Energy, Europe and the Economics of Innovation

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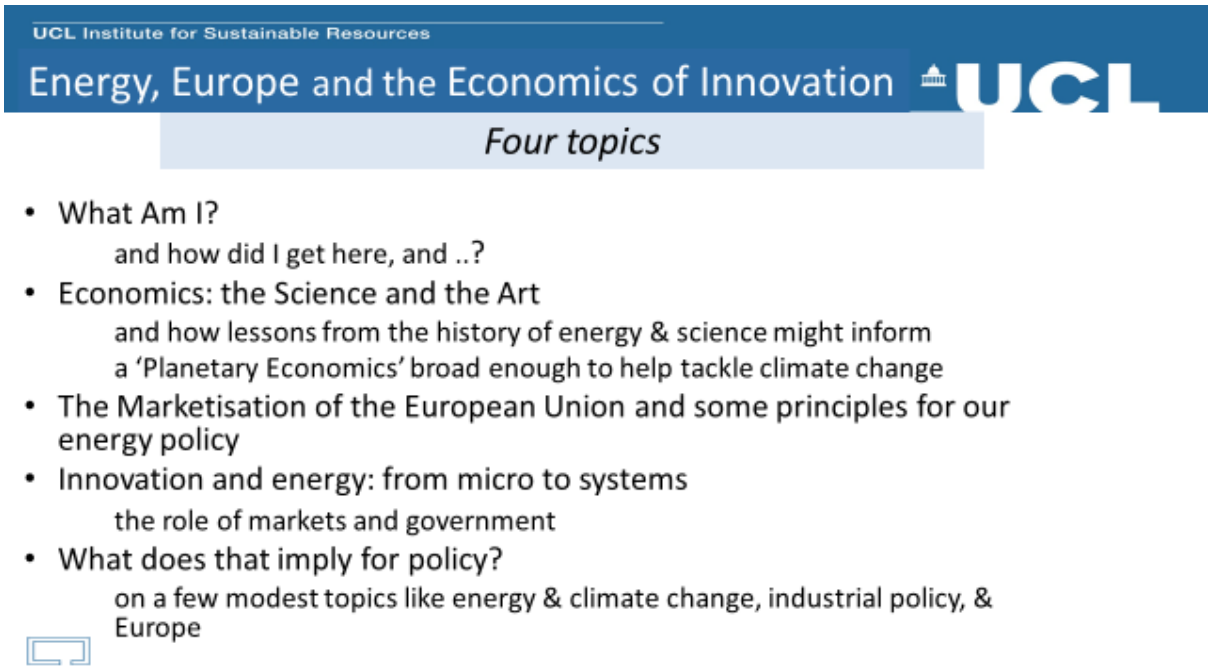
Based on what I've heard, an inaugural lecture has licence to be the opposite of a great dinner talk – for which the standard guidance, as many of you will know, is to deliver a funny beginning, a great ending, and not much in between. It is also a licence to talk a bit about oneself – which of course most of us like to do. So I am going to cover four topics:

- Say a bit about how I got here, including how come I am giving my inaugural lecture some 18 years after being awarded a University of London Professorship (don't worry Provost– I am not going to blame University Administration)
- Say a lot about economics – which I'll suggest is the 'science of an art' - particularly concerning innovation but starting with wider theory, on which I'll spend about half the time as it's so fundamental
- .. and apply this particularly to issues in Europe and its – and our – energy policy, particularly the role of markets & governments



You will not be surprised, that in the course of this I will draw a lot on the conclusions of a book completed shortly before joining UCL, with the rather immodest title, *Planetary Economics* …

Finally, draw some broader policy implications, few minor topics as indicated, like energy & climate change, industrial policy, and Europe. For on this journey, I will extend the thinking to argue that several of the traumas of our time can be traced to a period in which public discourse and policy became too dominated by one particular form of economic ideas, and that we are not going to solve the challenges facing us – including but not only energy and climate change - without broadening our understanding of economics.

What am I? Well, [apart from being intellectually over-ambitious] - academia is defined by disciplines and I have always been a problem child. I remember at age of 14 resenting having to choose between music and geography for my school exams - I chose music. And again at 16, when I loved history, but for once in my life followed advice, and abandoned that to focus on science and maths, which at least led me successfully into Natural Sciences at Cambridge – graduating in physics and maths after brushes with psychology, physiology and geology along the way. You can see I early on I had problems with focus, which have endured.

Cambridge was great; the only problem was that after 3 years I realised I really wanted to do things more directly relevant to the wider world. Fortunately, the Cavendish Laboratory had created a **refuge** for people like me, called the **Energy Research Group**, where I did my PhD on the engineering and economics of how electricity systems could manage the variability of renewable sources –one colleague suggested I was probably the only person on the planet to have done cost-benefit modelling of energy systems which were 50% nuclear and 50% renewables.

That was followed by two years' post-doc in electrical engineering at Imperial College - where I realised not only did I have problems knowing my preferred academic discipline, but actually **whether to be in academia at all**. Fortunately, I was offered a job at Chatham House – the Royal Institute of International Affairs - which like Cambridge had set up an energy program after the oil shocks of the 1970s, but now wanted an expert to lead their work on **coal, electricity and maybe the environment**. A great place for someone who was researcher by intellect, but emotionally wanting to engage with public policy on the issues of the day.

So crossing boundaries seems to have become a theme of my career, which has also **straddled the interface of research and policy**. It doesn't make for an easy life, but it's certainly made for an interesting one. In Europe this was the era of acid rain – the damage to air quality, lakes and forests in particular from sulphur pollution – and depletion of the planet's ozone layer. And both of those problems, which seemed **daunting at the time, we have ultimately got under control** through combinations of **technology, policy and painstaking international negotiations.**

Which leaves us still with the Grandparent of all global atmosphere problems, namely climate change, which became a key focus of my career. What always fascinated me was not so much the problem, but the solutions. Our societies have been built on **fossil fuels, which have brought tremendous benefits** to humanity. Decarbonising the global economy is not a challenge for the fainthearted. When I started in the field the world was emitting under 25 billion tonnes of CO2 annually, it is now over 40. So – ESRC evaluators note – you might say, not great marks for impact of my research.

It was at Chatham House that I began deeper engagement with economics. I was intrigued by a **remark from Rob Stavins** at Harvard, that the topic of climate change was dividing the scientists from the economists like nothing he had seen before. That was mainly around attitudes to **risks. I am not going to talk about that side** of things, because I found myself questioning the mainstream economic view more concerning its approach to technology, innovation and policy. But that's to jump ahead.

After a frenetic decade at Chatham House, I needed a change and also had concluded that the international effort on climate change, largely embodied in the Kyoto Protocol, **could go no further**

unless we got better at implementation, and that would require **better policy and better technologies**. I took up a half-time Professorship at Imperial College, but for various reasons didn't, so to speak, convert the try to a full time role.

The UK had just established the Carbon Trust, as the lead body to help British business move to a low carbon economy. Their Chief Executive Tom Delay - delighted you could join us today - approached me and said that he thought they should have someone on staff with expertise on climate change – not as obvious as it sounds, by the way, and a somewhat loaded suggestion to which I said yes. I had for personal reasons moved to Cambridge, where I was invited to take a research position in the Department of Applied Economics. Being rather naïve, I hadn't reckoned on the fact that Cambridge University said they don't recognise University of London professorships. But I wasn't too worried. I had moved into a different stage, and alongside that contract research role I became the Carbon Trust's Chief Economist.

Indeed **for almost fifteen years** I worked half time in a "doing" job – working with business on emission reductions and low carbon innovation, and then moving to the energy regulator Ofgem – alongside research positions in Economics at Cambridge, and more recently as a recently Professorial Associate position at UCL. It was **amidst these varies experiences and transitions** that I decided to take time out to write a book on what we have learned – an ambition which started out intending to be more overtly on policy, before I concluded that the underlying challenge was the **inadequacy of theory – or competing theories - and how to recast them.**

I guess that book helped with the offer to become Professor of Energy and Climate Change at UCL – and being rather disconcerted to find I had reached my mid 50s, I took the opportunity to have one real job, with thanks, above all, to Paul Ekins and UCL for bringing me at last to one main professional identity, despite my best efforts. Hence the eighteen year wait for this sort-of-Inaugural lecture, in which I will at last turn to the intellectual substance.

On Economics

Economics is a fascinating discipline: hugely powerful in shaping the way many governments and policymakers think. A discipline intended to understand and help the real world improve all our lives; yet controversial in that, and in many ways also very theory-driven. I find it intriguing to start with an age-old question as to whether economics is a science or an art: as you can see, the Oxford English Dictionary (at least, when I first probed this before the age of internet), implies it is the science of an art – 'the art of managing the resources of a people and its government'.

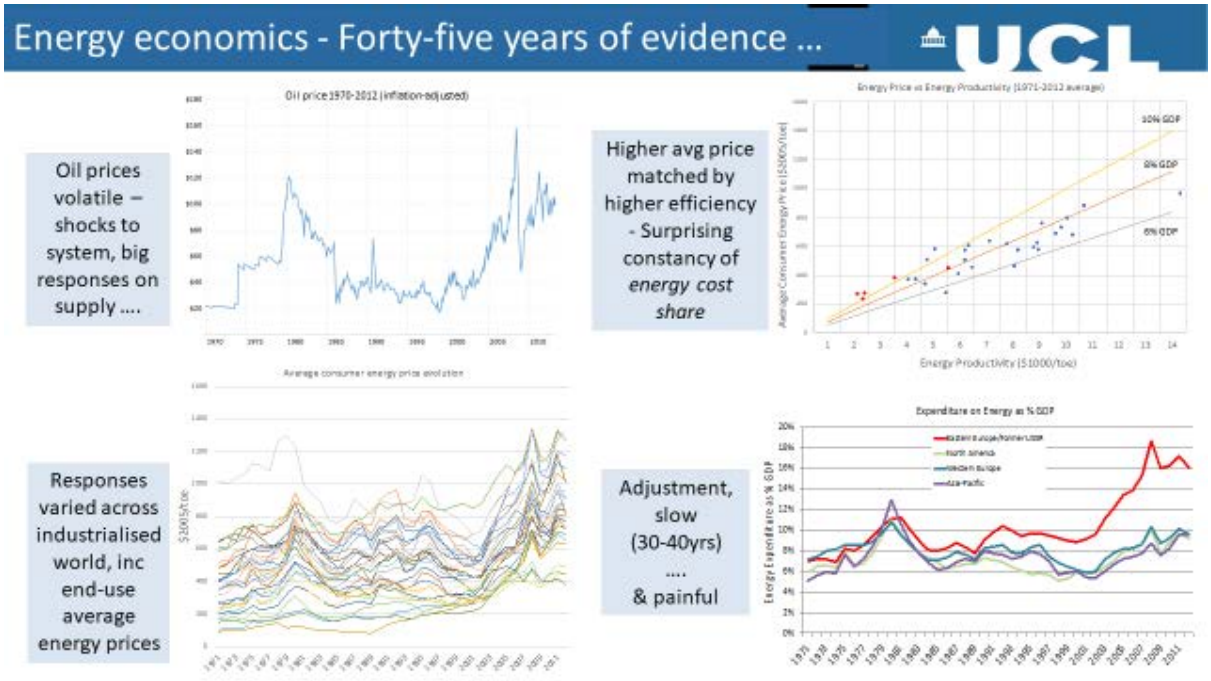
Trying to apply this to energy and in particular climate change, I argue, requires a heady combination of both elements. The 'people' are almost everyone on the planet, today and in the future. The 'resources' in question span much of the physical world. As for the government that is supposed to manage all this …

The climate change literatures have struggled to define the beast. Nick Stern famously called the unpriced emissions of greenhouse gases 'the biggest market failure in history'. It has massive and thorny moral dimensions. And social science has called it a ''super-wicked" problem in the sense of being just so infernally complex (OK there is a more precise definition, but I'll live with the sheer complexity).

I'm going to look at relationship between the first and last of those framings: from the relatively simple framing of a market failure (albeit a huge one), compared to one that is hard to comprehend let alone solve: and specifically I will try to make more sense of the energy-economy dimensions.

Good science starts with data

We now have the benefit of evidence of almost half a century after the world was rocked by shocks to the supply and price of oil, on which it had come to depend so heavily – its real price over the 1970s quadrupled. Sadly, I won't have time to talk you through this data, but I will just draw out four high-level points:



- The oil shocks stimulated massive investment in new technologies, including offshore oil not least in the North Sea. Oil demand also ceased its rampant growth. Pessimists had predicted oil would run out. Instead, by the 1990s many economists argued that the markets had won over the political controls that drove instability, and stable low prices would be ensured. In 1999 *The Economist* famously predicted a world of $5/barrel oil - shortly before the Millennium heralded an era of grinding ascent, surging to prices even higher in real terms than the previous 1980 peak, before retreating to levels which as we speak are around those after the 1973 oil shock. Please don't either ask or offer an opinion on the price for this year - I wouldn't believe either of us.
- Second, overall **end-use energy prices** – including taxes and all the other fuels - were all over the place. Most of the countries that started with higher prices in 2000 were less impacted by the subsequent shocks. Prices in Japan and some western European countries stayed high, averaging over twice those in the US. But the eastern block – just a few countries in the data here – shielded themselves from that. It didn't last, and all were significantly affected by the post-Millennium rise (and more recent fall) in all the fossil fuel prices.
- The bill: end-use prices, together with consumption, shape the **overall end-use cost**. People, companies, and governments all reacted with measures and policies to improve energy efficiency. Whilst almost all attention focuses on the *price* – whether international oil, or domestic fuel and electricity – the *bill* is actually more intriguing. The share of GDP of most of the rich countries spent on energy has, surprisingly, been roughly constant – mostly in the range 6-10% of GDP: those countries with energy prices twice as high have over the period been roughly twice as efficient in their use of energy – in fact, a bit more so, on average – a slight tendency that those with higher prices ended up spending less on energy.

- ... In fact the biggest anomaly was with eastern Europe, which underlines how long adjustment takes and how painful it can be. For decades eastern Europe had sought to keep energy cheap. As it opened up its economies and adjusted to European – market - energy prices, to meet the terms imposed by EU membership, these countries actually ended up with by far the biggest energy bills, relative to wealth. In the UK we've had raging political debates whenever the end-use energy bill (including transport and business) has exceeded about 10% of GDP. Some of eastern Europe hit over 18%, some of the European elites told them that was just markets and efficient pricing (including paying the same carbon price across Europe), get used to it.

Now the economists in the audience might think that's **a simple story of prices and markets. Yes, and no – it's actually far more –** as I hope by the end of this talk you'll all appreciate.

So with apologies for the brevity on that, brings me to the core of my topic, and in particular, the **Three Domains**. What on earth am I talking about?

Good economists tell **jokes about their own discipline**. You might have heard the one about the chemist, the engineer and an economist stranded on a desert island – if not, look it up. **One I've always liked more** is one about an old man scrabbling around one night under a street light. To a sympathetic passer-by he explains he is looking for the keys he dropped. However, to the apparently rhetorical question "so you dropped them around here?" he points his finger away and says, "no, I dropped them over there but its too dark there."

The lights of neoclassical economics start from the proposition that humans seek to optimise their wealth from a given set of resources and associated technologies. It demonstrates why markets are far better at doing this task of resource allocation than governments ever could be. Really simple, really powerful. Yet, we are now confronted by a **twin, lurking fear: that economic logic was somehow distorted into an ideology of free markets, in ways which deliver both levels of inequality that are morally indefensible, and degrees of global environmental damage that cannot be sustained**. I contend that these are areas in which there is still insufficient attention and understanding.

The rather immodest title of Planetary Economics is not meant crudely to be about the Planet itself – though it does touch on that in ways I don't have time to address today - but about the huge breadth of understandings – plural – that we need to tackle these problems.

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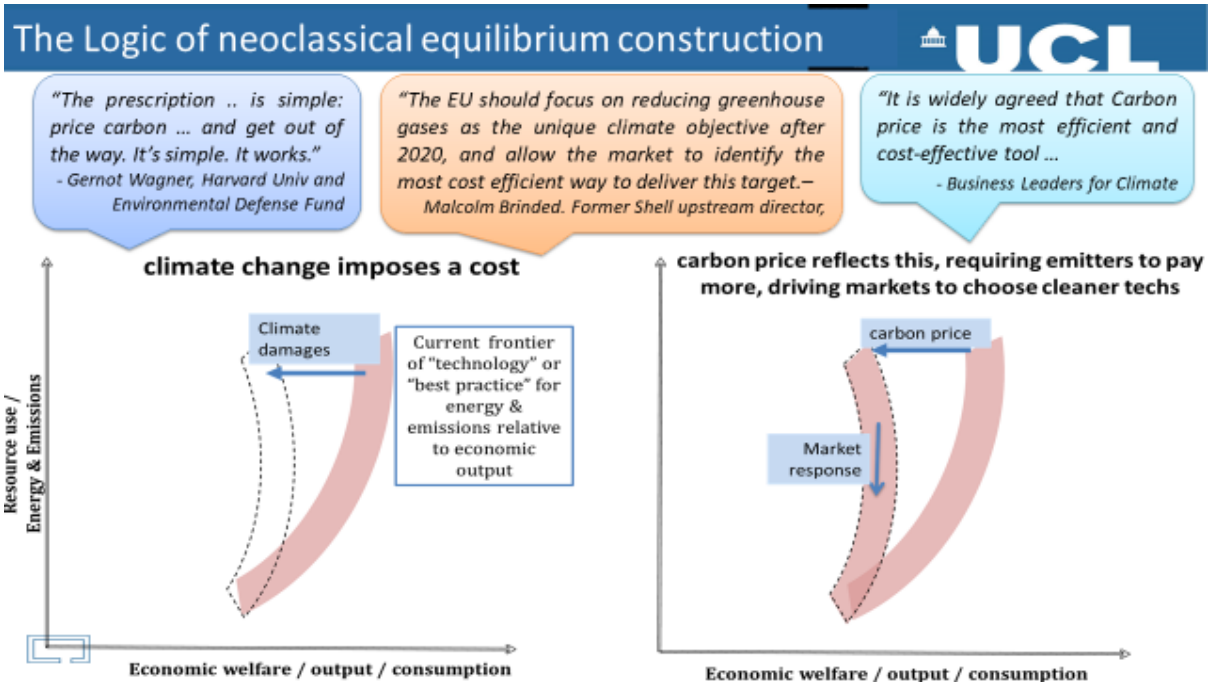


To simplify only a little, the basic neoclassical idea is that people seek to make the best use of the options available – to maximise their economic welfare by making best use of the options available (whether output or consumption is a reasonable proxy for this is not my focus today). In economic jargon, they should operate at a 'frontier' which is often called the technology or possibilities frontier, but which would be far better termed the 'best practice' frontier since possibilities are almost limitless and technologies that deliver them evolve. We are assumed to operate roughly on this frontier as far as possible because anything else implies that we are basically wasting money. For individual actions to align to an overall efficient outcome, prices must reflect the costs.

The left hand figure shows a generalised frontier, in which we can get more economic welfare (the bottom axis) by using more resources (the vertical axis). What makes neoclassical economics interesting is that there are millions of millions of different resource inputs and associated frontiers, and similarly billions of decisionmakers & trillions of decisions. The science of neoclassical economic theory is that given the right prices, an ideal market will settle in a general equilibrium; and its beauty is that it will do so in a way that minimises overall costs and maximises welfare.

The particular frontier of interest in this talk is when the vertical represents energy inputs, or use of the atmosphere as a free dump. A well known caveat to the general theory concerns unpriced impacts. Environmental damage for example imposes a cost, which reduces welfare – an impact commonly known as an externality, because it's external to market decisions. That's represented by the dotted curve – what seems to be enhanced welfare from using more resources may not be, because of the associated damages which are not paid by the individual decisions at the time.

Good economics, correctly, implies that should be internalised – in this case with a carbon price, so as to bring the cost into markets. In classical theory, the price should reflect the damages – as implied in the right-hand figure. Requiring emitters to pay for pollution gives them an incentive to pick cleaner technologies instead, which then leads the system to settle in a new and cleaner equilibrium. Pricing the externality – as with a carbon price - is vital to market efficiency.

One immediate observation is that such 'externality pricing' torpedoes part of the politically powerful convergence between economic and some political – particularly libertarian - perspectives on markets. As well as appealing to economic efficiency, equating individual choice with efficiency is politically appealing to those who fundamentally distrust governments. Externalities immediately split this: markets can only be efficient if governments force people to pay for the external damage of their activities.

Accepting the need for government action in these circumstances – which almost economists do – the theory of pricing externalities is simple, neat – but unfortunately, still completely inadequate:

- The people who will suffer from climate change – the damages which reduce aggregate welfare as represented by the dotted curve on the left hand diagram – are spread around the world and most of them probably haven't been born yet. It is the here and now who will pay the carbon price on the right hand diagram, and they generally don't like paying for something which was previously free to them.
- Partly because of that, despite more than 25 years of debate, the estimated cost-equivalent of climate damage is anywhere from pretty modest to something that would break the bank. It is also a number subject to political machination. The US Treasury eventually settled on a number approaching $40 per tonne of CO_2 as representing climate damages.
  (In parentheses: The Trump administration has magically changed that, to provide a cost-benefit justification for pulling out of the Paris Agreement, without changing one jot of the scientific or impact assessment. They simply dictated that a country (it happened to be the US, of course) has no responsibility for the damages it imposes on other countries; and that it should discount the value of future impacts far more heavily than the previous analysis, by about 90% for each future generation so that damages to the grandchildren's generation should count for only about one percent of equivalent damage to the present generation. Climate change is a global and long term problem and those changes essentially wiped the damages from the ledger).
- A good alternative though, is to set a target, cap emissions, and let the market find the price required to meet it. Which is roughly the approach of the last quote on this slide. Still, the people who will pay the energy bill are not remotely the ones who will suffer from climate change. They resist, complain, and block.

So and sadly, after 25 years of this almost universal core recommendation from economists, hardly anywhere has got close to imposing a reasonable cost of carbon – the UK is amongst those to have made some of the best progress and should be congratulated. After all, this is a long term business – as indicated, major system adjustment can take 30-40 years – but that just amplifies the tension between those paying, and those benefiting.

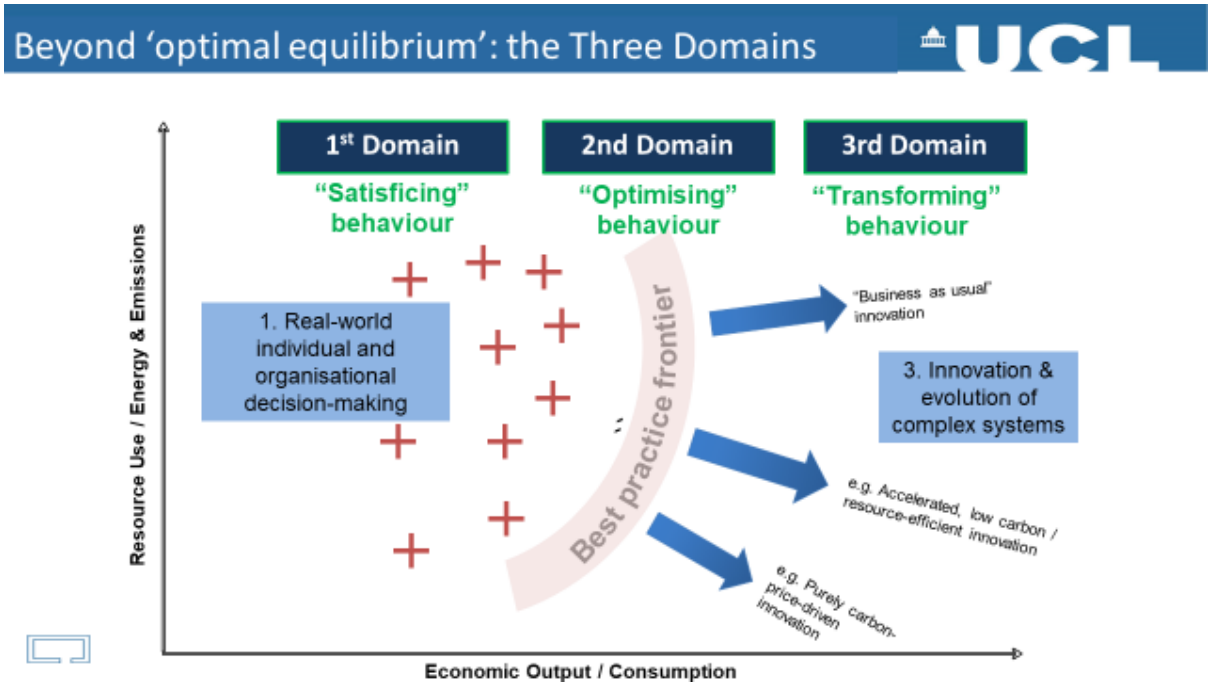
But most importantly, all this is only a small part of the economic story. Not wrong, but seriously incomplete. And my economic argument includes a suggestion that by paying more attention to the non-price parts of the pictures, we can actually improve the political prospects for getting the prices right.

For reality is actually far more interesting – and more practically promising. In the first place, most real people and organisations don't actually make optimal choices that bring them to the frontier of best practice. How many of you woke up this morning and thought "OK, I'm going to optimise my energy use today"? How much do you believe companies and governments really optimise their use

of resources? If you think they do, just look at the evidence, which I have tried to capture by the red crosses - most of us, most of the time, are far from the frontier. There are all kinds of opportunities to do much better.

Since I like to start with reality, I call that "First Domain" behaviour.

The makes "Second Domain" the field of mainstream neoclassical and welfare economics, in which the 'representative agent hypothesis' represents infinitely cloned beings [I didn't say human] who strive to make optimal economic choices based on relative prices, and hence actually do sit close to the frontier. Of course its more complicated than that and there is a huge risk of caricaturing economics in this, but I would still maintain it's a reasonable approximation of the common underlying assumptions.



However most fundamental to the thesis is that the frontier moves. Of course it does. Its called innovation, infrastructure, institutional development and lots of other things that change and improve what is possible at any given point in time. Of course economics recognises this in principle, but to preserve its purity the neoclassical approach becomes a tangle of equilibrium-that-keeps-changing and generally assume that the innovation driving this is a mix of just two processes: technologies which fall like manna from heaven (or government R&D grands), pure market-based innovation. In reality, Third Domain economics – the economics of the evolution technologies, infrastructure, institutions and more – is about far more than this.

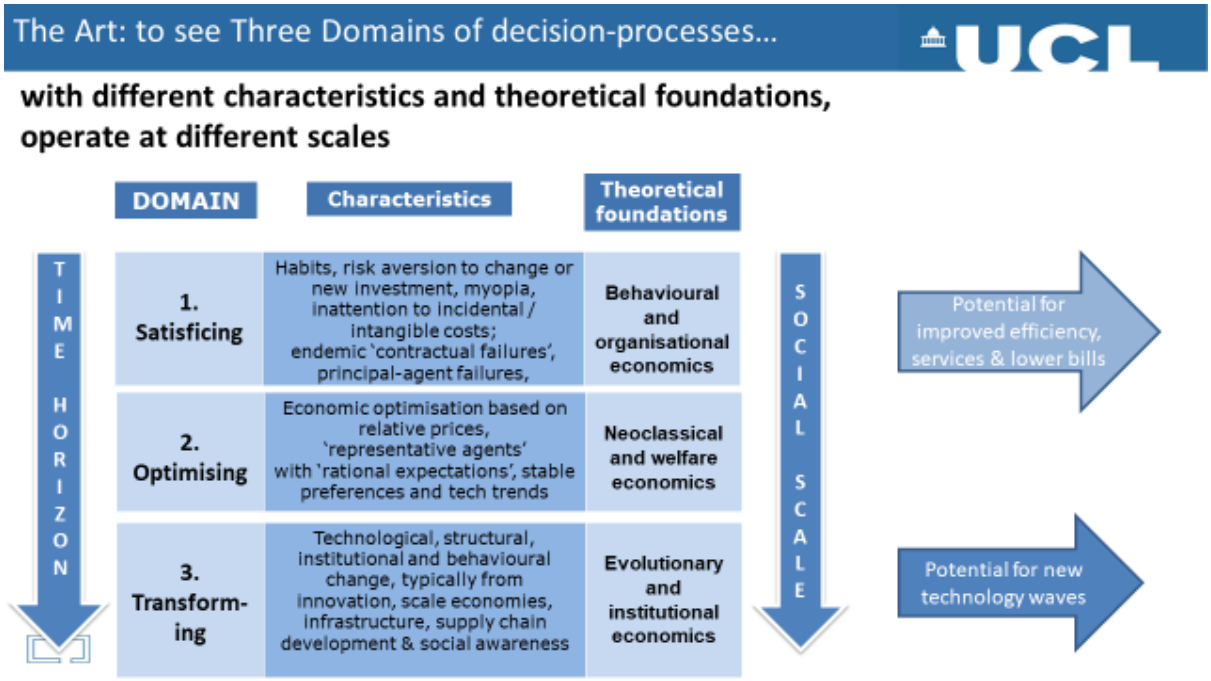
I will return to this, but the essential point is that when faced with something like climate change, we really care about both the pace and direction of innovation. We want the frontier to evolve to the bottom right – giving us options for more welfare with less energy and CO_2. Third Domain economics is the science of understanding those processes in reality, not as a convenient abstraction

which enables us to preserve the simple and sometimes ideological assumptions of its rather distant second domain cousin.

Of course all these are interrelated. Indeed, consider that two decades after the oil shocks, we'd made great progress in greater efficiency – moving somewhat closer to the frontier, whilst making good money out of it. Companies made far more efficient equipment. It wasn't that people were forced down the curve by high energy prices, and slipped back up again when prices fell; people moved towards the frontier, and the frontier moved, though certainly prices affected the pace of both. We ended up more than doubling GDP, with almost static energy consumption and – as it happens – declining per-capita carbon emissions. It's a dynamic system.

Around the Millennium, many environmentalists said what we then really needed to decarbonise would be another oil price shock, to drive people to clean energy. **We got a good a good price shock, but the supply response largely achieved the opposite.** Oil companies a lot richer, they looked to find more oil and smarter technologies for getting it out – like shale – investing billions in ways which enable us to mess up the atmosphere more cheaply. They used their money to move the top – high emitting - end of the curve, so they could stay in business. It is all far more complex than traditional theories imply.

I try to give the theoretical approach more flesh in the next figure, which summarises the key decision characteristics of each domain and the increasingly well-developed theories underpinning each of them. But I can't underline enough that I am not trying pose these different domains as alternative theories in a battle over which is right. Frankly I have seen enough of that in academia and it's an unproductive waste of time. On the contrary, my argument is that they are all right, but describe different processes which dominate at different scales.



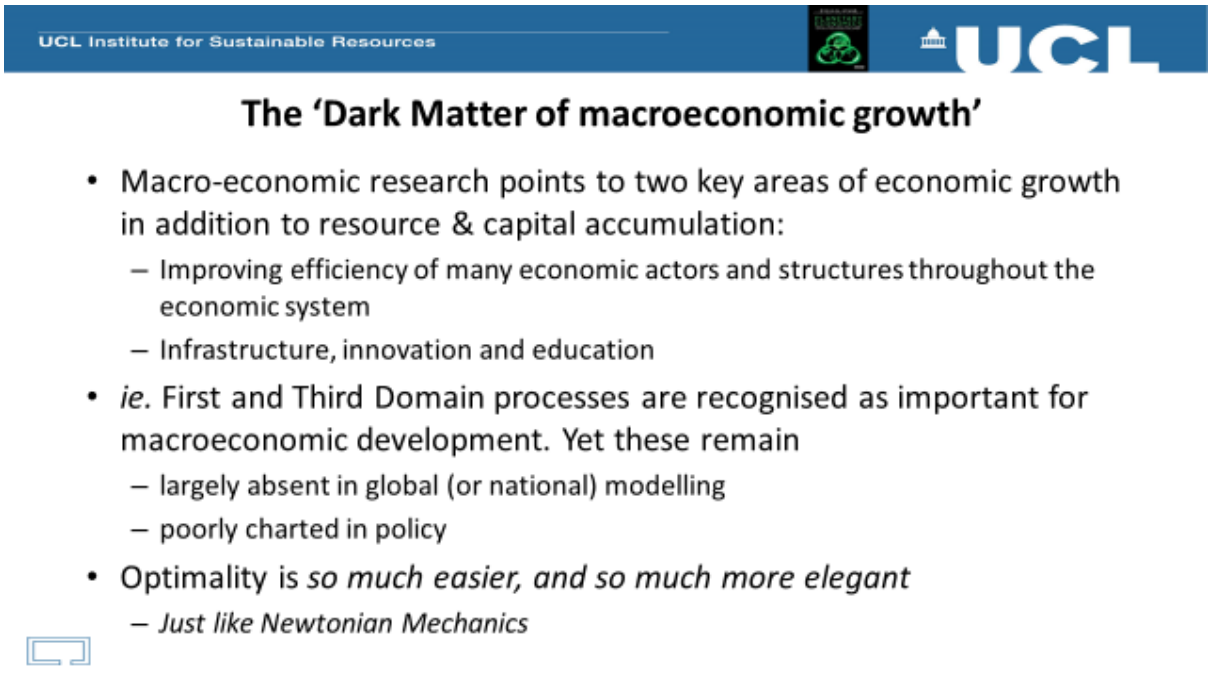
First domain behaviours characterise small-scale decision-makers generally with very limited time horizons. Markets typically operate over larger scales, and the major investors in particular have time horizons of maybe a couple of years to a couple of decades. Third domain processes involve

the global diffusion of new and better ways of doing things, and the energy sector that has historically taken many decades. The different domains just describe the characteristics which dominate at different scales.

But I do think our energy policy debates over the past decade have been unnecessarily toxified – if that's a word – by over-emphasis on equilibrium-based pure market theory, and hopelessly inadequate understanding of innovation in energy. I found it interesting that when I joined the energy regular Ofgem, most of the people were familiar with neoclassical theory, as one would hope – it was their job to supervise markets. A surprising number were becoming familiar with behavioural theories, not least because we were banging our heads against the fact that perfidious consumers did not seem to be taking advantage of the opportunities to save money by switching suppliers (let alone, energy conservation); moreover many of those 'sticky customers' were in fact the poorest, creating a difficult combination of both inequity and market inefficiency.

But no-one had a clue what I was wittering on about when I started talking about evolutionary economics. When faced with a strategic challenge in which innovation is key, third domain economics becomes the science-and-art of what my colleague Mariana Mazzucato has termed *Mission-driven* innovation.

But I digress – we can come back to that, because I need to **take the theory a bit further.** First Domain processes are not optimising, and there is absolutely nothing in Third Domain theories to suggest that innovation will be anywhere near optimal in its pace, or desirable in its direction. It is from that insight that we can link from the micro to the macro. For **the Three Domains fit with emerging understanding of macroeconomic growth.**



Just as I was completing the book, I attended a keynote lecture by Prof Tim Besley at annual Government Economic Service conference. I was actually rather startled when Tim focused on the fact that within the **long-running crisis of macro-economic growth theory**, emerging clearly was evidence that **growth involved at least two other major forces** besides resource and capital

accumulation. They formed the 'residual' in the archetypal growth theories, the puzzle for economists which I like to call the 'Dark Matter of Economics Growth'. Those forces, he described as improving the persistent inefficiencies of many actors and structures throughout the economic system; and the benefits of infrastructure and innovation, including education.

In other words, First and Third Domain processes are recognised as important for macroeconomic development – even if those terms aren't widely known. It is just that we have lacked an elegant microeconomic theory of them. Similarly, at a meeting with the World Bank macroeconomics department last November, I was confronted with the 'Innovation Paradox': that because developing countries tend to be **further from the frontier – something on which we have increasingly sophisticated measurement, by the way** – they have more to gain from innovation, but many seem *less* able to do so – to adopt even best practice let along benefit from driving it forward.

The development of Behavioural economics has started to illuminate the 'black box' of First Domain economics, and rest of this talk should shed some light on Third Domain economics. But these non-classical domains remain largely absent from most global or national modelling, and poorly charted in policy.

Optimality, derived from neoclassical equilibrium theory – *is just so much easier, so much more elegant.*

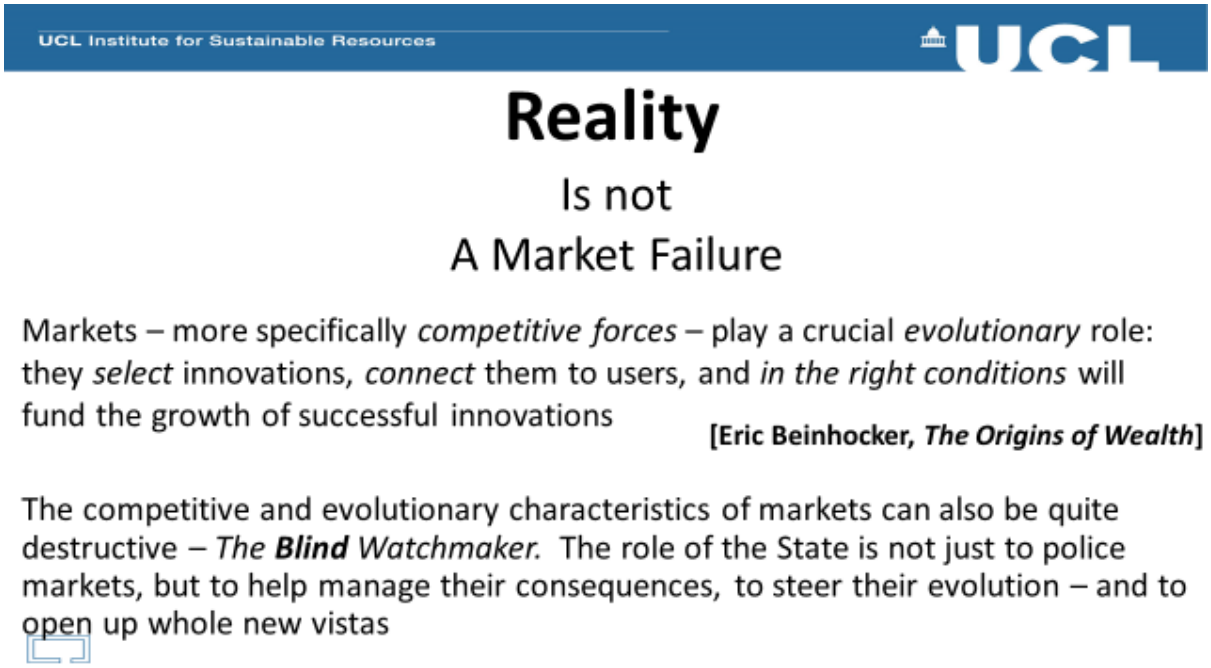
Rather like Newtonian Mechanics, which for almost two centuries most scientists thought described the universe.

Science eventually embraced the evidence that Newton's wonderful theory didn't work for the very small, or the very large – hence the development of Quantum Mechanics, and Relativity, respectively, to describe what we observe at those opposite scales. That didn't make Newton wrong. Just wholly inadequate for understanding the very small, and the very large.

Since writing *Planetary Economics* I have harboured a haunting fear that this is just a slightly pretentious way of stating the bleedin' obvious. But I've already alluded to the advice on climate policy which stemmed from Second Domain logic in its glorious purity.

To me the most significant insight, from an economics perspective at least, was when I finally abandoned the prism – or straightjacket – that such neoclassical reasoning implies, of everything being framed in terms of 'market failure'. Hardly any economists really believe the world is in a perfect equilibrium – which would actually make the subject very boring - but there is vast literature on market failure.

On policy too: the discourse in the UK Treasury is dominated by the need to justify government policy as intervention designed to correct market imperfections – just ask any other department that has to ask the Treasury for money.



So let me be clear: in my understanding Reality **is Not a Market Failure.** We do not describe Quantum Mechanics as a failure of Newtonian Mechanics (though the etymology is clear, since Quantum theory has almost nothing to do with mechanics). Einstein did famously struggle to believe that God would play Quantum dice with the universe, but he certainly did not see Relativity as Newtonian failure which God really should get on and fix. He explained what we observed, and made sense of it.

First Domain economics is about the reality of human and organisational behaviour, with all its quirks, characteristics, and complexities of needs and wants, myopia and motivation, habits and inertia, messiness and more. Third Domain economics is about the realities of innovation, essential infrastructure, and the development of institutions for more effective governance - often to yield the benefits of social collaboration at ever greater scales. **We will never understand real-world economics properly for as long as these other domains are framed as failures from an idealised a state of optimal equilibrium – a state which in fact does not itself exist in reality.**

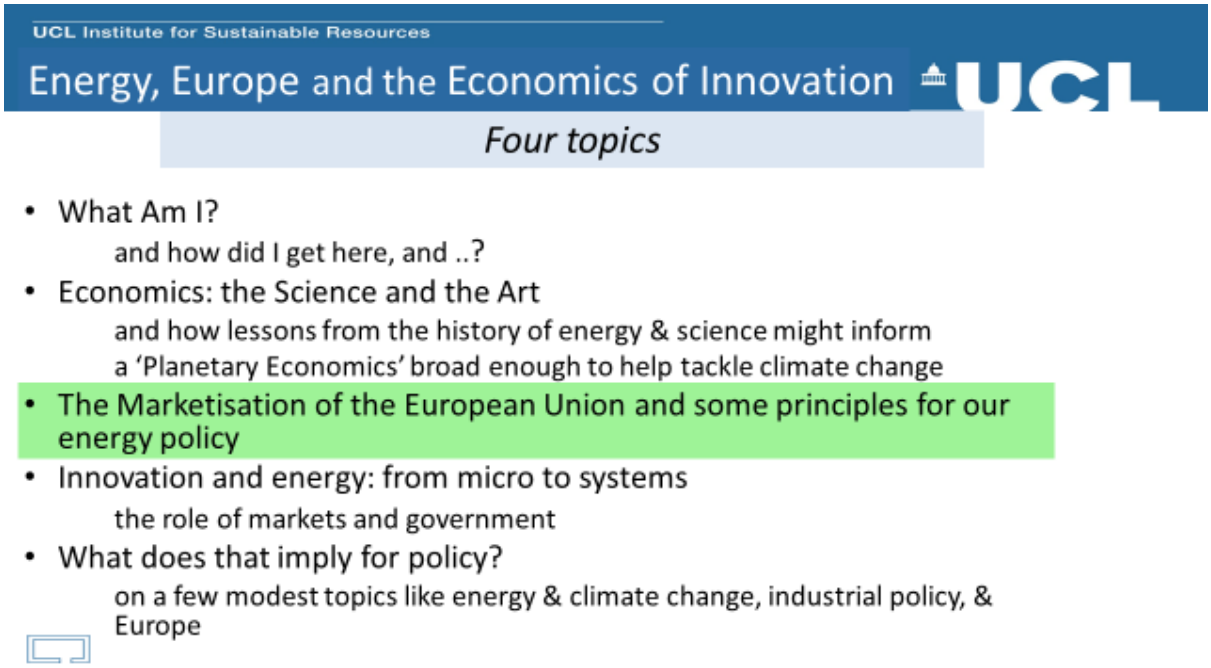
Which is just as well. For as Eric Beinhocker, in his brilliant book *The Origins of Wealth* points out, an equilibrium – which is the foundational concept of mathematical, neoclassical microeconomics – is actually a dead state. It involves no energy. **With energy – physical, or creative energy - things change. An equilibrium, without it, doesn't.**

Economics has famously been called the Dismal science. And if neoclassical theory is really the science of being optimally dead then I could well understand that label.

Fortunately, I think economics is about things that are altogether more exciting – and more optimistic.

In which also – lest anyone get the wrong impression – it is also about more sophisticated understanding of the role of markets and government, as indicated in the next slide which gives a very different, and in my view even more powerful, indication of why markets and competition are

important – but also, why they and their consequences need to be carefully managed. Which is what we haven't done very well over the past few decades – and at a huge cost to the individuals left behind, and now to our political foundations.



What on earth has any of this to do with Europe? I will argue, a lot.

Many of you will know that the EU started as a series of communities around industrial development and infrastructure – particularly in energy, with the Iron & Steel Community, and Euroatom.

It was only in the 1980s that the EU – at least in the eyes of the British – became most fundamentally identified with the "Single Market". The European effort that followed, in other words, became increasingly a second domain project, and increasingly defined by the four freedoms of movement in the Single Market.

Of the four freedoms, goods were relatively easy, given EU jurisdiction to negotiate product standards. Services have been harder, requiring much deeper regulatory alignment. People – freedom of movement - well we all know what has flowed politically from that. Capital – I'll touch on one aspect of that later. Energy has never really known if it is a good or a service or neither, though we have largely successfully established the Internal Energy Market.

Now to be clear - huge economic benefits have flowed from all this, but they are aggregate benefits, and often not so visible. So I want to make a provocative suggestion. I've indicated that markets are an evolutionary force, both creative, and destructive. And since first domain behavioural sciences emphasise that humans are both myopic and highly risk- and loss-averse, it is the losses that weigh heavily: for example, and most obviously, we may like cheap goods, but as workers we really do not like being undercut by the cheaper workers that produce them.

It is policies in the other domains – social policy, and innovation and infrastructure that help to generate growth – that are more obviously politically appealing. In other words, **the socially double-edged domain of competitive markets has been largely promoted as a European project, whilst the tools for dealing with the social consequences remained largely with Member States** – as do many of the strategic elements, notwithstanding the EU's structural funds, which largely moved east after expansion (and even this seems not to have bought the hoped-for popularity).

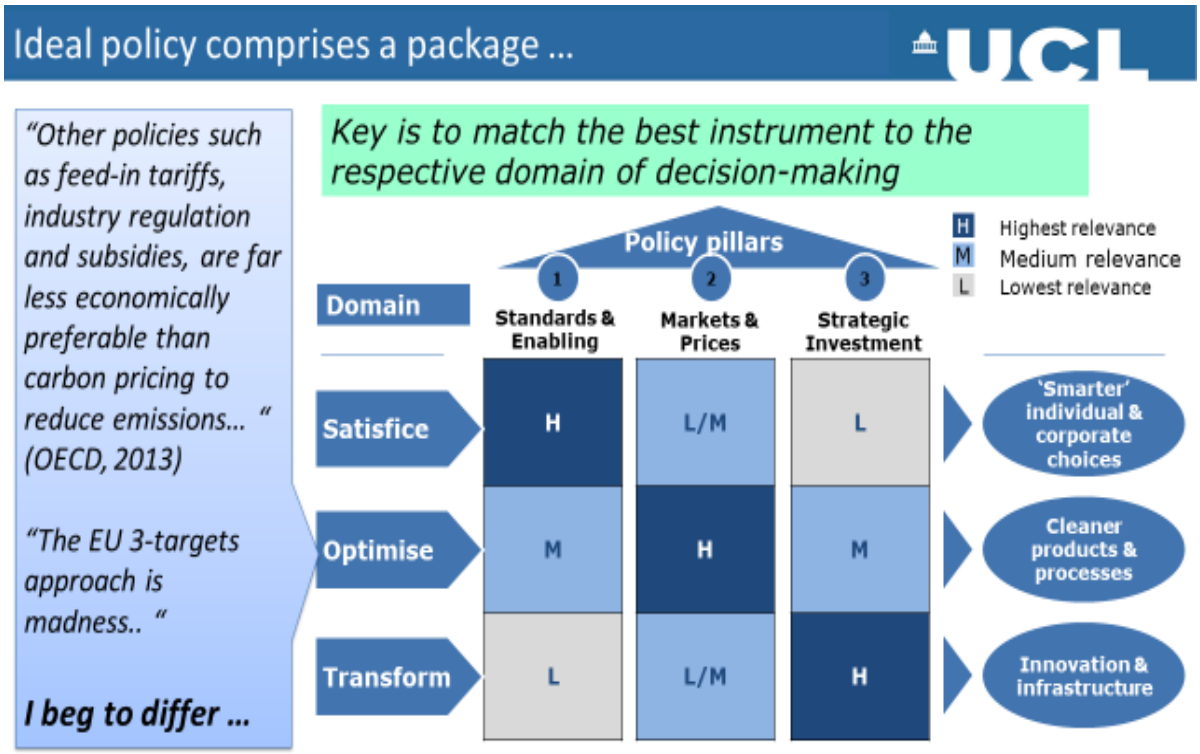
So my suggestion is that the European crisis has much to do with the intellectual mistake of equating good economics with second domain theories, with markets consequently writ as dominant and wide as possible as a key EU objective – leaving the EU in the firing line of the unpopular distributional consequences, whilst Member States gained credit where they supported the essential complementary measures. **So I fear that the drive to turn the EU into a largely second domain, market-led *raison d'etre* has had a lot to do with its growing unpopularity, which is not just a British phenomenon.** I don't know what the answer is: but it is a thesis worth considering.

Now to focus in on energy, in which after a lot of political struggle over at least 20 years we have successfully established the Internal Energy Market. Admittedly this has been nested in the curious and incompatible principles of driving to a fully open common market based on short-run marginal costs, whilst achieving decarbonisation and renewable energy goals, and still officially insisting that that countries still have sovereignty over their domestic energy supplies. State Aid rules intended to ensure the level playing field sit uneasily between these obviously inconsistent principles.

I want to explain why, in trying to navigate this almost impossible context, European policy – illustrated in particular through energy - has actually not been nearly as dumb as it is often portrayed. This flows directly from the three domains logic. As suggested in the Chart, given that there are different domains of economic behaviour, it follows that multiple policy levers make sense.

Good policy does not flow from pretending that the entire economy operates according to second domain principles, and that therefore all we need to do is create competition and ensure cost-reflective pricing (including of externalities). We need an approach which recognises different pillars of policy more appropriate to influencing the different domains. Let me briefly inject a couple of real-world examples.

Structural inefficiencies, information asymmetries, legitimate distributional concerns, and many other features of first domain economics give a clear and logical role to setting standards – whether on product safety, service standards or a host of other areas. In the energy arena, targets and standards for energy efficiency can make eminent sense – and since many energy-consuming technologies are traded, it makes sense to do so at European level. The empirical evidence, incidentally is unambiguous that energy efficiency standards save both money and emissions.



The UK coalition government that came in 2010 thought it had a better approach. It viewed the major problem of energy efficiency as being that home owners didn't have enough finance or the long-term security (they might move) required to invest in improving home energy efficiency. So the government introduced the 'Green Deal' loans system, based on viewing homeowners as rationally engaged optimising agents who just needed some help to overcome specific 'barriers' – mainly

finance. The Green Deal was possibly the biggest energy policy embarrassment of the coalition – a vast bureaucracy created, which in its original incarnation attracted only a handful of takers – and half of those were rumoured to be the civil servants who designed it.

The reality is that home energy efficiency is predominantly a first domain problem, and hence **it cannot be effectively delivered by second pillar instruments. Had that been simply explained to ministers (and the civil servants) it would have saved a vast amount of wasted time, effort** and missed opportunities to improve the UK's dismal housing energy efficiency.

At the other extreme, matching to the third domain, evolutionary sciences emphasise that new technologies and systems do not fall like manna from heaven. They often involve huge investment and time to build up the industries, infrastructures, institutions and supply chains on which they depend. They require strategic investment, usually led by, if not directly funded, by governments, and often influenced by regulatory structures - on which again, more later.

Again, targets can help. Indeed in my time at Ofgem, I was somewhat bemused when asked to lead submission by the Council of European Energy Regulators into the EU's 2030 package. As regulators, all were (rightly) in favour of markets, and most were very sceptical of renewable targets, subscribing to the common economic principle that one should set an overall emissions target and price and let the market do the work. The European Renewables Directive – a somewhat unusual EU foray into third pillar policymaking, driven by the decarbonisation agenda - was not popular. But in practice, all easily agreed to the proposition that we needed greater clarity about what decarbonisation might imply for the electricity sector - particularly regarding the likely contribution of intermittent renewables - so that appropriate regulatory structures could be developed. Even for regulators, the abstract ideal soon dissolved when faced with reality.

I have added in this slide a generic assertion by the OECD in 2013 that the soup of energy policy instruments it observed in countries was clearly inferior to just setting an emission target and carbon price: that found a more specific expression in the ritual denunciation by *most* economists of the EU's "three-targets" (efficiency, emissions, and renewables) approach.

I disagree. Of course in theory, a carbon price might increase incentives for low carbon innovation, if industries believe it will endure and increase. A high enough carbon price could also shock consumers into noticing how much money they are wasting in their homes and trying to do something about it. But it would be very inefficient and, most likely, people would vote the government out long before the effort achieved anything.

No government which tries to engineer an energy revolution by imposing an OPEC-style price shock in the name of climate change would last long, and nor should it. It would be a sledgehammer to crack a dozen different nuts – including, in the EU's recent history, the need to help the new Member States of eastern Europe radically improve energy efficiency, *before* they could fairly accommodate the additional impact on their already extortionate energy bills, which I noted earlier.

But perhaps the most important of all the 'nuts' to be cracked concerns innovation in the technologies and systems required to effectively exploit our major clean energy resources.

UCL Institute for Sustainable Resources

Energy, Europe and the Economics of Innovation

UCL

Four topics

- What Am I?
  - and how did I get here?
- Economics: the Science and the Art
  - and how lessons from the history of energy & science might inform a 'Planetary Economics' broad enough to help tackle climate change
- Innovation and energy: from micro to systems
  - the role of markets and government
- What does that imply for policy?
  - on a few modest topics like energy & climate change, industrial policy, & Europe

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Q: What two things do the following energy technologies have in common?

- Offshore oil extraction
- Shale gas
- Combined cycle gas turbines
- Solar PV
- Wind energy
- High efficiency lighting (LED lights)

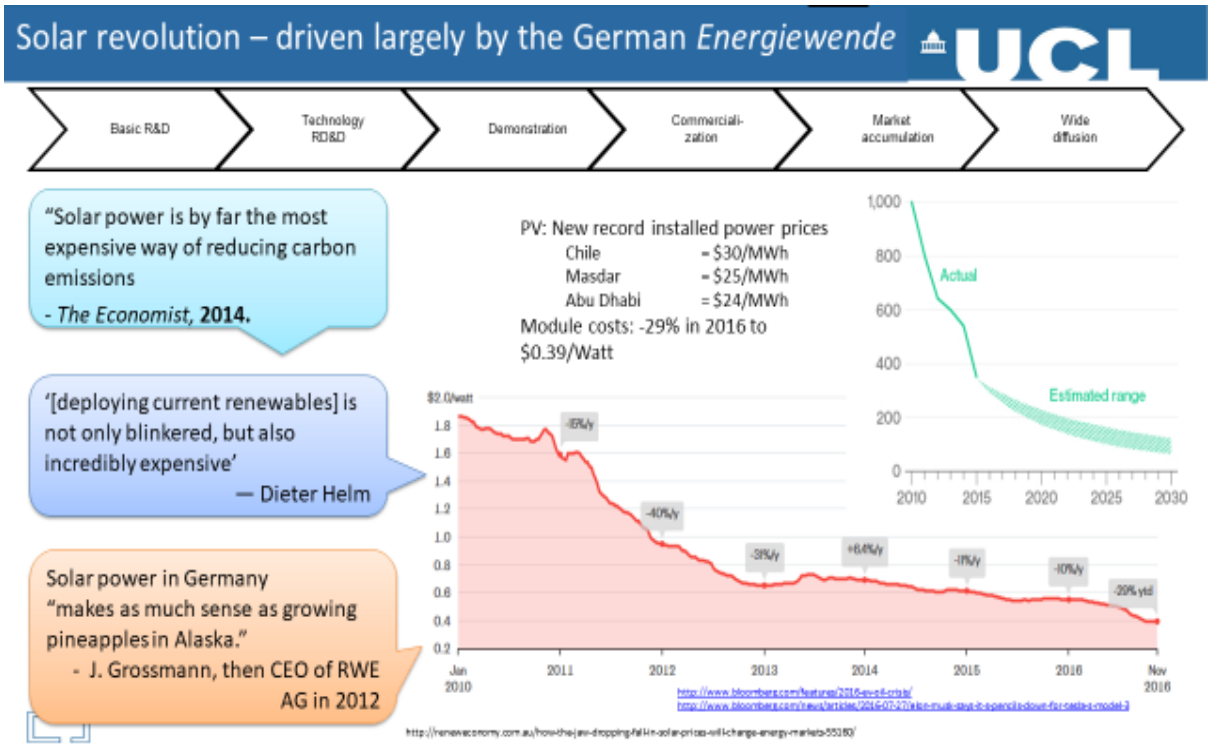
[1] They all turned out to be ***much cheaper*** than anyone expected

[2] They all involved government action at scale over many years

- *On both technology/resource development, and demand/price*

So let us move to an audience quiz. What do these key half-dozen energy technologies (and in fact, many more) have in common? The answer is, what they tell us about energy innovation. They all have turned out to be *much cheaper* than most people expected. And that process of radical innovation *involved governments* at most steps along the way, generally for decades.

The rationale for these innovation efforts varied. For offshore oil – and to a degree, shale gas - it was energy security. In both these cases, incidentally, the expenditures were vast but the vagaries of oil geopolitics created oil prices far above the marginal cost of existing sources – so in practice western consumers footed much of the development bill, albeit indirectly, thanks to the actions of foreign governments. For gas turbines and PV it was partly spin-offs, respectively from military and IT promotion, aided by major intervention in energy markets. For wind and a host of demand-side technologies the driver was indeed more environmental, but the underlying economic message about innovation remains similar. Its expensive, complex, and it takes time.



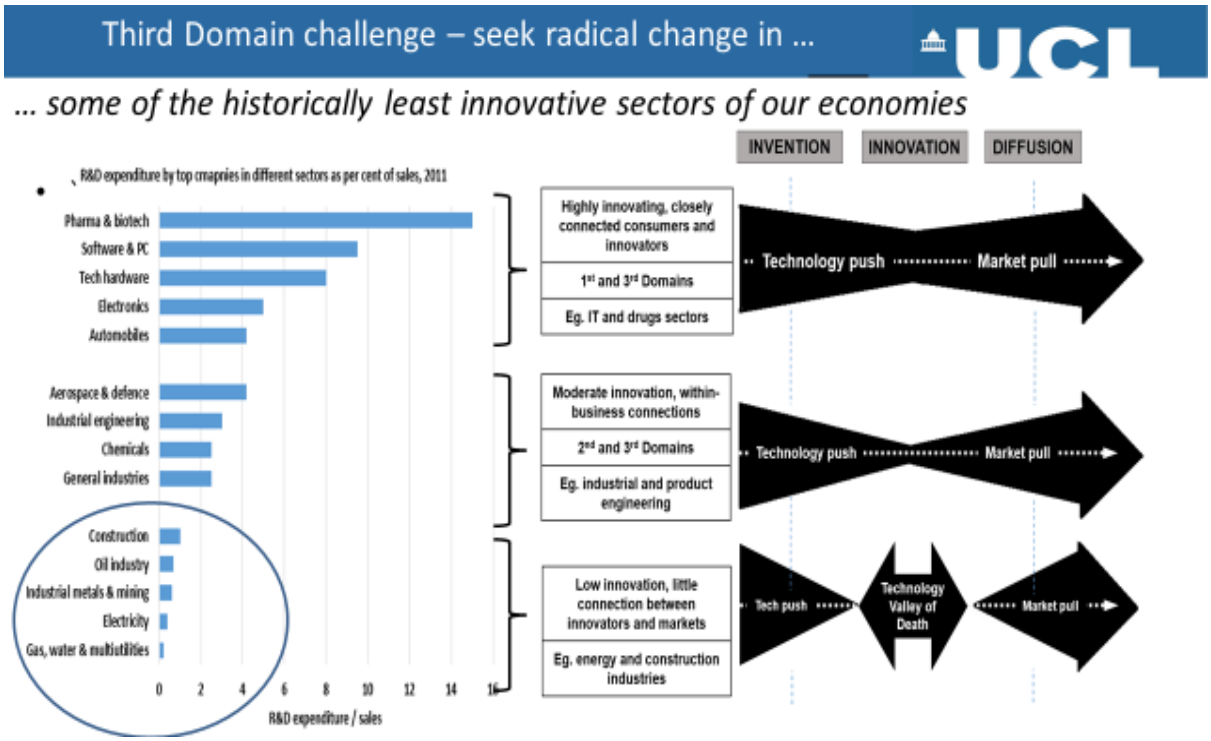
As suggested by the arrow chain across the top of this chart, all technologies need to evolve through multiple stages. I am liberally raiding here insights from the Carbon Trust's analysis of innovation-to-market programmes, which have to navigate the realities of fostering low carbon innovation. We learnt just how big and complex are the middle stages of market demonstration, commercialisation, and accumulation, which standard economic theory more or less ignores. The first two span what analysts in the field tend to call the 'technology valley of death' as technologies have to move from mainly public to mainly private funding. Market accumulation, and wider diffusion, is what fuels market learning, supply chain development and economies of scale.

Let me illustrate this by the stark example of solar PV. It really is only a few years since most economists consider PV a crazy way to generate energy; The Economist again (sorry, but its energy coverage makes it such an easy target) in 2014 cited research that used dubious methods and outdated data to reiterate the view that PV was the most expensive way to reduce emissions, and therefore dumb. Our own Dieter Helm was scathing about renewables deployment, for PV almost as much as wind. The CEO of RWE likened the German *Energiewende's* deployment of solar as making as much sense as growing pineapples in Alaska (I might note in parentheses that RWE's financial performance in the energy transition has been disastrous).

Throughout all these pronunciations, the cost of solar PV was plummeting. It is now amongst the cheapest energy source, particularly for developing countries. That has transformed the prospects for both energy access and low carbon development globally. It has also, incidentally, rendered almost irrelevant most of the economic modelling of the past 20 years that has tried to pronounce on the costs of cutting global emissions: solar, batteries, and wind are mostly already off the low end of the cost scale that most of these models assumed.

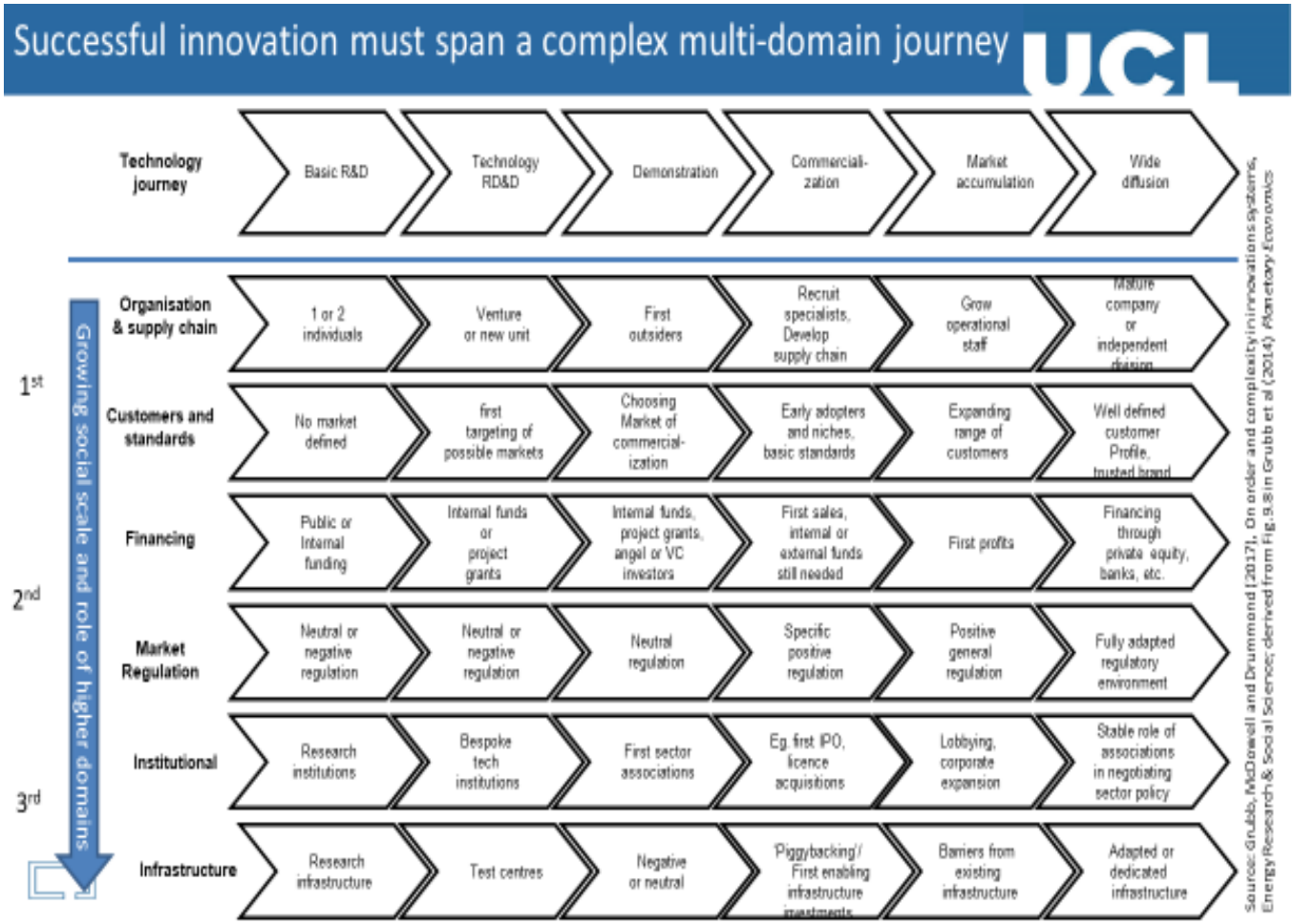
I'll return to Germany's role after first looking at the general question of why should governments get so involved in energy technologies? There are at least four broad answers to this question. One, as Mariana Mazzucato will rightly point out, is that in fact governments are involved in *most* major innovations.

But the case is even stronger in energy, in part because as the data in next chart suggests, sectors differ hugely in their R&D intensity – the amount that the private sector spends on R&D as a percentage of turnover. In pharmaceuticals and IT, its over 10%. In the main industrial sectors that have to decarbonise – the energy, materials and construction industries – the figure is under 1%. Of course the data is more complex, but the point remains: expecting these sectors to become radically innovative just because we change some relative prices is missing the point. And, as I noted when I first introduced the concept of 'third domain' economics as a distinct field, the oil shocks did not drive decarbonisation – they enriched the oil companies who, guess what, spent the money on finding new and innovative ways to get at more difficult resources, furthering our ability to mess up the atmospheric more cheaply.



So the third reason for government involvement across the innovation chain is that given a public problem – like climate change - we care about its *direction.* We want innovation that will help to solve the problem, not to make it worse. Hence Mariana's term, *Mission-oriented* innovation policies.

The fourth reason is however perhaps the most subtle, and feeds into all three others. It concerns the huge complexity of the innovation process, particularly for sectors which involve long-term investment for undifferentiated products, and which depend upon networks and other infrastructure. As I try to depict in the next Figure, in such sectors effectively spanning the innovation chain involves multiple journeys, way beyond the technological, and spanning all three domains. We need to make all these journeys together for an innovation to emerge effectively at scale in markets.



Amidst this complex picture, I would also draw attention to one particular aspect – which picks up my earlier brief remark about finance and capital markets. Innovation has always occurred, even in these heavy industries, and often with private money – think of the development of railways, for example. But when one looks closely, one finds that the finance was long-term, often raised by the original visionary, and highly committed to the venture. It was raised in a world very different from today's financial markets, where money can move in an instant and quarterly returns so often dominate that decision.

In terms of the "three pillars of policy" I depicted earlier, in other words, it used to be case that competition could not only promote innovative ideas and entrepreneurs, but deliver long-term finance to support their vision, so that markets could substantially finance third-pillar strategic innovation. The financialisation of the capital markets has largely broken this link between the second and third pillars, creating the fourth reason why governments have to be deeply involved in innovation which is pursued for the longer term, and partly public, benefits.

So to return to the *Energiewende.* The massive German investment in particular enabled a whole new industry to develop, funded through the German *Landesbank* which famously weathered the financial crisis better than most. It supported the development of supply chains stretching back to large-scale, low-cost Chinese manufacturing as well as all the stages in between, right through to the skills and standards of local implementation and the enthusiasm of households and farmers to be able to generate their own, clean energy.

Germany's *Energiewende* was not growing pineapples in Alaska. It was watering a strategically crucial technology in the fertile soils of a country that combined the industrial capacity, financial structures, credibility and political stability to drive an industrial revolution of the first order – one which has transformed the prospects for both enhanced energy access and low carbon development globally.

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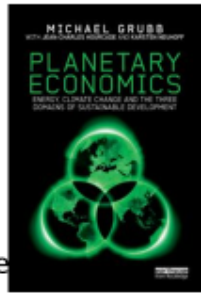
Four topics



- What Am I?
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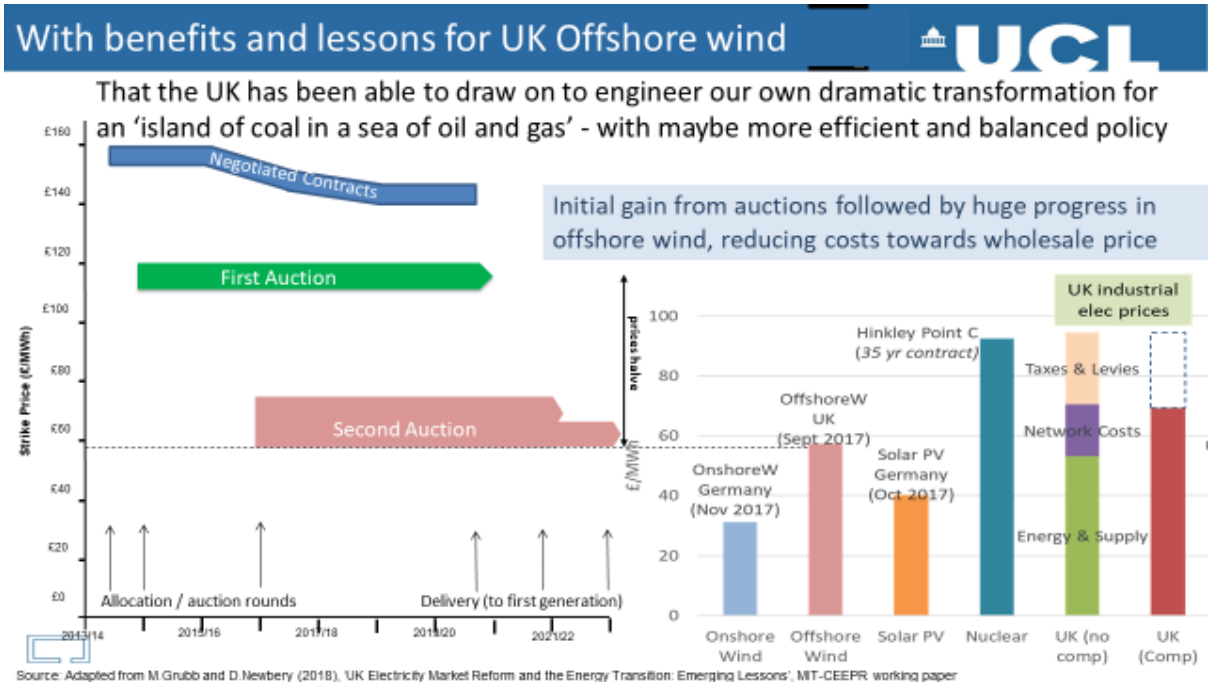
Some implications for UK and European policy

So where does all this leave the UK, and wider European policy?

Fortunately, the coalition government – offsetting its shambles of the *Green Deal* energy efficiency programme – did learn from the continental efforts on renewables and, indeed, moved to do one better. This is not the time or place to go into detail of the UK's Electricity Market Reform, but the UK adopted the principle of long-term, government-backed contracts for renewables, and then brought to bear on this the benefits of competition, through auctions.

The next chart shows the astonishing outcomes for offshore wind. Many people (including myself) had assumed this would remain amongst the most expensive renewables, the pursuit of which was only justified by the enormity of the resource and the trenchant opposition to the cheaper onshore wind. Just five years ago, the government awarded "kick-start" contracts for the industry at £140/MWh and there was scepticism when the industry said it could get costs down to £100/MWh by 2020 – which is about what UK businesses currently pay for their electricity. Yet with sustained commitment and scale – including other European auctions over the intervening period - the price for two major offshore windfarms emerged at £57.50 per megawatt-hour (MWh), half that in the first auction, less than 3 years earlier.



For a given average energy output, that puts offshore wind costs at well under half that contracted for the Hinckley Point nuclear power station (given its 35-year contract), and close to that of natural gas power generation. It was, as one senior civil servant put it, "a total shock – of the best kind." How that was achieved in detail is a long tale which includes, incidentally, the Carbon Trust's efforts to help coordinate the offshore industrial innovation chain.

A massive new energy resource - variously estimated at several times total UK electricity demand – has thereby been opened up, with a potential economic scale which matches that of North Sea gas. Both industries required capital investment of £5-10bn/yr; the investment associated with the recent renewable auctions has been cited at £17.5bn. The potential value of the energy produced is comparable.

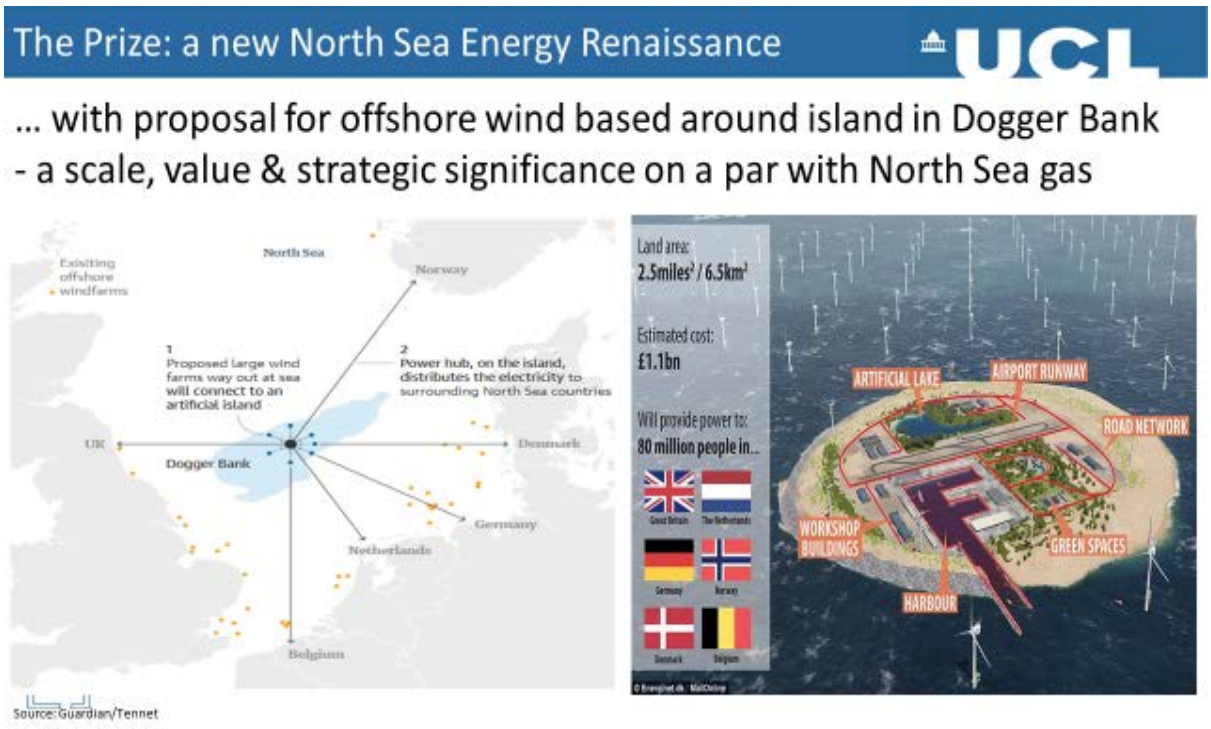
Before we can proclaim a North Sea renaissance, with a seamless transition for rising wind as the gas declines, some thorny issues certainly need tackling. My concluding point is that this should transform our strategic electricity policy – and if possible, at least a sectoral approach to Brexit.

At the general level, note one almost unique feature of electricity. In most sectors, there is at least an argument to say that economic losses incurred from leaving the Single European Market could be partially offset by trade with others. But we cannot trade electricity, or pipeline gas, outside the Internal Energy Market (noting of course that Norway remains within it). Our interconnecting line currently under construction to Norway will be the longest subsea cable in the world. We are not going to build one across the Atlantic, or trade electricity directly with China. Leaving the customs union is totally irrelevant – we have nothing conceivably to gain. The European continent is our only trading partner for electricity or pipeline gas.

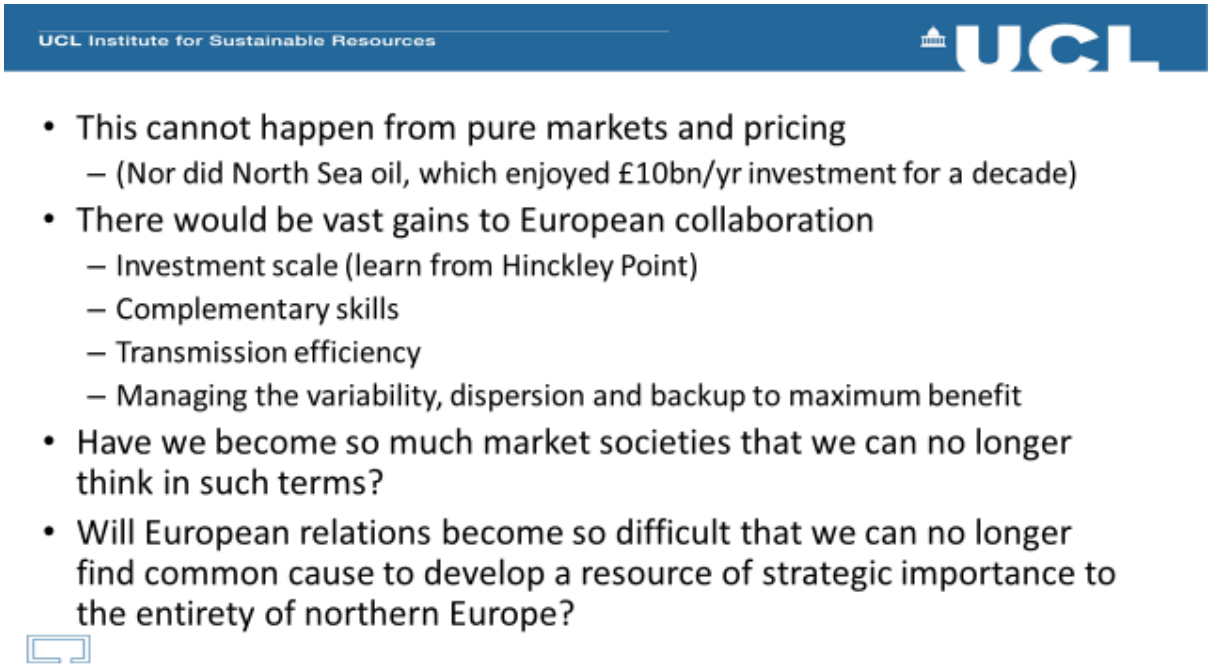
And on our doorstep, I have pointed to the prize of a North Sea energy renaissance based on renewables, of huge economic and environmental value. The vision to deliver this is, however, complex. Flexible interconnection with other countries, to manage the variability and tap into Scandinavian hydro, will be vital.

The most attractive resource of all is likely to be the wind (and possibly wave or tidal) energies that flow across the Dogger Bank, in the middle of the southern North Sea. The German-Dutch transmission owner Tennet has developed a proposal for an artificial island there which would form a base for the industry – wind turbine assembly and maintenance, and electrical interconnections. About half the Dogger Bank is in UK territorial waters; the other half, divided between several other EU countries. Regional coordination, obviously, would be hugely beneficial.

Of course that should still be possible after Brexit in principle, but leaving the Internal Energy Market would complicate affairs and reduce UK leverage. The best we could aim for would be some form of special regional framework of energy governance – accepting that all of the other parties involved would inevitably look to the European Court of Justice as the obvious legal foundation. We are not making it easy for our European partners who would be crucial to the endeavour.



To bring this back to the wider economic themes of my lecture: it should be obvious that this kind of development cannot be driven by a carbon price and competitive markets alone. It requires strategic investment – both financial, and political - on a large scale. As indeed did development of the North Sea oil and gas industries – not only upstream, but also to convert the gas boilers in every house in the country.



In this slide I summarise the case and pose the two fundamental questions. A social scientist once asked, when did we make the unbid transition from using market economics to being market societies? How has this affected the way we think? Are we still capable of thinking in these strategic terms, or do we shrug our shoulders and say that only the Chinese can do things on that scale? And do we risk souring political relations, and complicating legal relationships, so much that we deprive ourselves of the physical benefits that now lie within reach?

In thinking through the more general implications of the *Three Domains* logic, we also need to review some other fundamentals. Not only to they imply three distinct pillars to policy; it means considering the connections between these pillars. We are not looking at modest changes to clean up last century's energy system: we are in the midst of a revolution, at all levels of energy.

I don't have time to go into details so let me just poke at the following. There is a cast-iron case for carbon pricing – nothing I have said contradicts that. Yet we are worried about energy bills, which are economically regressive – high prices hurt poor people more.

Energy efficiency programmes are pursued partly for the social benefits, which would normally be funded from taxation, but in fact the cost has mostly been levied on energy bills. We have engineered our policies so that strategic energy investment, such as has helped to drive the renewables revolution and is implicit in major development of the North Sea resource, is also paid from energy bills. Yet at the same time, the Treasury is collecting £1-2bn/yr revenues from carbon prices.

We know the Treasury hates "hypothecation", or earmarking of tax revenues, and why – but Is it not time we had an honest discussion about using some of those carbon tax revenues to help fund energy efficiency and strategic investments? I'd suggest the strategic aim should be a three-pillar package which drives the transformation whilst keeping energy bills within the observed range of constancy I observed at the beginning of this talk – 6-10% of GDP. That is eminently achievable, but only if we integrate the three pillars better, and consider such options.

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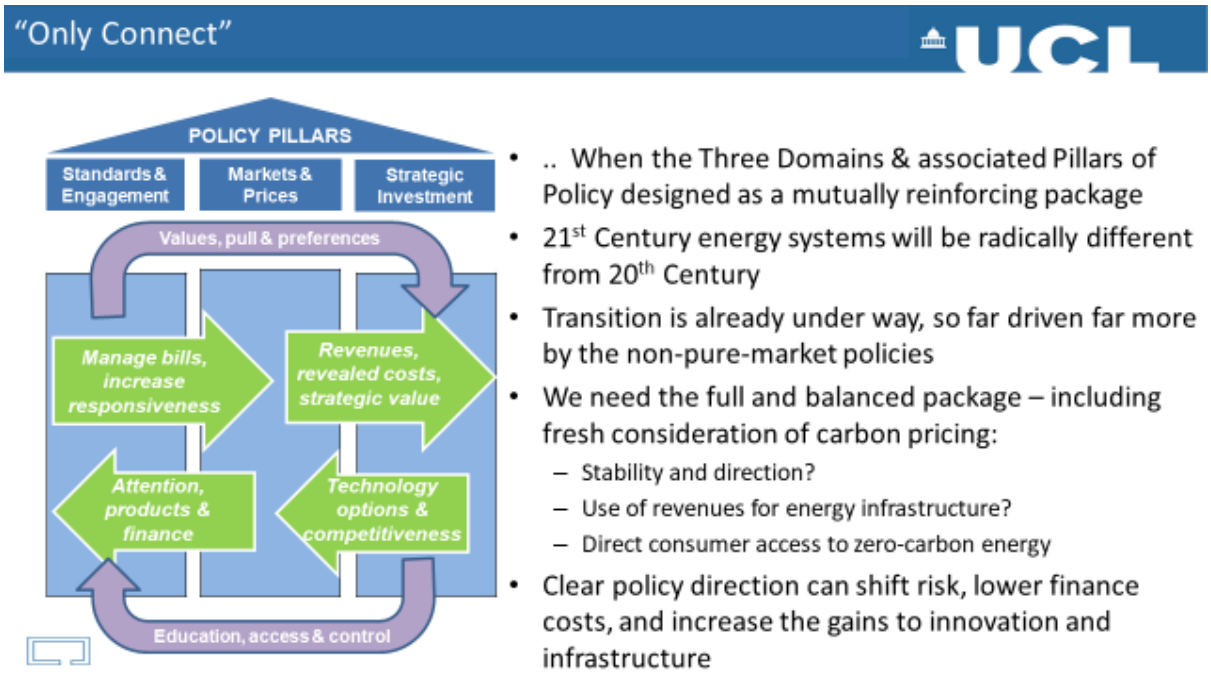


So, I can finally draw to the broader conclusions, moving from policy back up to the theoretical foundations, on which I offer two final points from this broad sweep.

The first: I have framed the Three Domains as a way of categorising different economic processes – discuss. They are actually more than that. The first domain inevitable draws on insights about human and organisational behaviour that were the study of psychology and management sciences long before behavioural economics became fashionable. The third domain helps us to avoid being trapped in our thinking by the current 'frontier', but as illustrated by my North Sea example, in practice one needs recourse to physics and engineering to understand how much that 'frontier' could change and where strategic investment could most usefully focus.

Ultimately, that it is a choice that the economics profession has to make. It can confine itself to the comfortable theories and analytic solutions of neoclassical economics and modelling. Or it can fully embrace the other domains; but if it is to so, it must acknowledge that means opening up to the idea of *interdisciplinary economics* – a broad church, with honest appraisal of the boundaries, relevant scales, and disciplinary intersections of its different theories.

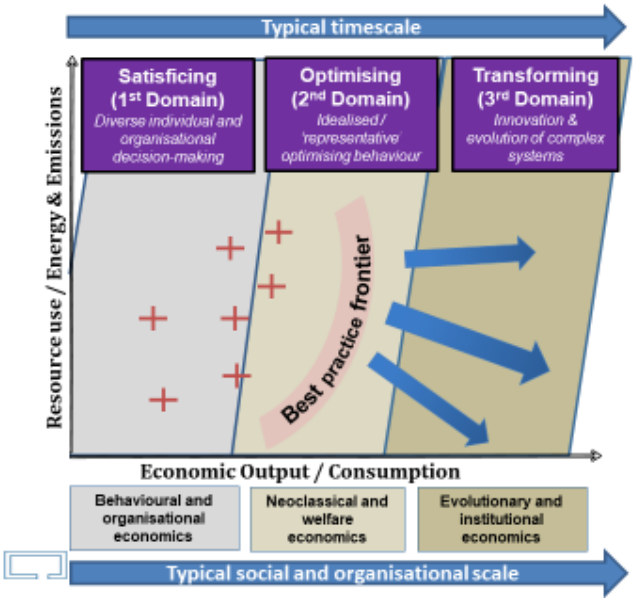
Conclusions, Theory

Interdisciplinary Economics

- The answer to Laurence Tubiana's question is that economics helps when it respects the boundaries of a given economic theory, but can hinder when it tramples across them
  - *The academic community needs to decide what it sees as the legitimate scope of economics*
- Fully understanding the Three Domains inevitably must draw also on other disciplines
  - ***Social and psychological** dimensions of risk perceptions and First Domain behaviours*
  - ***Engineering and physical determinants of** Third Domain innovations and infrastructure*
  - *The **regulatory and institutional** dimensions of both*

And finally: why energy, and climate change? The framework I have mapped out, in principle, is a much more general one. Indeed, once when I gave a conference talk alongside a financial economist, he remarked to me afterwards that he found it fascinating because he could see how it could be equally applied in his field. There is the vast conventional terrain of analysis and modeling based on the assumption that we are financially rational beings. There is the emerging field of behavioural finance. And – as a financial historian – he was well aware that financial systems themselves have always evolved, and indeed, that revolutions in financial systems have sometimes accompanied technological and economic revolutions.

Pulling it together: Broadening economic horizons



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

Time for full integration …

Yet, I think there is a straightforward reason why such a broad framework is unavoidable in energy and climate change.

At one extreme, we are dealing with problems that are driven by the individual choices of seven billion decision-makers, with respect to a commodity – energy – that most of them scarcely ever consciously think about. The habits, routines, and constraints through which those unconscious decisions get taken are intrinsic to understanding the problem, and solutions.

Yet at the opposite end, climate change forces us to think about the deliberate transformation of what have been some of the most complex, interlinked and infrastructure-dependent techno-economic systems that humanity has ever developed, over timescales of decades to even a century or more.

Just as with physics, therefore, we have arrived at a point which demands different economic theories for different scales, grounded in the realities we observe. And that, I would contend, is why we need *Planetary Economics.*