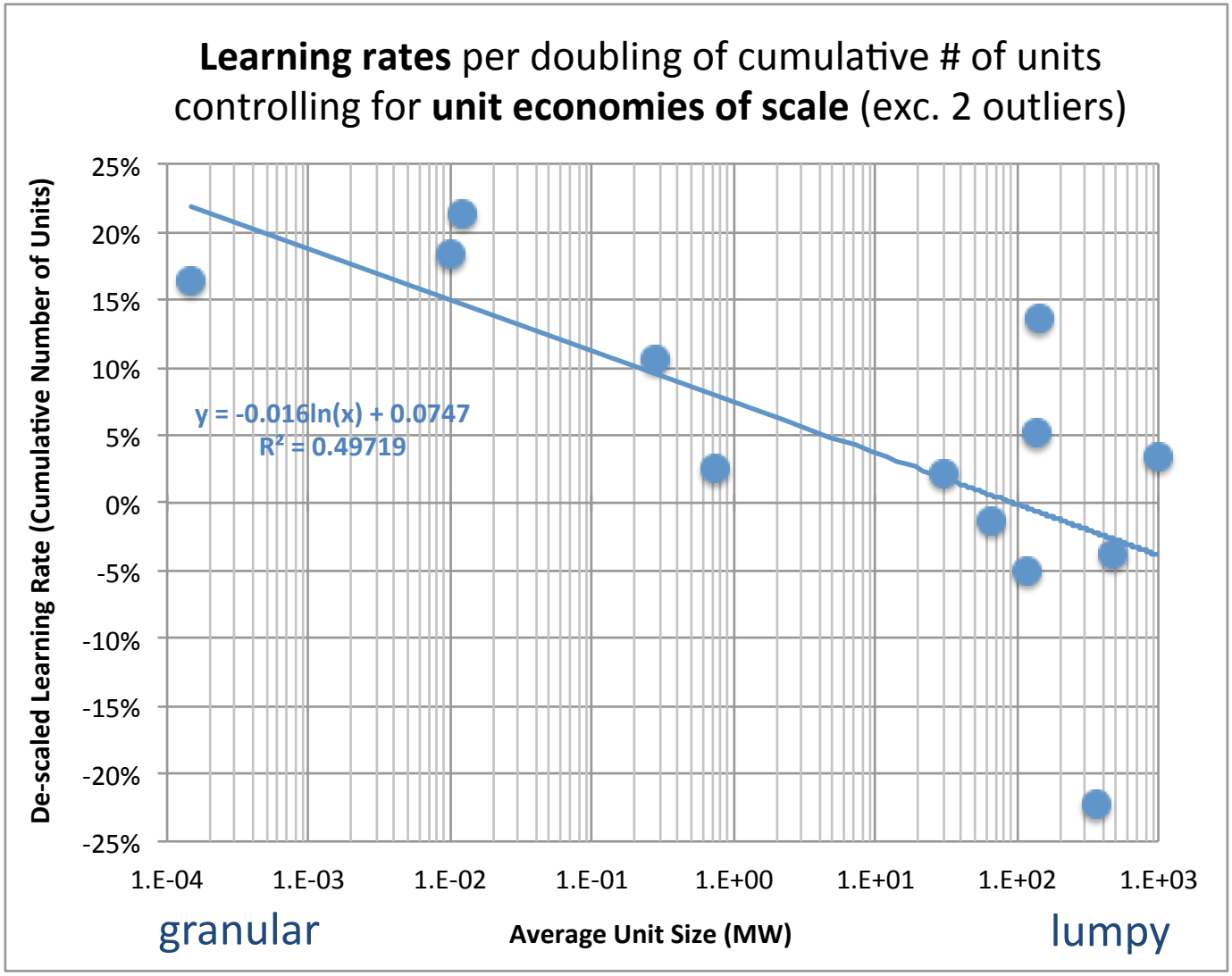
-> higher rates of cost reduction

-> more units

Higher learning rates (on average) are associated with standardised production of **large number of units**



Granularity (3): **more unit numbers** enable **higher learning rates** (*controlling for unit scale economies*)

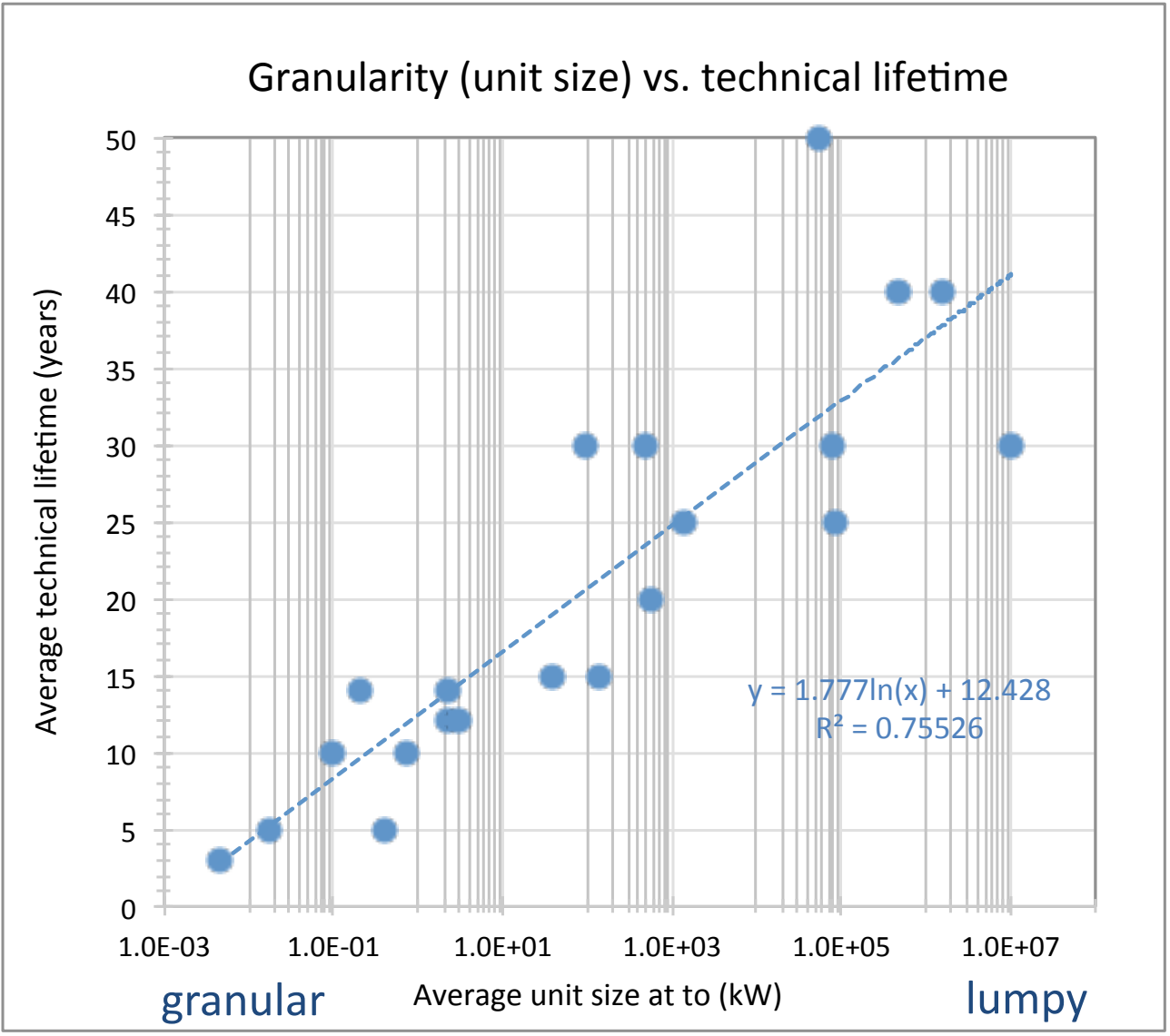


unit scale is a stronger predictor of learning rate **after controlling for economies of scale**

NB. two outliers excluded:
-35% nuclear
+32% geothermal

Data from: Healey, S. (2015). Separating Economies of Scale and Learning Effects in Technology Cost Improvements. IR-15-009. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Granularity (7): **shorter lifetimes** of smaller units enable rapid turnover and reduce **risk of lock-in**



lock-in = resistance to change in technological systems

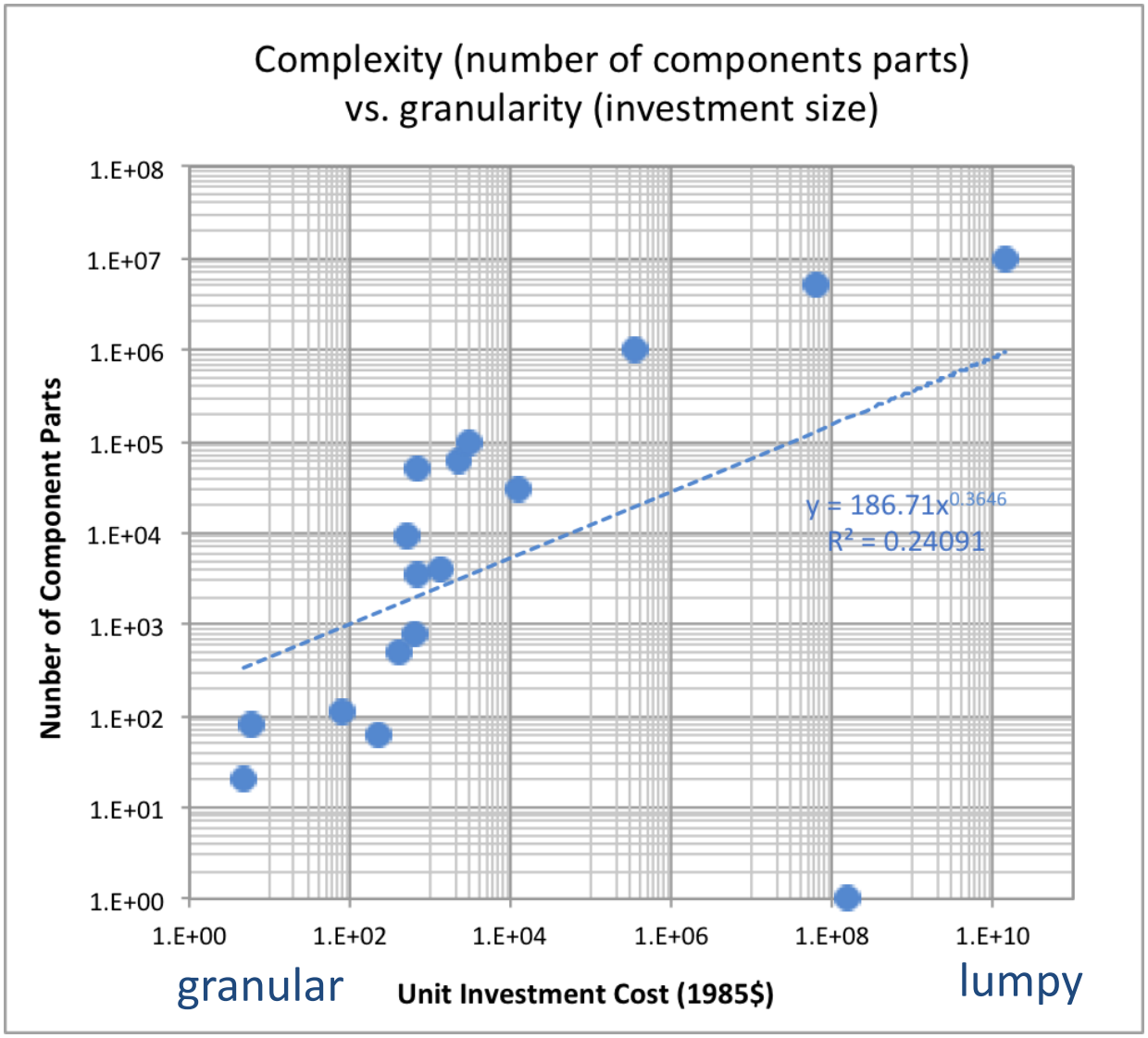
causes:

- **technological**
- institutional
- behavioural

granularity:

- **shorter lifetimes**
- more rapid innovation cycles

Granularity (7): **lower complexity** (interdependencies) of smaller units further reduce **risk of lock-in**



lock-in = resistance to change in technological systems

causes:

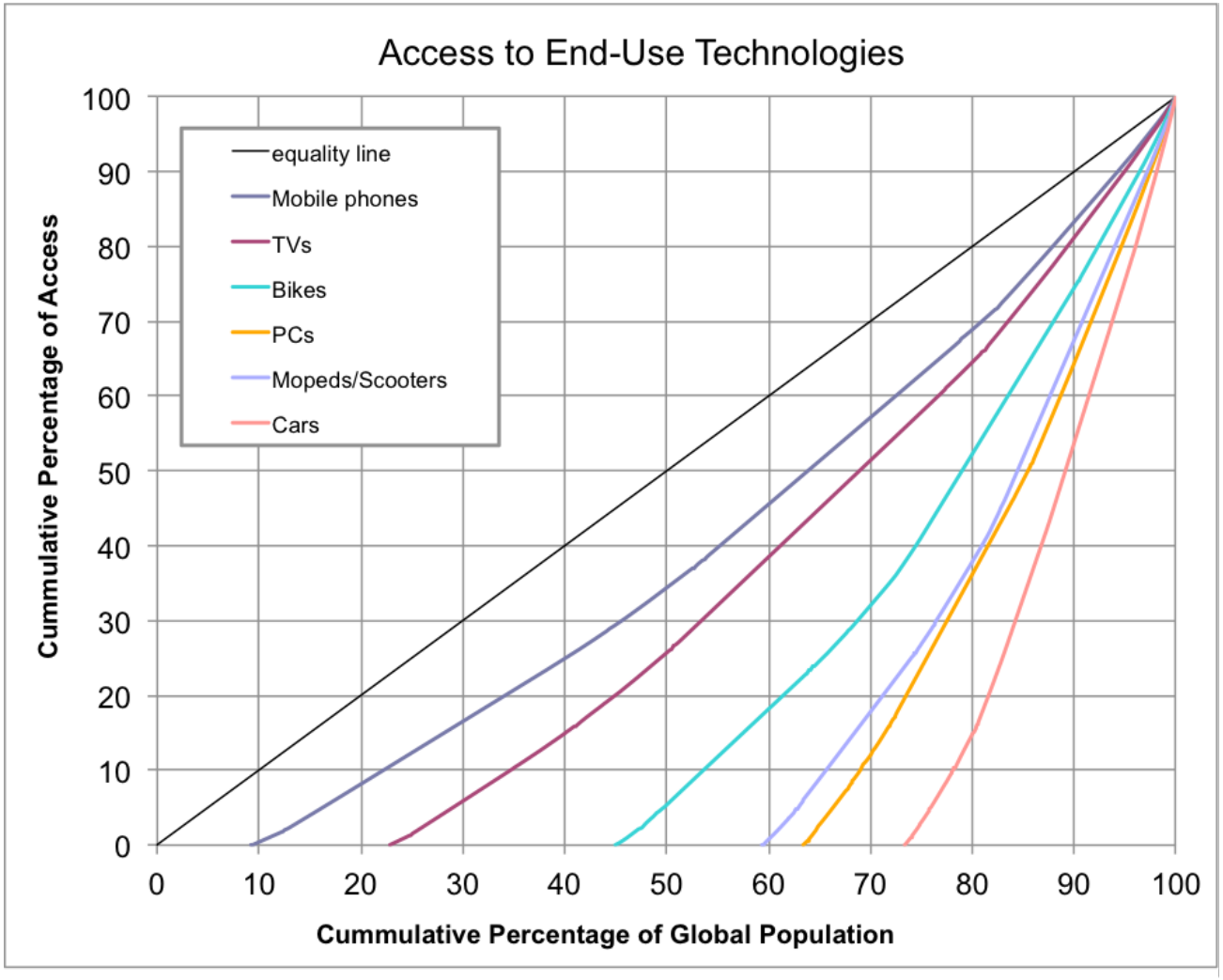
- **technological**
- institutional
- behavioural

granularity:

- **lower complexity**, (as measure of interdependency)

Component data from: Ayres (1988). *Manufacturing Review* **1**(1): 26–35.

Lorenz curves can describe distribution of **access to useful technologies** (and service infrastructures)



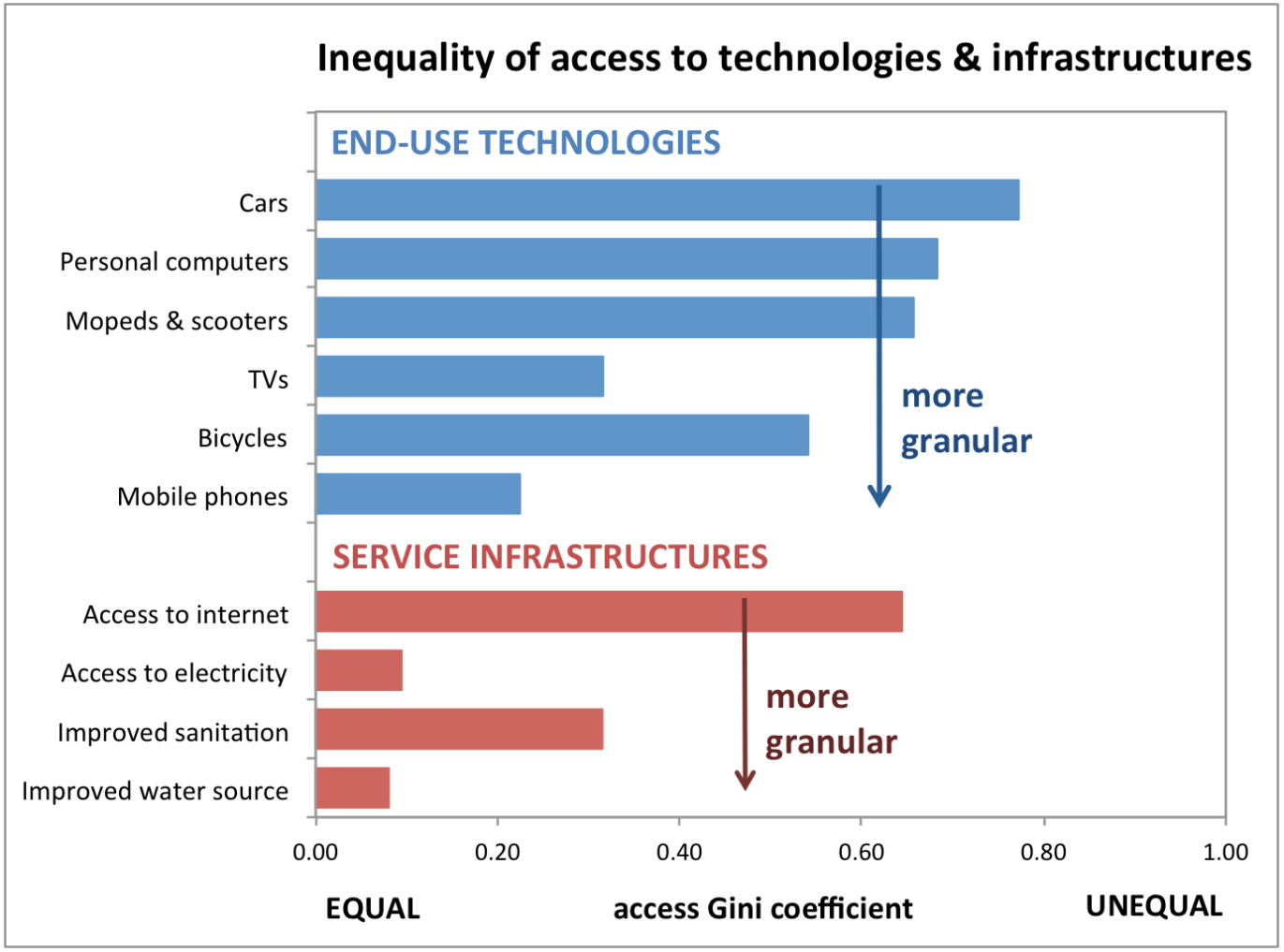
Lorenz curves: distribution of **access to technologies**

NB1. includes non-access

NB2. not all countries: ~6bn people

Data from: Zimm, C. (2017). International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Granularity (8): lower barriers to adoption result in more **equitably distributed access** to useful services



Gini coefficient = measure of distributional (in)equality

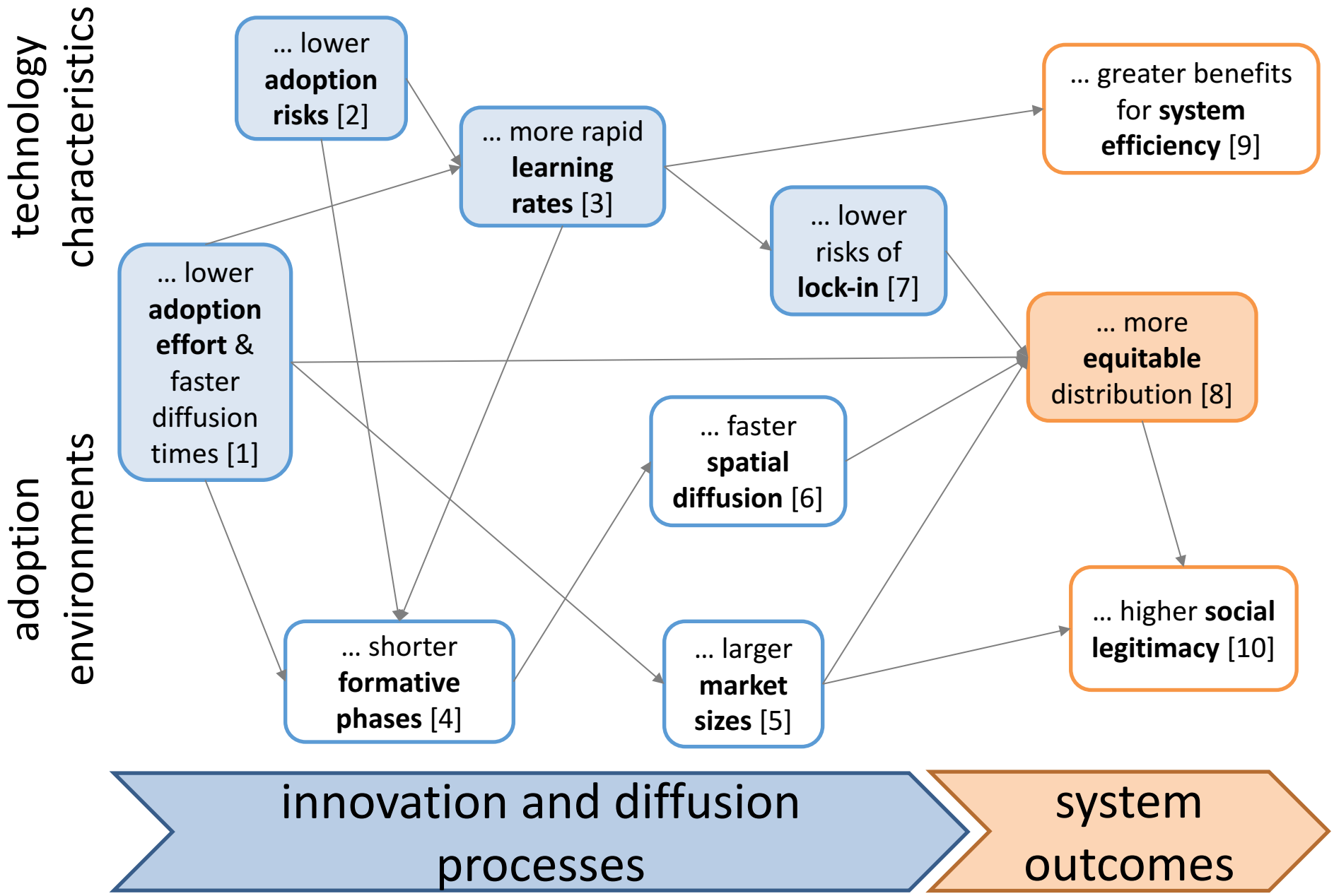
calculated from Lorenz curves

0 = perfect equality

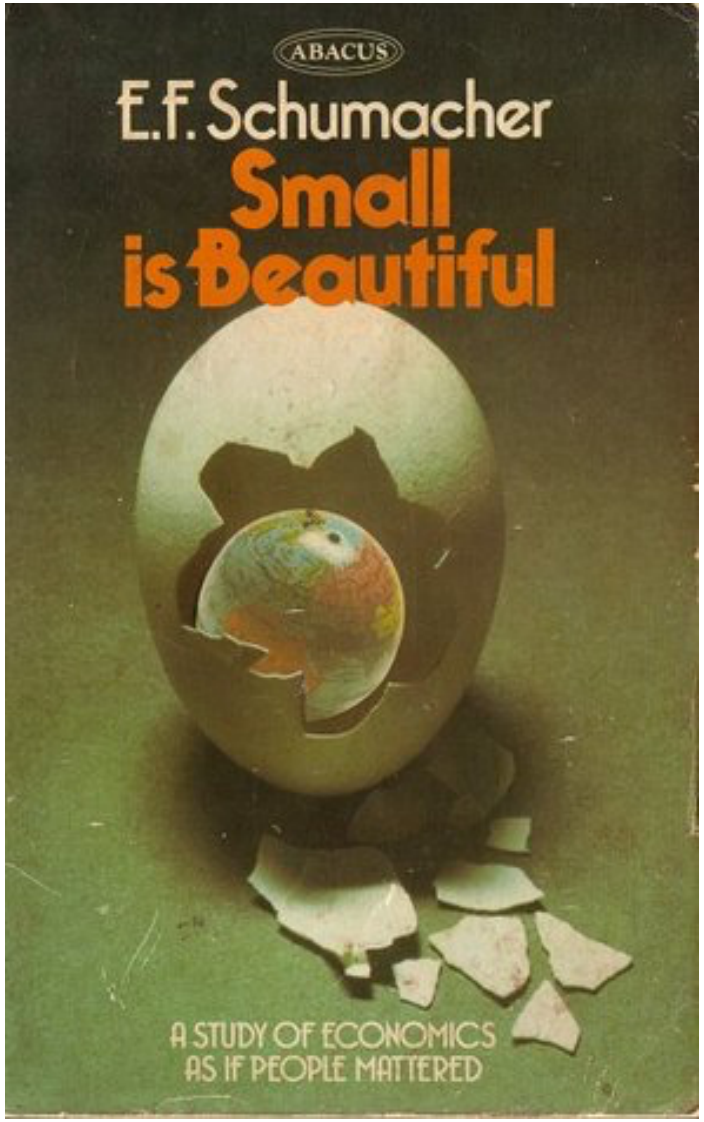
1 = perfect inequality

more granular = lower cost per additional access

In sum: **Granularity has many generalizable benefits**



But benefits of granularity depend on **replication, standardisation ...**

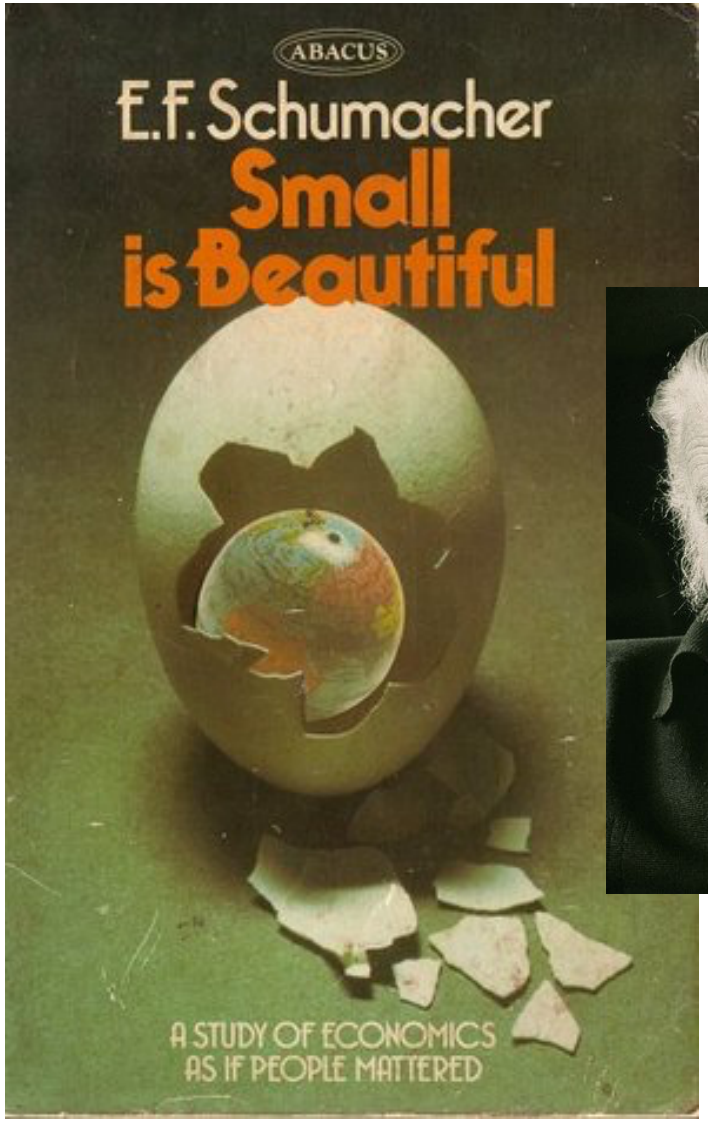


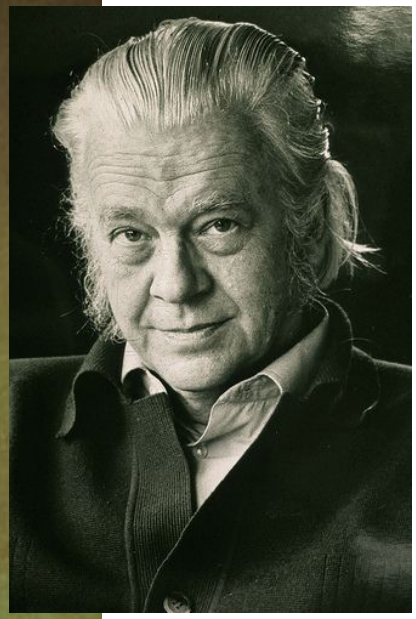
But benefits of granularity depend on **replication, standardisation ... *and* access to infrastructure**

granularity benefits	**production, manufacturing** (standardisation, serialisation)	**installation, adoption** (learning, accessibility)
required conditions	dominant designs homogeneous producers	repetitive installation low skill adoption *distributed, modular infrastructure*
potential issues	experimentation & variety heterogeneous producers	bespoke installation high skill adoption *system-wide, lumpy infrastructure*

other more general issues with granularity:
(1) transaction costs; (2) dispersed impacts; (3) lifecycle impacts ...

Granularity is not a hegemonic strategy ... but it is too often a marginalised one





Times editorial
1 December 1977

"Dr Schumacher did not advocate smallness as the answer to everything. The title of his book has misled many people. What he was talking about was **the appropriate size for different structures – some large, some small**. He concentrated only on smallness only to counteract the idolatry of gigantism."

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