The Other Denial:

Innovation and Infrastructure in the economics of energy transition

Paper for Annual Conference of the
Institute of New Economic Thought,
Edinburgh, 23rd October 2017

Session:
In the long run we are all dead? Climate change and denial

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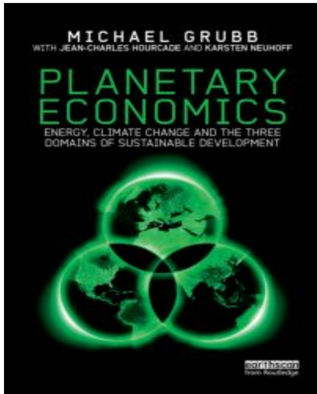
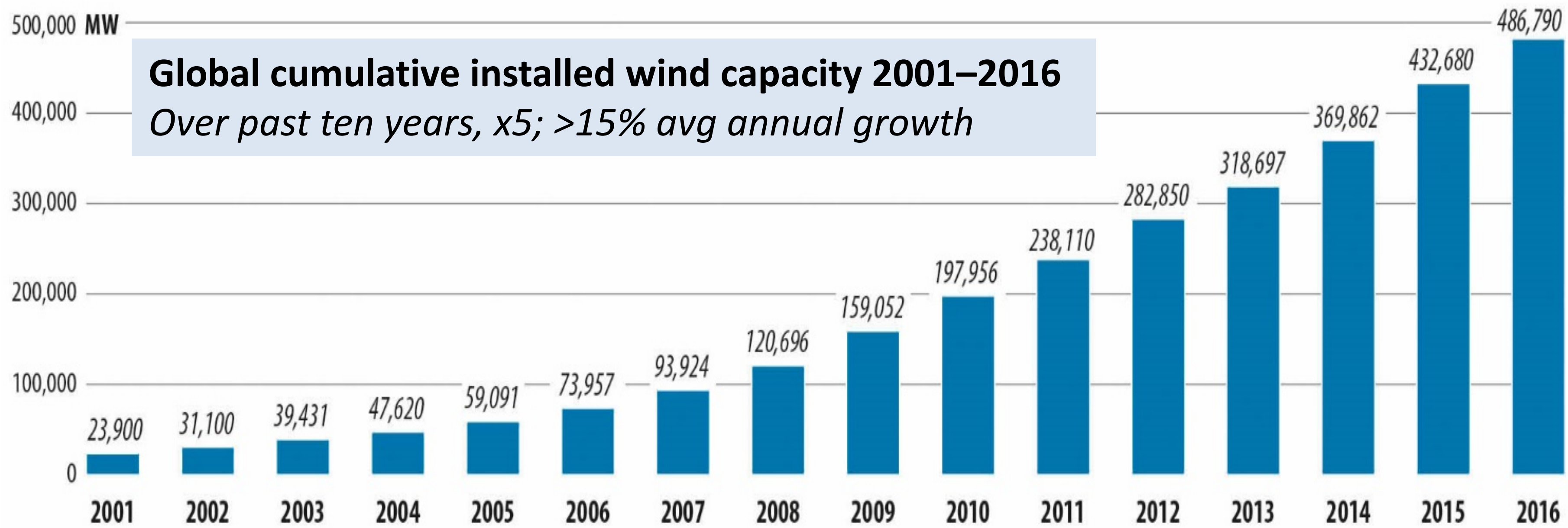


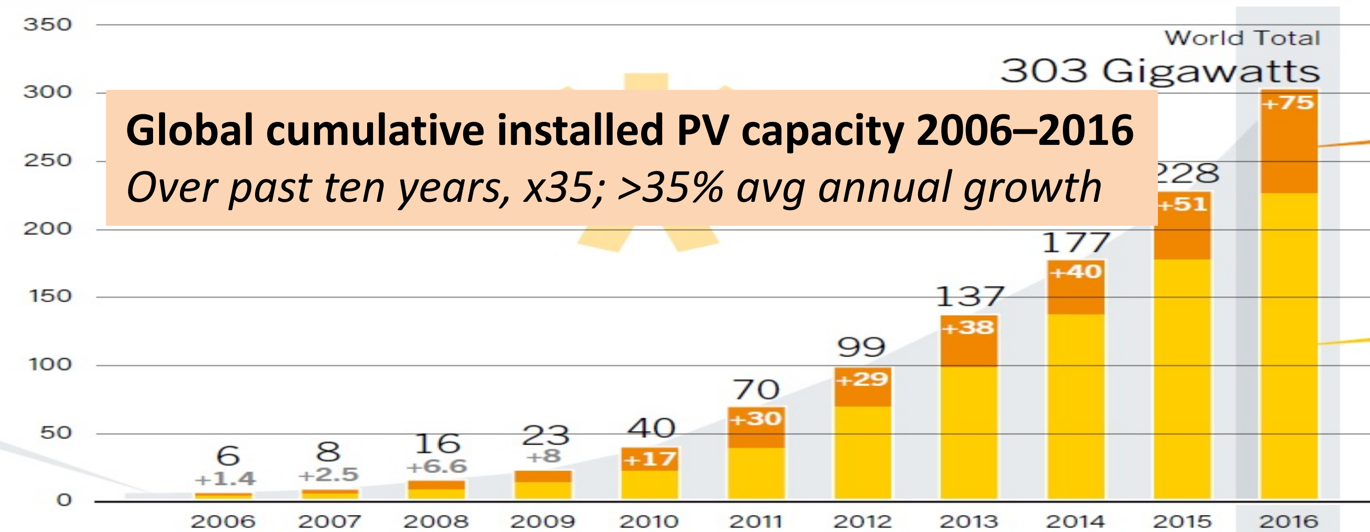
Introduction & Overview

- Innovation is central to economic development (eg. Schumpeter, Solow Residual, etc)
- Innovation is inescapable in considering scenarios of deep CO2 emission reductions
- The mathematical properties of ‘learning-by-doing’ were demonstrated analytically half a century ago
- .. And now empirically documented in terms of ‘learning curves’ for hundreds of energy-related technologies, complemented by rich literature on innovation systems
- Yet most economic models and many policy recommendations from economists continue to ignore what we know about learning & innovation
- THIS MATTERS

Global policy-driven capacity growth in wind and solar

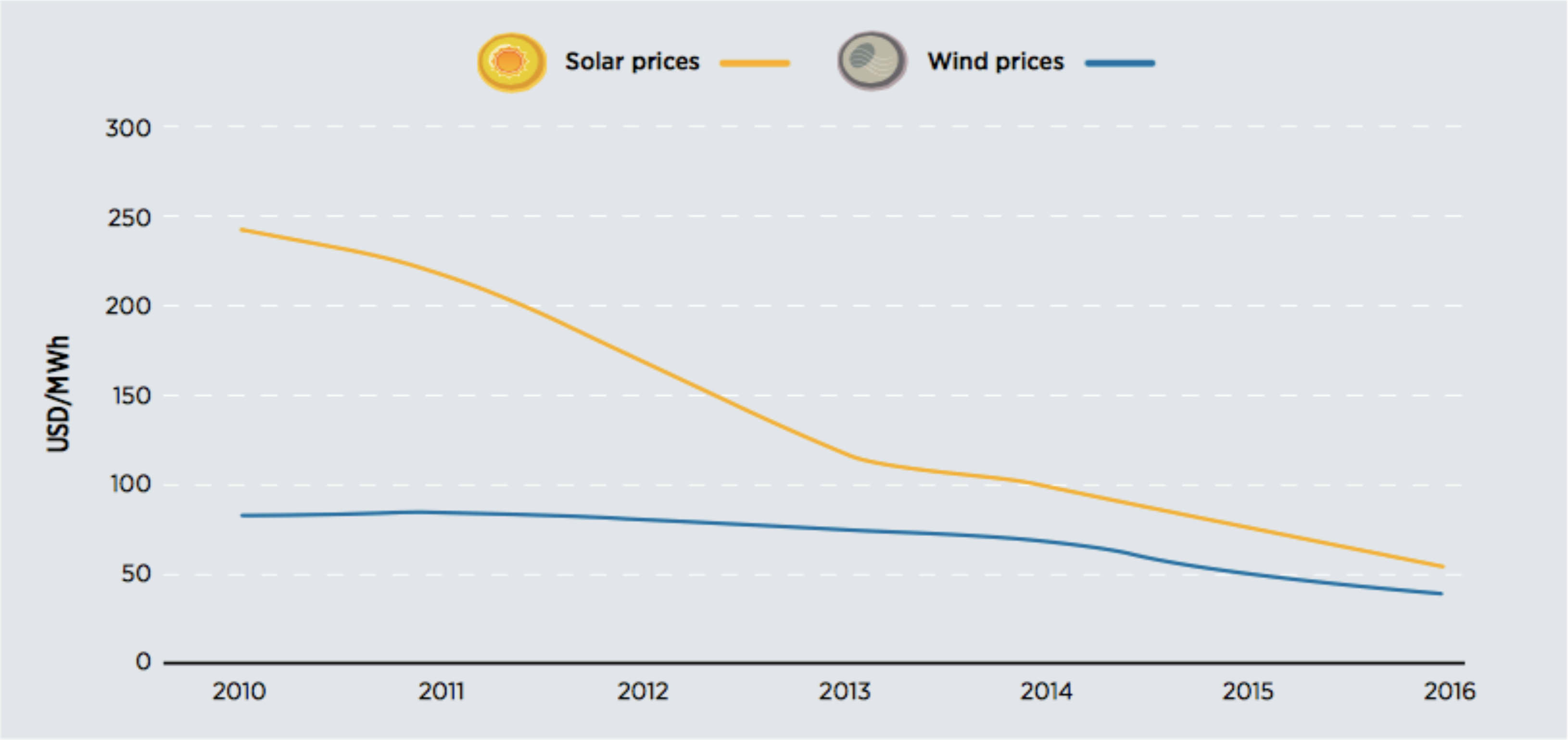


Source: Global Wind Energy Council



- 'strategic deployment' accompanied by cost reductions corresponding to 'learning curve' expectations

Figure 1 Average prices resulting from auctions, 2010-16



Source: IRENA, 2017.

- .. also documented across a wide range of other supply and demand-side technologies including w.r.t. energy efficiency

"This Changes Everything"

" solar power is by far the most expensive way of reducing carbon emissions …. the CO_2 price would have to rise to $185 a tonne ….” - *The Economist,* **2014. Err ……**

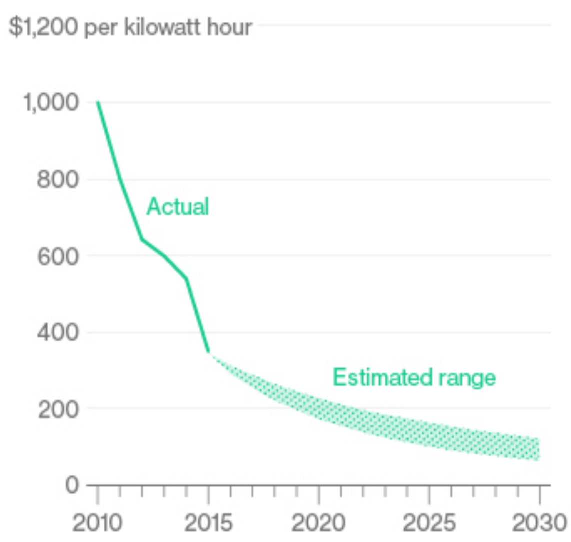
PV: 2016, installed power prices **below wholesale** *elec* **prices** in many sunny regions

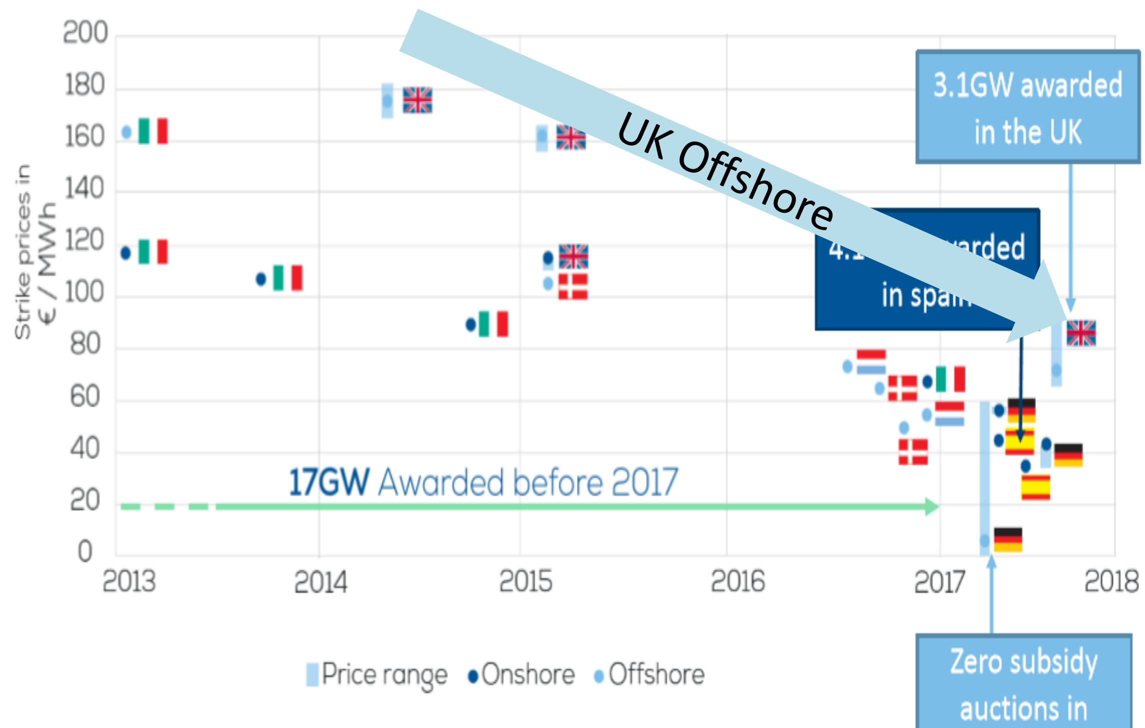
Chile	= $30/MWh
Masdar	= $25/MWh
Abu Dhabi	= $24/MWh

Module costs: -29% in 2016 to $0.39/Watt

Even offshore wind energy: series of auctions across Europe have seen prices tumble to about half that of 5 years ago

Batteries also …





‘The perils of the learning model…?’ (Nordhaus, 2013)

- Critique centred on data uncertainties and ‘correlation is not causation’ – price reductions would also drive growth
- But:
  - Timing – capacity growth has generally led cost reductions, clearly the two reinforce each other *
  - Surge in private patents as markets grew *
  - Common sense:
    - Technology learning-by-doing
    - Private sector revenues resource private R&D
    - Economies of scale in both unit size and production volume
    - Development of supply chains & infrastructure
    - Experience and improved financial confidence in capital-intensive sectors drive big reductions in cost of finance
- **Assuming ‘zero’ is an unacceptable approximation to something we know to be positive and crucially important**

* Bettencourt et al (2013) document ‘A sharp increase in rates of patenting [during 2000-2009], particularly in renewable technologies, despite continued low levels of R&D funding. …. reveals a regular relationship between patents, R&D funding, and growing markets across technologies … growing markets have formed a vital complement to public R&D in driving innovative activity.’

The transformation has been achieved mainly by policy

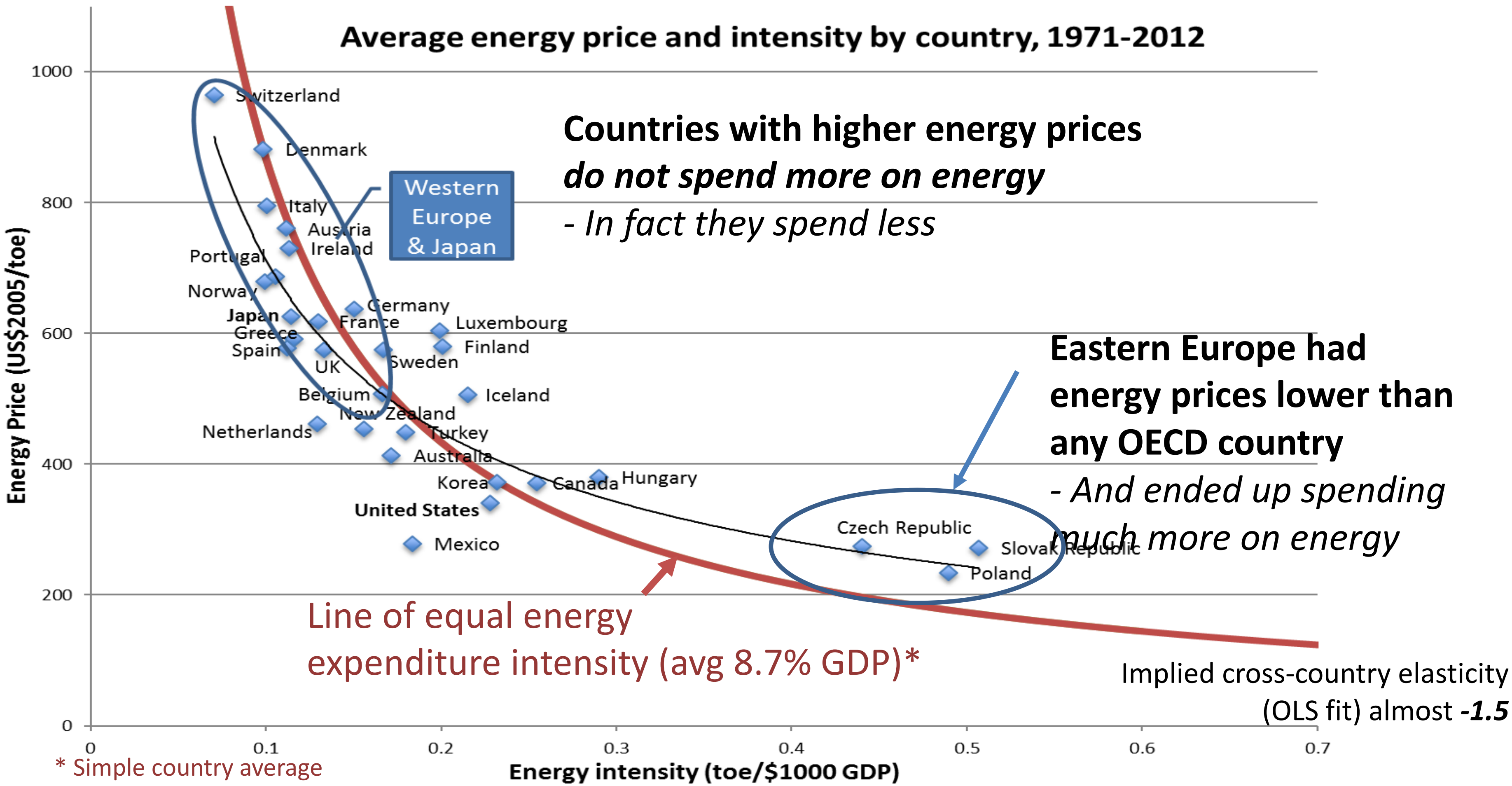
- ignoring mainstream economic advice on cost and tech neutrality

- Consistent critiques across many economics communities about the 'crazy cost' of renewables deployment
- Static "$/tCO2" taken as the metric – rather than any formalised analysis of learning benefits
  - ignoring the strategic nature of the problem, all that we know about innovation as an evolutionary process involving private sector, and the main point of government actions
- In the language of *Planetary Economics* book (Grubb, Hourcade and Neuhoff 2014), illustrates the dangers of "Second Domain" economics applied to a "Third Domain" problem
  - as per Laurence Tubiana's provocative challenge – has economics helped or hindered?
- Recent analyses (eg. Newbery 2016) have finally begun to derive the formal economics of policy taking account of induced innovation –
  - suggesting that eg. renewables deployment was indeed good economic policymaking (and the earlier the action, the better the cost/benefit)
- But still ignored in most global modeling of the problem!

More than just technology/sector-learning

Evidence of wider adaptive economic processes,

eg. in apparent 'constancy of energy bills' reflecting enhanced efficiency



* Simple country average

Source: Grubb et al (2017), 'An exploration of energy cost constants, affordability limits and adjustment processes' – report to INET

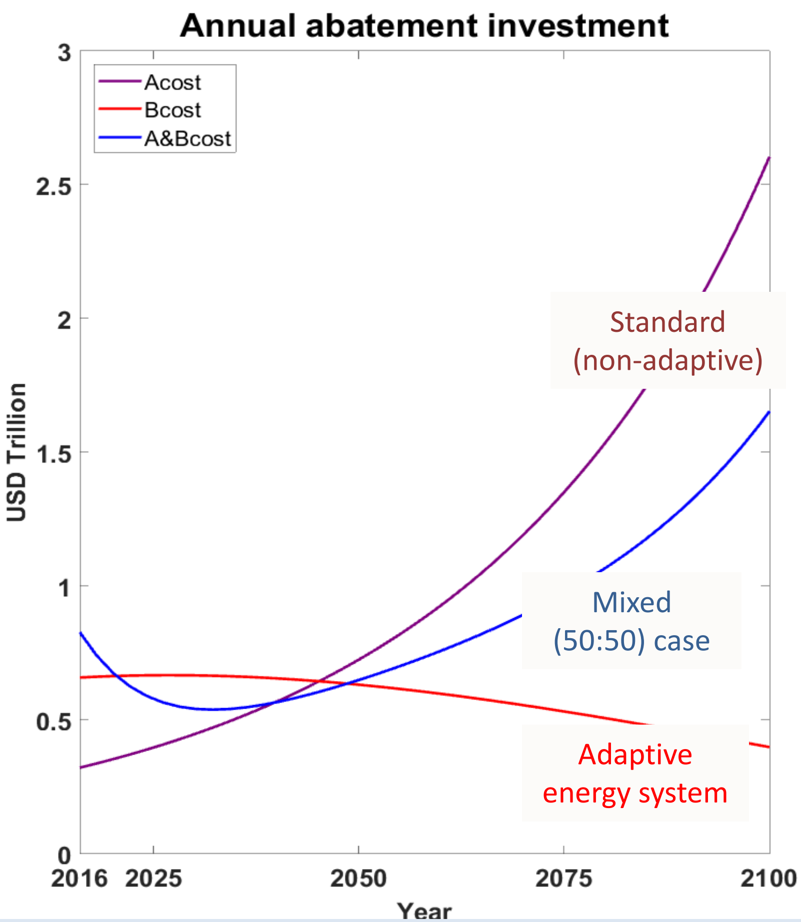
Beyond technology/sector-specific policy …

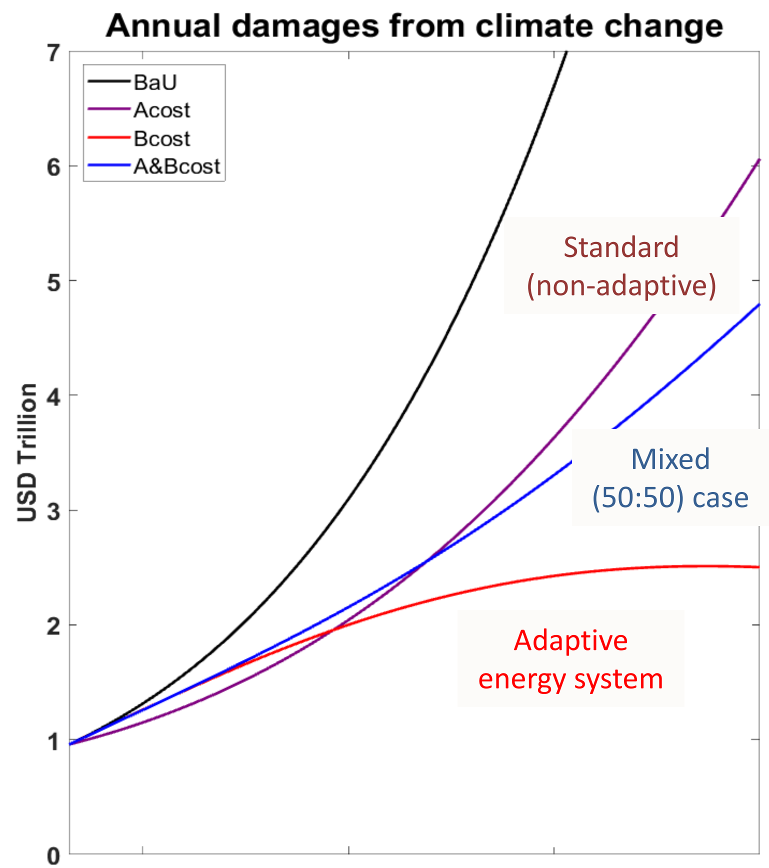
Induced innovation has further implications –*Illustrative model*

- Seek a simple, transparent *stylised reduced-form model*
- Mitigation (abatement) costs defined to depend on both the ***degree*** and the ***rate*** of abatement relative to reference projection:
  - Rate-dependent costs reflect the *inertia* of change – investment in strategic deployment, changing underlying pathway or overcoming political obstacles
  - Formalised as $= C_a \times (\textbf{degree} \text{ of abatement})^2 + C_b \times (\textbf{rate} \text{ of abatement})^2$
- The Ratio of the two (C_b / C_a) reflects the **capacity of the system to adapt to emissions mitigation** – overcoming friction from change (derived in paper) relative to enduring cost of emissions constraint
- Climate damage assumed to be direct function of Temperature approximated through **cumulative CO2 emissions**
  - Also quadratic dependence of damage, upon T^2

Numerical assumptions (See Annex) drawn from conventional C/B literature

With induced innovation / 'adaptive' energy system, optimal effort higher due to learning / pathway benefits



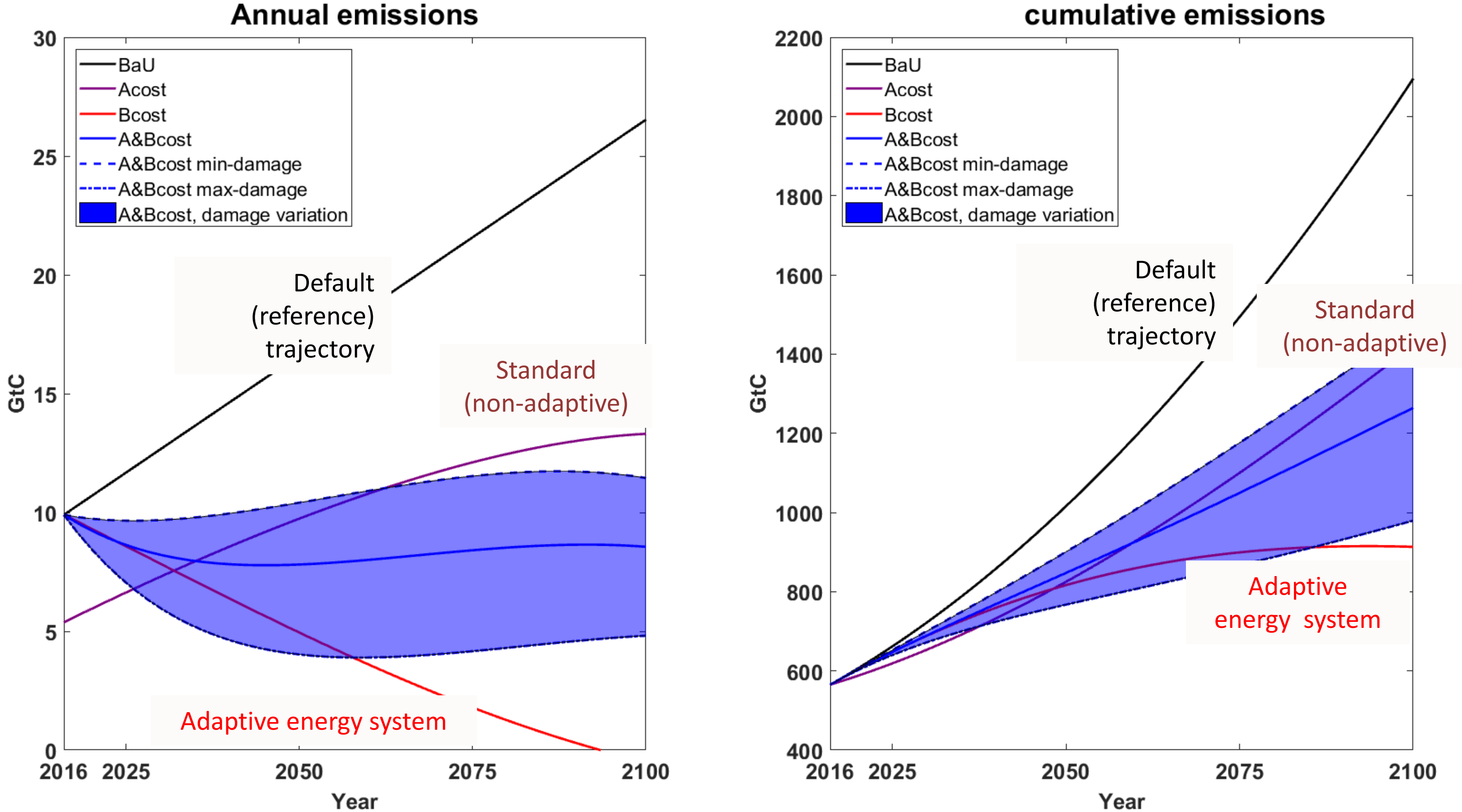


- **Effort**: If adaptive system, much bigger early efforts because they have much higher benefit

Timely investment: Optimal global investment can cut annual costs (abatement + damage) towards end of century by at least 5 times as much

*Most other parameters similar to Nordhaus, *A Question of Balance*

The 'global optimal trajectory' is radically different for a system which 'resists but adapts' to emission constraints



Source: Grubb, Mercure, Salas and Lange (2017), EPRG working paper / paper to World Bank Conference on Sustainable Infrastructure, Washington, 27-28 Nov

Conclusion

- There is overwhelming evidence that learning in technology and systems is
  - central to economic development
  - can be estimated
  - Is crucial element in tackling climate change
- Efficiency improvements and clean energy deployments to date
  - Have delivered significant emission reductions
  - Have driven transformative reductions in costs (*eg.* of renewable energy, efficient appliances and electric vehicles)
- Economic analysis
  - So far has mostly ignored these realities
  - To be useful, needs to expand from neoclassical / equilibrium frameworks to encompass "all Three Domains" of economic decision-making
- THIS MATTERS
  - Taking account of learning (including technologies, systems and more) radically changes perspectives on costs, optimal policy, and political strategy
  - … including the prospects for and design of coalitions and clubs for tackling climate change

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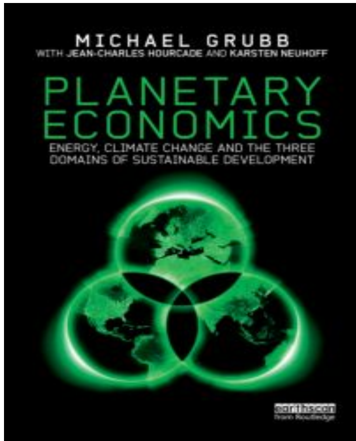


[Annex slides on
terminology, “Three Domains” and modelling]

Terminology used

Adaptive system = **Innovation** + Infrastructure + Structural change

Innovation = public R&D + **learning**

Learning = public policy learning + **private sector learning**

Private sector learning = learning-by-searching + learning-by-doing + learning-by-using (in technologies, systems, supply chains, business models, & financing structures)

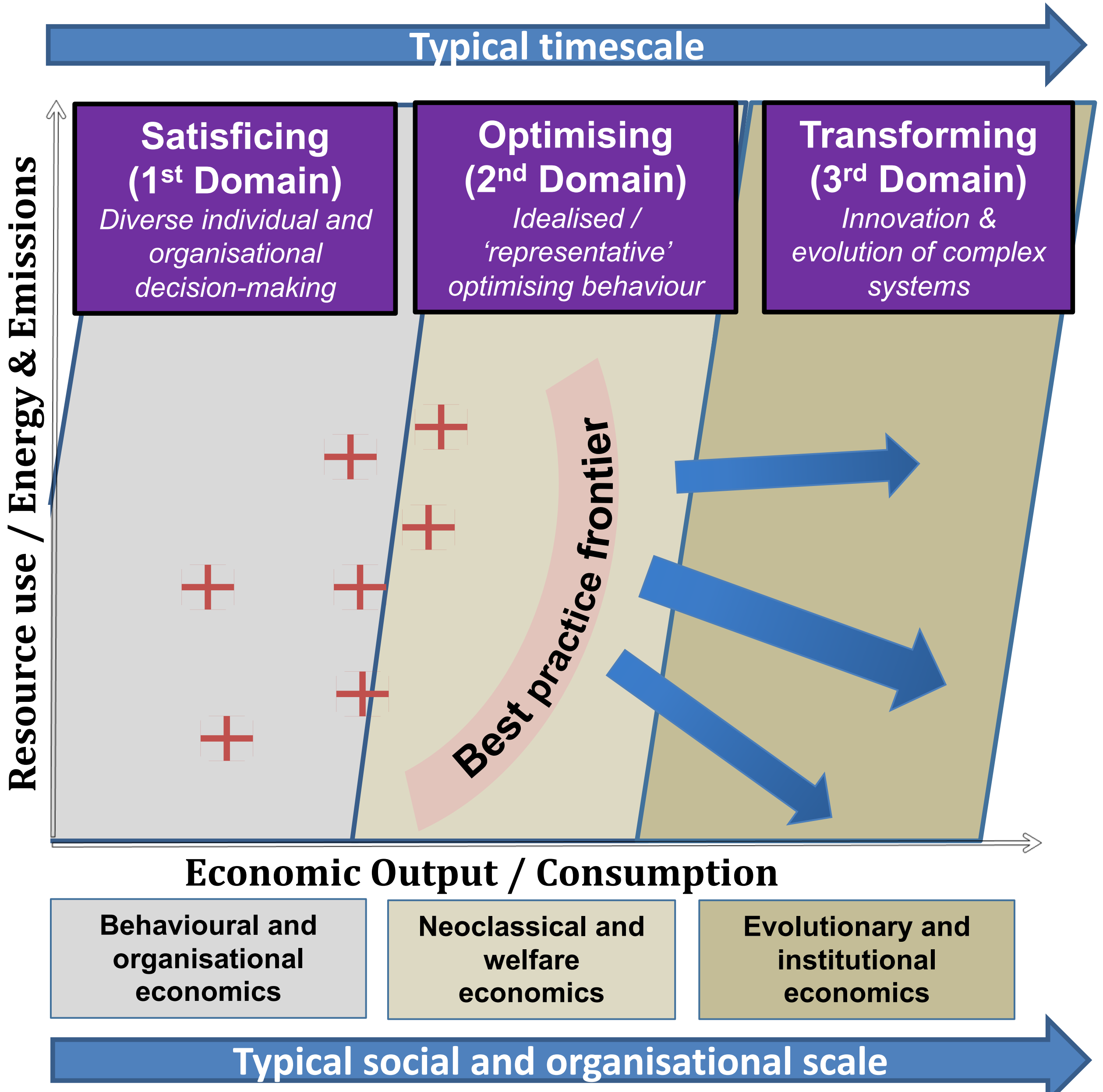
Induced innovation = learning induced by policy direction (eg. technology incentives or emissions pricing or constraints)

Broadening economic horizons: 'Three Domains'

For a problem which spans from

- the inattentive decision-making of seven billion energy consumers, to
- long-term transformation of vast and complex infrastructure-based techno-economic systems

To date, far more progress on energy efficiency and technology / renewables etc policy than carbon pricing



Some key assumptions in the numerical modelling

Real discount rate 2.5%/yr.

Climate change damage \$3trn/yr for an additional 500GtC emission. – cf global GDP mid Century typically projected in range \$85-150 trn/yr

Reference emissions growth linear 800MtC/yr (2% of 2010 emissions) - corresponds closely to the reference projection of the IEA (2012).

Abatement costs parameters

- Purely enduring costs (c_b =0): 50% cut in global CO_2 emissions in 2040 costs \$2trn (eg 2% of GDP@\$100trn). This is towards the pessimistic end of literature.

- Purely transitional costs (c_a =0): the same cutback, on a linear trajectory of abatement, results in the same total integrated cost over the 30-year period, but these are now attributed as transitional costs of reorienting the energy system over these decades.

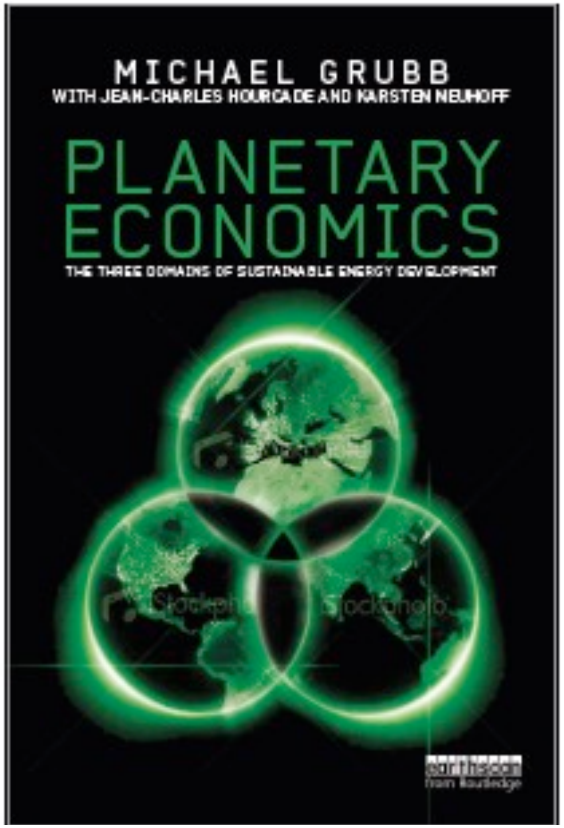
Mathematical formulation

Emissions	$e(t)$
Cumulative Emissions	$E(T) = \int_0^T e(t)dt$
Reference Emissions	$e_{ref} = e_0 + e_1 \cdot t$
Marginal Damage (X=temp)	$d(t) = d_1 \cdot X(t) + \frac{d_2}{2} \cdot X(t)^2$
Cumulative Damage (r=real discount rate)	$D(T) = \int_0^T e^{-r \cdot t} \cdot d(t)dt$
Cost Abatement Type A	$c_A(t) = cost_A \cdot \left(e_{ref}(t) - e(t)\right)^2$
Cumulative A. Cost Type A	$C_A(T) = \int_0^T e^{-r \cdot t} \cdot c_A\,(t)\,dt$
Cost Abatement Type B	$c_B(t) = cost_B \cdot (e_1 - \dot{e}(t))^2$
Cumulative A. Cost Type B	$C_B(T) = \int_0^T e^{-r \cdot t} \cdot c_B\,(t)\,dt$
Min. Function	$\mathrm{F(T)} = D(T) + C_A(T) + C_B(T)$

To avoid confusion with the time horizon T in the model, X(t) here used to denote temperature change; as explained this is approximately proportional to cumulative emissions: X(t) = E(t) * 500. In all the modelling work presented here we set d_1 = 0, so that the focus is simply upon the quadratic damage function.

Planetary Economics:

Energy, Climate Change and the Three Domains of Sustainable Development



1. **Introduction: Trapped?**
2. **The Three Domains**

Pillar 1

- **Standards and engagement *for* smarter choice**
- 3: Energy and Emissions – Technologies and Systems
- 4: Why so wasteful?
- 5: Tried and Tested – Four Decades of Energy Efficiency Policy

Pillar II

- **Markets and pricing *for* cleaner products and processes**
- 6: Pricing Pollution – of Truth and Taxes
- 7: Cap-and-trade & offsets: from idea to practice
- 8: Who's hit? Handling the distributional impacts of carbon pricing

Pillar III

- **Investment and incentives for innovation and infrastructure**
- 9: Pushing further, pulling deeper
- 10: Transforming systems
- 11: The dark matter of economic growth

12. **Conclusions: Changing Course**

4CMR

Routledge/Taylor & Frances, Published March 2014

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