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Article

Policy complementarity and the paradox of carbon pricing

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Abstract

We present an economics framework appropriate to the exceptionally broad scope of the climate change problem. This considers that economic and social processes, particularly those involved in purposive transitions of energy technologies and systems, involve the interplay between three distinct domains of decision-making and associated actors. The first concerns small-scale and often short-term decision-making, much of which reflects extensive 'satisficing' and habituation as identified in behavioural economics. Calculated economic optimization decisions, especially of companies in the energy and energy-intensive industries, then best reflect the core assumptions of neoclassical and welfare economics, including discrete market failures. Third, at the largest scale are strategic judgements made by big actors (e.g. governments, large multinational companies) relevant to transformation of complex systems over long periods—particularly concerning innovation and structural changes, for which lessons from theories of evolutionary and institutional economics are most relevant.

Economically, these can be logically mapped in relation to the technology (or more accurately, 'best practice') frontier. Each has corresponding policy implications: most directly, respectively in terms of (i) standards and engagement to establish norms; (ii) competitive markets with the critical role of prices; and (iii) strategic investment in innovation and infrastructure. Each faces challenges of implementation and government failure, as observed, for example, with wholly inadequate carbon pricing to date, naïve and ineffective approaches to enhancing energy efficiency, or misdirected support to R&D. Based on the domain distinctions, we argue that the corresponding pillars of policy are naturally complementary, and can be mutually supportive: strong standards and norms on energy efficiency, for example, would enhance the political space for carbon pricing by reducing its direct consumer impacts, while carbon pricing has multiple positive two-way interactions with enhanced low-carbon innovation.

From this we also posit a 'carbon pricing paradox': that adequate carbon prices, the central recommendation of most economists, are in most jurisdictions only feasible (or even optimal) if equal analytic and policy attention is devoted to the other pillars, and the wider context of macroeconomic and fiscal policies. Only these other aspects can reduce the absolute cost impact of carbon pricing (potentially turning into a gain) and offer consumers and businesses better lower-carbon alternatives, which are critical to establishing climate-compatible pricing structures across our economies.

Keywords: energy policy, policy mixes, policy packages, energy efficiency, strategic investment, low carbon innovation

JEL classification: A12, B41, B5, D04, D8, D91, L5, L98, 013, 014, 03, Q4, Q54

I. Introduction

The shift in energy and climate discourse towards net zero emissions by mid-century has further widened the gap between ambition and actions. This reflects the genuine complexity of delivering deep emission reductions, with associated changes in technologies and structures across major economic sectors. This necessarily involves citizens as consumers, workers, and voters, and governments and others making collective, strategic decisions.

More than three decades on from the first economic contributions to climate change policy debates, we are far from the 'classical' framework long favoured by many economists, in which carbon pricing is assumed as the primary and best instrument to address climate change and deliver an optimal level of global greenhouse emissions. The present reality is a mix of targets, with varied and often hybrid pricing systems, and innumerable other measures. Increasingly indeed—most obviously, with the introduction of the huge US subsidy programme of the 'Inflation Reduction Act'—there seems a risk of policy-makers adopting command and control approaches supported by subsidies and abandoning the pursuit of market-based approaches to tackling climate change.

The difficulties of pursuing a universal carbon price are increasingly recognized, alongside the need for other measures. Such 'other measures' are however typically understood and framed in economics in terms of fixing specific market failures, such as R&D spillovers and information barriers (Nordhaus, 2013; Baranzini *et al*., 2017; Stern and Stiglitz, 2017), or as 'second best' compared to an optimal carbon price (e.g. Klenert *et al*., 2018).

Other fields of research complement the traditional economics approach with detailed empirical analysis of the complex interacting processes involved. Increasingly, these draw on different theoretical foundations and use a diverse set of analytical approaches that offer valuable insights into how carbon is deeply embedded in our behaviour, cultures, industries, infrastructure, and urban systems. For example, behavioural economics, organizational theory, and psychology study patterns of behaviour, the role of norms/cognitive routines in shaping consumption choices, and the web of obstacles that impede economically efficient use of energy. Evolutionary economics and innovation systems literatures study transformations in technological systems, including the interactions between infrastructure, institutions, networks, and path dependencies in energy transitions.

It is difficult for policy-makers to effectively navigate these disparate fields of study that seem to lead to different policy implications. The desire for simple messages, and ideological disputes, risk fostering a simplistic 'either/or' approach to policy recommendations.

Instead, this paper presents a framework that groups these varied approaches into three 'domains' of decision-making, as first set out in Grubb *et al*. (2014), while reflecting the subsequent discussions of the concept and experiences of climate policy design. This theoretical framework characterizes three distinct yet complementary modes of decision-making, to identify complementarities in apparently conflicting approaches to both the theory and practice of emissions mitigation:

(i) satisficing and behavioural theories, along with 'missing contracts and split incentives', which underpin many policy recommendations, for example on energy efficiency;
(ii) neoclassical and welfare theories which emphasize the role of markets and externality pricing, and of public decisions based on optimal equilibrium analysis;
(iii) evolutionary, complex systems and transition theories, which highlight the role of innovation and structural change, strategic investment, and market shaping.

This framework aims to preserve economic rationality in policy discourse, but shows why the 'classical' approach would benefit from acknowledging its interactions with the other domains of decision-making. Competitive markets and carbon pricing retain a central role, but we conclude that other policies rest not only on ideas of 'fixing market failures', or are 'second best', but can be justified in their own rights, because they address different challenges and associated decision-processes, all of which are important to effective transitions.

We also offer a resulting paradox: that carbon pricing can only succeed through the recognition of its own theoretical boundaries, and the resulting need for complementary intellectual frameworks and policies, which can in turn support the quest for effective market responses. In drawing conclusions, we also indicate how this broadened framework is, in fact, entirely consistent with some of the foundational economic texts.

Against this background, section II starts by explaining our use of the term 'domains', and why we delineate three, with reference to the classical concept of the technology frontier. Section III then shows how this logically maps on three different categories of policies ('pillars'), drawing out their intrinsic complementarity. In section IV we discuss potential challenges, in particular relating to government as well as market failure. Section V discusses the complementarities between the policy pillars and the dynamics of transition. Section VI then draws conclusions.

II. Three domains of decision-making

(i) A framework for complementary economic perspectives

We differentiate three ‘domains’ of decision-making, tracing each back to its theoretical foundations in academia. By ‘domains’ we mean specifically, *modes of decision-making* by various actors, and associated processes and constraints, often associated with decisions relating to different social scales (from individual to government) and temporal (from short-term to multi-decadal) horizons.

The analytic rigor and mathematical consistency of welfare economics, particularly combined with the rising force of Hayekian ideas[1] from the 1970s, has accorded markets and their role in efficient resource allocation a dominant role in modern economic thought and policy-making, particularly in Western countries. Other schools of economic thought, such as evolutionary, Schumpeterian, and Keynesian economics, as well as broader sustainability transitions literature, conceive the role of markets in quite different terms. Along with Schumpeter’s ‘creative destruction’, evolutionary economics emphasizes the role of markets as selecting and funding promising innovations and harnessing Keynes’ ‘animal spirits’—a process of evolutionary selection, with positive feedbacks then creating multiple path-dependences.

There has traditionally been little integration across different schools of thought. Aside from theoretical interest, this paper is motivated by the fact that climate change responses must span an arguably unique breadth. The ultimate risks are long term and global, so the strategic objective of policy concerns the *direction of development* of energy and related technologies and systems. Yet, the problem ultimately also involves the decisions of eight billion energy consumers, consuming a few main products (energy, travel, food), with choices constrained by complex infrastructures and supply chains.

Consequently, even aside from the global public-good nature of climate change, the necessary changes may require going beyond a standard prescription of competition with internalizing an environmental ‘externality’. In economic terms, this simple prescription casts it as a ‘comparative static’ problem, which is, moreover, often analysed with tools appropriate to marginal perturbation from an equilibrium state. Samuelson’s classic economic text observed that this takes numerous elements as exogenous ‘data for that system... which economists have traditionally chosen not to consider as within their province.... [including] tastes, technology, the governmental and institutional framework... logically there is nothing fundamental about [these] traditional boundaries of economic science’ (Samuelson, 1983, pp. 8–9).

Consequently, the central aim of this paper, and of the book from which the arguments are drawn,[2] is to present an intellectual framework that helps to organize wider economic fields, including developments in behavioural and innovation sciences. Specifically we aim to clarify the core ‘problem spaces’ for which each is most appropriate. This non-hierarchical framework accords a clear role for neoclassical theory while leaving space for parallel theories that better describe processes which operate primarily outside its underlying assumptions.

The ‘best-practice frontier’ in Figure 1(a) and (b) represents the ‘menu’ of best available ways to produce a given measure of welfare (x axis: e.g. economic output) associated with a given level of resource input (y axis: e.g. fossil fuel consumption and associated emissions). The underlying assumption of most microeconomic theory is that people and organizations strive to optimize economically, as guided by prices and preferences. This implies operating on the frontier of innumerable technology options, to maximize consumption while minimizing costs and hence trade-offs between different resources, by making the best use of available technologies.[3]

(ii) The first domain of decision-making: behaviour, organization, and habituation

In practice, there is a well-documented shortfall between the best-practice frontier, and how energy is used by most actors. Known as the ‘energy efficiency gap’, the persistent tendency for actors to consume significantly more energy than is optimal given available technologies was already well-recognized in the 1990s (Eyre, 1997) and persists today (Saunders *et al*., 2021; IPCC, 2022, chs 5, 6, and 9). This is indicated by the red dots to the left of the frontier in Figure 1(b). This suggests opportunities to reduce energy consumption and costs simultaneously, by moving towards the best-practice frontier. The IPCC Fifth Assessment noted, concerning buildings, that

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[1] There being a notable distinction between the classical economic focus on the role of prices for efficient resource allocation, compared to the logic and moral philosophy developed by Hayek which emphasized the role of information available to individuals for decision-making, which could not be available to governments (Hayek, 1937); and from this also, the wider aversion to government planning expressed in his later writings.

[2] Sections II and III offer brief summaries of the framework in *Planetary Economics: Energy, Climate Change and the Three Domains of Sustainable Development* (Grubb *et al*., 2014), winner of the 2021 Marcel Boiteux International Prize for ‘outstanding book contributing to energy economics and its literature’ by the International Association for Energy Economics.

[3] In this illustration, the curve bends back at exceedingly high resource input to reflect the evidence that excessive consumption can damage economic output, as exemplified by the myriad damages that may result from excessive consumption of fossil fuels, such as urban pollution and oil market volatility, that are typically inadequately priced.

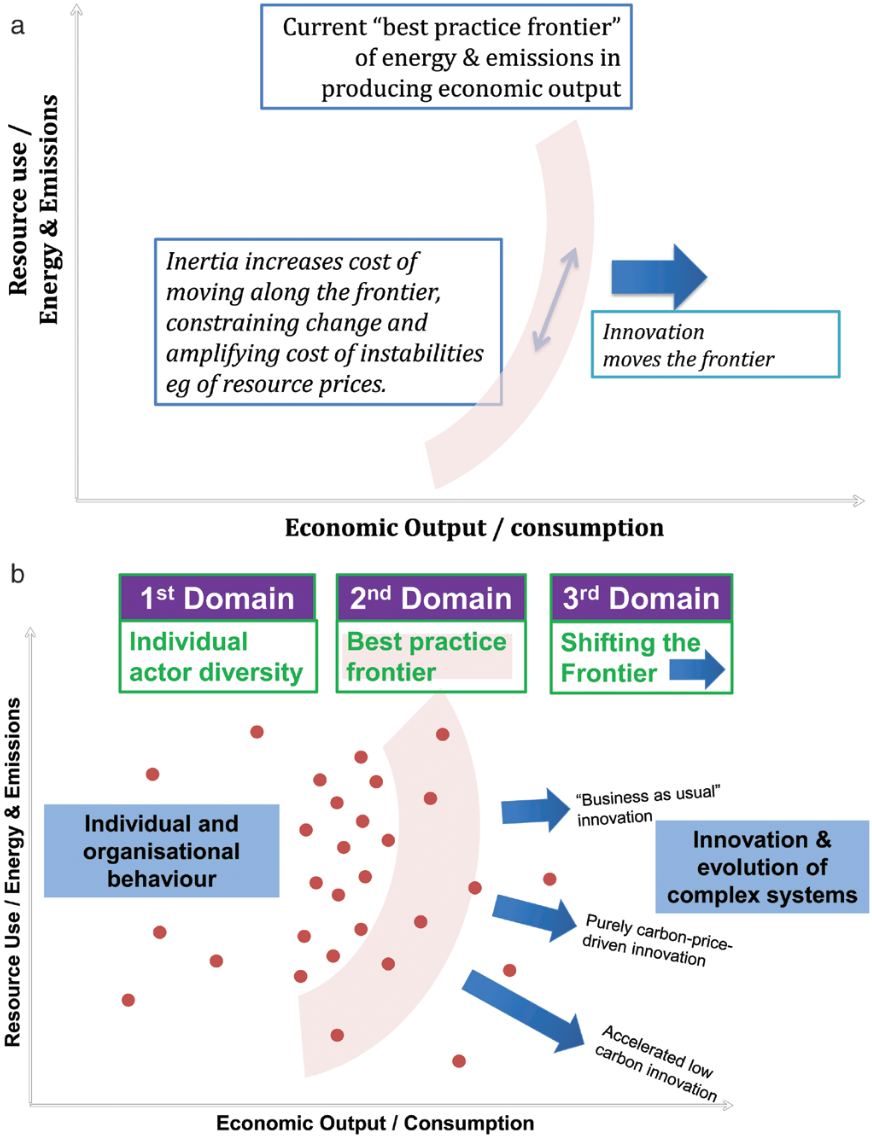

Figure 1 : (*a*) Resource trade-offs at the best-practice frontier. (*b*) Resource trade-offs and opportunities: three domains. *Source*: Grubb *et al.* (2014, ch. 2), 1(b) as refined by the authors.

'Reductions of heating/cooling energy use by 50–90% have been achieved using best practices... [and] can be economically attractive' (IPCC, 2014, Technical Summary 9.3).

Many analyses indicate that hidden costs only explain part of this apparent efficiency gap. A leading researcher noted back in 1997 that 'Barriers to energy efficiency are well established. Neo-classical economic theory allows a taxonomy of the barriers as deviations [but] psychological, social and institutional aspects of energy use allows a fuller description' (Eyre, 1997).

Mainstream acknowledgement of 'sub-optimal' behaviour traces back at least to the works of Simon (1955, 1959). This introduced the concepts of 'bounded rationality', and associated literatures on 'satisficing' behaviour, the observation that individuals and organizations appear sufficiently satisfied with sub-optimal behaviour. A recent review (Antonioni *et al.*, 2022) notes 'ample evidence that human beings do not always optimize... behavioural science has based part of its success on taking as its starting point what individuals actually do, rather than a theoretical idealization'. Studies from cognitive and social psychology, sociology, and neuroscience demonstrate numerous reasons why people do not operate as *homo economicus*. Examples include: loss-aversion, the observation that people value losses much more than similar-sized gains (Kahneman and Tversky, 1979; Tversky and Kahneman, 1991); status-quo bias, the inclination to prefer the current state of affairs (Samuelson and Zeckhauser, 1988; Kahneman *et al*., 1991), which has been used to explain 'stickiness' in consumer markets such as mortgages, banks, and energy tariffs; and priming, the finding that behaviour tends to be influenced by subconscious cues (Bargh *et al*., 1996) and learning by following or mimicking others (vicarious learning). 'Opportunity cost neglect' is the tendency of people to not fully consider the implications of alternative choices and therefore miss out on better or cheaper options (Frederick *et al*., 2009).

The extent to which this matters, in any given context, is an empirical not a theoretical question.

The energy efficiency gap is not the only observed gap between environmental views and behaviour, seen in behavioural economics as a product of motivations, capacity, and constraints (Carlsson and Johansson-Stenman, 2012). These gaps depend on both structural and decision-making characteristics, but crucially, 'there exists spillover effects from structural to psychological barriers' (Antonioni *et al*., 2022). For example, energy efficiency improvements could save money and improve comfort for a tenant who lives in an inefficient property and struggles to pay energy bills, but they face multiple, interacting constraints that would prevent them from insulating their home and upgrading their heating system. In addition to the economic 'split incentive' between tenant (paying the bills) and landlord (paying for energy efficiency improvements), likely constraints also include: lack of access to capital, lack of information, inability to make physical changes without landlord consent, and limited time, knowledge, and capacity to navigate technologies and contractors.

As a result, policy responses designed using neoclassical ideas alone, focused on altering relative prices, typically do not change behaviour to the extent hoped. In sections III and IV we document a striking example of policy failure resulting from a failure to recognize this.

We consider these decision-making processes as comprising the 'first domain' of decision-making, with theoretical roots in behavioural economics and empirical social sciences, and a focus on the observed decision-making of individuals and less energy-intensive organizations, particularly relating to energy consumption. A defining characteristic of first-domain behaviour relating to energy is habituation—habits, rules of thumb, and inattention combined with deep 'structural' impediments, which individuals come to take for granted. Homeowners often don't contemplate energy efficiency before buying, and tenants seeking accommodation rarely question or even think about lobbying or negotiating with their landlord to invest in insulation. The scope to respond to energy price signals is thereby limited, and the intrinsic short-termism of much individual decision-making is amplified by 'split incentives' and other structural barriers.

However, a key feature of first-domain behaviours is also their diversity, reflecting a breadth of individual and organizational motivations and constraints, as suggested in Figure 1(b). This may include 'early adopters' of new technologies, and pioneers who breach beyond the frontier, often motivated by non-economic considerations, but who in general may not alter the shape or position of the frontier in the absence of wider progress.

(iii) The second domain of decision-making: economic optimization

None of the above negates the relevance of price in decision-making (though the evidence of price elasticities suggest typically modest impact of price on energy demand for many end-users).[4] More significantly, and particularly for energy-intensive industries and energy companies, many decision-making processes align well with neoclassical assumptions, actively seeking to operate close to the best-practice frontier. Their decisions can be highly responsive to price signals, including investment horizons over the medium term (e.g. from a few years to 1–2 decades, the timescales over which investors tend to seek returns). We refer to this mode of decision-making as 'second domain', with the key characteristic being its underlying assumption of deliberative *optimizing* behaviour.

Based on the simplifying assumption that actors operate as *homo economicus* to maximize utility with rational expectations, neoclassical thinking logically concluded that in perfect markets they would thus be along the best-practice frontier. As well as externalities, widely recognized market failures include incomplete information, competition and markets, as well as transaction costs. These result in actors often being short of the 'best-practice frontier' (one reason why we draw the frontier in Figure 1(a and b) as a band, not a line).

This introduces some ambiguity in definitional boundaries, reflecting the interaction of behaviour and structure noted above. The large energy efficiency gap in the buildings sector can be cast either in terms of behaviour or—at least to some degree—in terms of missing markets and 'contractual failure'. A pragmatic delineation may concern the ease, costs, and practicalities of 'correcting the market failure'. It is, for example, hard to envisage

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[4] Labandeira *et al.* (2017) identified almost 1,000 estimates of energy price elasticities for different energy products, sectors, and countries, finding the average price elasticities of (total) energy demand to be –0.22 in the short-term (STPE) and –0.6 to –0.66 in the long-term (LTPE).

a complete set of contracts and markets fully resolving price signals around energy consumption from rental terms to the construction industry via the housing and rental markets; nor would this theoretical ideal seem the most feasible and cost-effective approach, given the practical capacity and short-term outlook of most tenants. Whether the resulting efficiency gap predominantly reflects first- or second-domain decision-making modes, or comprises a mix, is largely semantic since the conclusion is the same, pointing to 'pillar 1' policies as indicated in section III(i).

In addition, while many optimizing models present as reflecting the principles of general equilibrium in deriving a global least-cost emissions trajectory, this neglects numerous other assumptions, including convexity and perfect foresight. Within the foundations of general equilibrium theory itself, nothing implies that a market with cost-reflective prices will necessarily deliver anything more than a local, static optimum—the famous Sonnenschein–Mantel–Debreu 'anything goes' critique (Rizvi, 2006).

Obviously, a key feature in this domain is the central role of markets and competition, including the pressures for improvement and dynamism injected by new entrants. Over time, therefore, second-domain decision-making processes generate 'business-as-usual' innovation—delivering a greater level of output for a given input (or level of emissions), i.e. shifting the frontier in Figure 1 to the right. Especially when faced with climate change, however, the question is not *whether* but *how* the best-practice frontier moves, as suggested by Figure 1(b)—we care whether innovation is towards higher- or lower-carbon technologies.

Neoclassical economics acknowledges the fundamental importance of innovation as a driver of economic growth, though in the classic Solow growth model it appears exogenously as factor-neutral productivity improvement. Along with modern developments, mainstream economic theories of endogenous technological change date back to Arrow (1962) and Hicks (1932) as well as the foundational writings of Schumpeter (1942). Subsequent mainstream approaches to representing innovation in economics fall mainly into one of two approaches:

(i) *separable*—if not like 'manna from heaven', innovation occurring exogenously to the economic system as a result of *targeted interventions* separate from markets, e.g. public R&D;
(ii) *optimizing*—innovation is the result of economic agents displaying optimizing behaviour over time in responses to prices and price expectations.

The first approach leads to the treatment of innovation within energy-economic modelling either (*a*) as 'manna from heaven' improvement via exogenous variables, or (*b*), more rarely, as a factor which can be changed by public direct investment (e.g. education and R&D programmes) separate from economic policy.

The second approach assumes that, if left to their own devices, markets will deliver innovation at an optimal pace and direction once market failures have been corrected for, an approach embodying the insights of some branches of endogenous change theory and modelling in which 'technological change arises from intentional investment decisions made by profit-maximizing agents' (Romer, 1990).

Both the pace and direction of innovation are, obviously, influenced by policy. The pace can be enhanced by public R&D, but in the presence of an inadequately priced global public good (or bad), there is no reason to assume that such innovation will enhance overall welfare, particularly given the observed path-dependency of innovation based on incumbent technologies (see next section).

Carbon pricing (and correction for R&D spillovers) can—and, empirically, does (Calel and Dechezleprêtre, 2016)—influence the direction of technology innovation, shifting the frontier further downwards and to the right, through induced innovation. However, foundational economic literature notes that the complex implications of induced innovation open the possibility of multiple 'equilibria' on an innovation possibility frontier (Ahmad, 1966). In the context of climate change, moreover, it is hard to impossible for private actors to predict or rely on a long-term carbon price trajectory; indeed, given the history of carbon pricing sketched in sections III and IV, confidence in this would be highly irrational. Moreover, in the hybrid, target-driven structure of the Paris Agreement, cap-and-trade systems, and net-zero targets, the price is itself reflexive: successful innovation would lower the cost and hence price of achieving a target. This potentially undermines or 'cannibalises' the expected incentive for the innovation required.

Finally, large-scale innovation is typically driven by large corporations seeking to further their competitive advantage, and evidence suggests this tends to be incremental in nature, delivering efficiency gains within existing processes and technologies, rather than radical shifts to technologies in which they have no established advantage (Grubb *et al.*, 2021). This seems particularly the case in the energy sector, for reasons that can best be understood through the lens of decision-sciences which focus explicitly on innovation and transitions associated with non-marginal change—the third domain.

(iv) The third domain of decision-making: innovation and systems transformation

Third-domain economics is concerned explicitly with large-scale shifts in technology, infrastructure, and institutional systems. In the context of climate change, the goal is to shift the best-practice frontier of Figure 1 downwards (decarbonization) as well as to the right (enhancing welfare) at pace, reflecting a wholesale switch to low-carbon technologies and systems. While innovation emerges at many scales and can be driven by start-ups and large corporations alike, the third domain relates to the aggregated impact of these advances on the economy-wide pace and direction of change.

Third-domain decisions therefore relate to strategic, market-shaping interventions that accelerate progress towards a public need that would otherwise not be met by economic actors. The scale, coordination, and timescales over which societal transformations and associated innovations mature and diffuse, mean that key decision-makers within this domain are usually governments or organizations with a particularly long-term view. The third domain ultimately describes the transformation, rather than the optimization, of systems.

As noted, innovation is itself a focus of mainstream economic study based on second-domain decision-making, and many markets *do* deliver innovation at pace and scale. The IT revolution, for example, while still strongly rooted in innovations stemming from public R&D (Mazzucato, 2013), has been largely driven by the private sector with limited additional public-sector support. Highly innovative sectors such as IT and pharmaceuticals typically spend 10–15 per cent of turnover on R&D, in no small part because the path from product development to market is clear and (for IT) relatively rapid, providing close connection of 'technology push and market pull'. This contrasts sharply with the energy sector, and several other heavy energy-using sectors central to tackling climate change, which typically have spent less than 1 per cent (Figure 2, right-hand panel).

The historically weak innovation forces within the energy sector can be attributed to lack of product differentiation and the incidental nature of energy costs (=> first domain), along with historically slow and expensive development cycles and interdependence with network and other infrastructures (=> third domain), as well as barriers to entry (a classic market failure). The result, as indicated schematically in Figure 2 (left-hand panel) is a disconnect between technology push and market pull, impeding adequate private-sector innovation.[5]

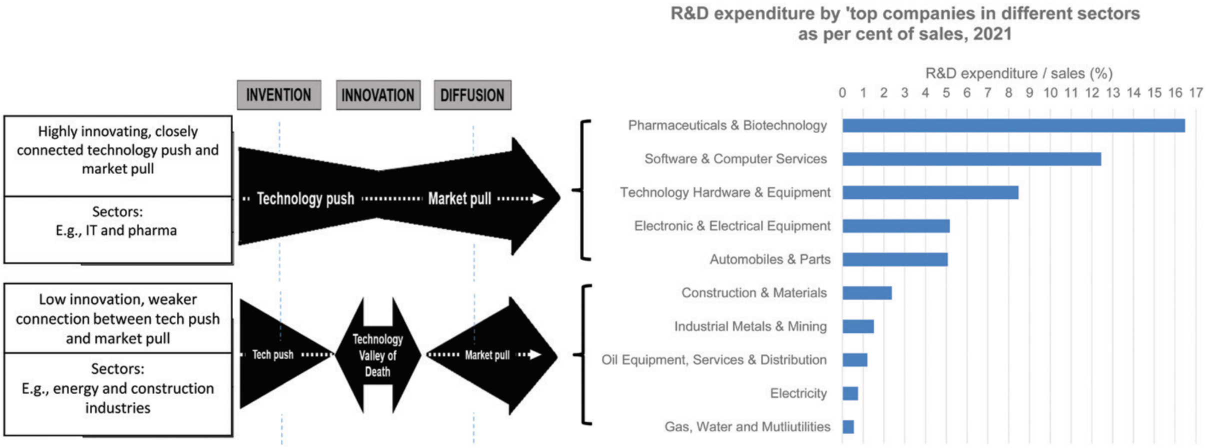

Figure 2: Innovation characteristics and R&D spend across sectors. *Source*: As in Grubb *et al.* (2014, ch. 9); data updated from the EU Joint Research Centre on Industrial Investment and Innovation, R&D Scoreboard 2022, https://iri.jrc.ec.europa.eu/scoreboard/2022-eu-industrial-rd-investment-scoreboard.

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[5] *Lack of product differentiation:* unlike IT or pharmaceuticals, energy technology innovations cannot generally offer new and functionally different products to consumers—almost all ultimately produce either voltage to drive electrons, or a very limited range of hydrocarbon molecules. They ultimately compete on cost margins against incumbent technologies, to sell like products: electricity or molecules. This forecloses any potential for radical profits from low-carbon innovation, equivalent to, for example, the ability to bring a new iPhone or cancer-inhibiting drug to the market. *Lengthy development cycles:* energy supply technologies tend to be large, complex, expensive, and slow to develop (carbon capture and storage technologies, for example, have been in development for over a quarter of a century and are still largely within the demonstration phase). By contrast, development cycles in innovative sectors such as IT are relatively quick and cheap. *Barriers to entry:* the energy sector is dominated by a small number of incumbents who offer the same product but benefit from decades of learning and development, expansive pre-existing infrastructure, and immense lobbying power. This may be exacerbated by dependence on access to (necessarily) regulated network infrastructures.

In the economic modelling of climate change, the potential for policy-driven disruptive innovation was captured in the seminal contribution by Acemoglu *et al.* (2012), showing that abatement is *not* a simple matter of 'climbing up the abatement cost curve' based on a carbon price, but rather involves a dynamic process of competition between innovation in high vs low carbon industries. The model suggested that sufficient innovation in the latter could, in fact, render global mitigation potentially cheap—though limitations included absence of inertia and intertemporal dependencies that also influence innovation as well as the potential pace of diffusion of resulting technologies (Pottier *et al.*, 2014).

The key issue distinguishing second- and third-domain processes concerns the underlying intellectual frameworks employed by decision-makers, influencing understanding of the appropriate roles of governments and the types of policies. Numerous economists dismissed investment in renewables deployment, as recently as a decade ago, on the ground of excessive cost relative to the assumed efficiency of a carbon price and R&D (e.g. Helm, 2012; *Economist*, 2014).[6] This turned out to be badly mistaken. The revolution in the cost of renewables and the potential for large-scale, cheap emission reductions has now been shown, by a large body of evidence, to have been driven by targeted policies that created favourable market conditions for renewable technologies, *despite* the prevailing economic policy advice (e.g. Grubb *et al.* (2021), a systematic review of 228 research papers on induced innovation).

As with first-domain theories, there are a wide range of analytical fields dedicated to exploring innovation and related third-domain processes. A related paper (Grubb *et al.*, 2017) explored in more depth the empirical literature around energy-related innovations (with case studies on lighting, fossil fuel generation, and renewables), from which we highlight at least three main literatures illustrating the distinction between second- and third-domain decision-making evaluation.

The literature on *technology innovation systems* studies the 'generation, diffusion and utilization of a technology' (Carlsson and Stankiewicz, 1991) through the interactions of actors, institutions, and technologies/infrastructures.[7] From this follow policy approaches which emphasize the multiple functions of successful technology innovation strategies, in which traditional economic factors are only one element (e.g. Chaminade and Edquist, 2005; Hekkert *et al.*, 2007; Bergek *et al.*, 2008).

Literature on broader *transitions* highlights a central role of the existing socio-technical regime—including market design and associated institutions—and the processes by which innovations nurtured in niches may 'break through' (Geels, 2002, 2004). Such 'multi-level perspectives' emphasize the importance of supporting niche developments and building in various forms of learning (learning-by-doing, using, and interacting). Niches gain momentum and are more likely to lead to widespread adoption if they align well with the existing regime, if expectations become more precise and broadly accepted, if learning processes results in a dominant design, and if powerful regime actors join to convey legitimacy (Geels, 2002, 2004, 2011; Markard and Truffer, 2008; Schot and Geels, 2008).

The discourse of such analysis differs from the classical economic framing of innovation, going well beyond just the role of government R&D and markets. One limitation from many economists' standpoint is that these approaches tend to be non-quantitative and not expressed in quantified models.

The third set of approaches then involve formal *complexity sciences*. These inform views of economic systems which emphasize dynamics and uncertainty. Viewed as a complex system, the economy comprises mutually interacting agents, subsystems, institutions, technologies, and regulatory and political systems (Anderson *et al.*, 1989; Arthur, 1999). Complexity theory studies systems with interacting internal elements, and the emergence of a resulting macro structure. As such, complexity theory informs, draws upon, and interacts with elements of Keynesian, Schumpeterian, developmental, and evolutionary economics, as well as more specialized theories (Beinhocker, 2007).

These literatures tend to underline the centrality not of separating 'technology push' (government R&D) from 'demand pull' (markets) but, to the contrary, the centrality of understanding their complementarities. The lack of connectivity between these explains the data of Figure 2, and is underlined by a large literature on the energy

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[6] Examples of the former include: 'what are Britain and Europe's politicians doing?... channelling scarce customers' monies towards wind farms, solar panels and biofuels... Which stand no serious chance of making much difference to decarbonization... It's not only blinkered, but also incredibly expensive'(Helm, 2012). Globally, wind and solar energy have already reached deployment levels, and (particularly for PV) vastly exceeded cost reductions, projected in many models of that era for 2030 or 2040 or beyond. In recent reports, the International Energy Agency has referred to PV as 'the cheapest electricity in history' and essentially thrown away previous projections in favour of increasingly renewables-dominated electricity scenarios (IEA, 2020, p. 214).

[7] Defined as (i) actors; including technology developers, intermediaries, users, financers and regulators; (ii) institutions; structures that set and form 'the rules of the game' comprising laws and regulations, social and technical norms, and shared expectations; and (iii) technology and infrastructures, i.e. the technical characteristics.

'technology valley of death' (e.g. Weyant, 2011; Nemet *et al.*, 2018*a*; Ellwood *et al.*, 2022)—a structural disconnect that results in a combination of high risk and low reward for market-based innovation.

This indicates the need for policies beyond carbon pricing and R&D, to stimulate innovation, and accelerate early adoption of low-carbon technologies, until they attain self-sustaining diffusion. Since innovation, by definition, is impossible to predict with precision, and is interdependent with infrastructure and social dimensions, this in turn points to the centrality of *strategic* decision-making by large-scale actors, involving *judgement* about the risks and opportunities for transformational change (Mercure *et al.*, 2021). Namely, the actions of governments orienting systems for the long-term public interest (e.g. Mazzucato, 2016), and of major multinational company boards, exercising decisions about whether to invest in activities which exacerbate climate risks, or start to alleviate them.

Figure 3 summarizes the resulting overall framework and associated decision-making characteristics.

III. Three pillars of energy policy

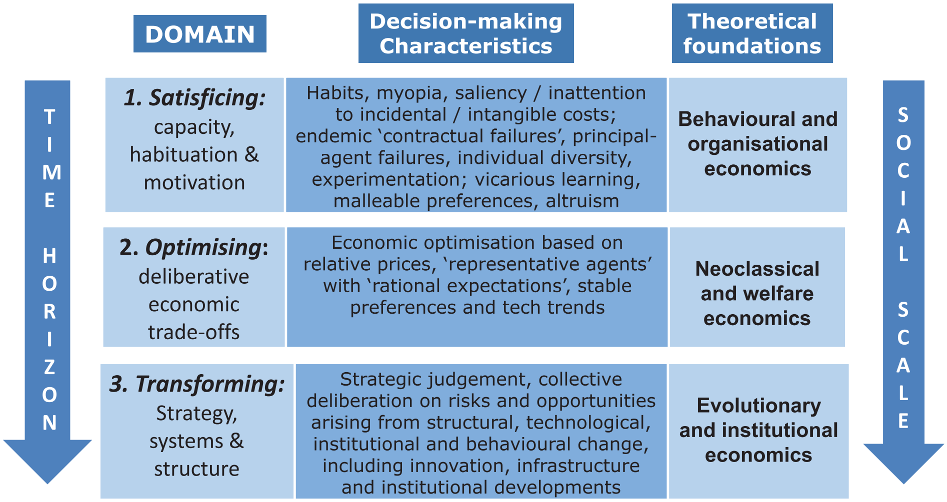
The three domains of decision-making imply three distinct areas of opportunity, which can be broadly chararacterized as:

- *Smarter choices* by individuals and organizations, leading to reduced demand for energy and/or fossil fuels, with a shift in average behaviour towards the best-practice frontier.
- *Substituting cleaner products and processes* in contexts where pricing and market structure dominate decisions, particularly relating to changing the conversion systems (such as electricity generation).
- *Industrial innovation and infrastructure investments*, that reduce the cost of technologies that are currently too expensive or are not yet commercially available at scale, enabling associated low-carbon industries to grow and to bring down costs through learning, economies of scale, and growing confidence which reduces the perceived risks and hence cost of finance.

For each of these opportunity areas and their corresponding domains, there are leading—though not exclusive—policy instrument types (IPCC, 2022, ch. 13). There are many ways of classifying policy instruments, and here we outline how the three domains approach leads naturally to classify three pillars of energy policy (Grubb *et al.*, 2014). We provide an example of polices from each of these pillars from the electricity sector in the EU and UK context.

(i) Pillar 1: promoting smarter choices

The nature of first-domain decisions explains why an energy or carbon price on its own is a blunt instrument in these contexts. *Standards and engagement* are particularly relevant to foster smarter choices to make best use of



DOMAIN	Decision-making Characteristics	Theoretical foundations
1. Satisficing: capacity, habituation & motivation	Habits, myopia, saliency / inattention to incidental / intangible costs; endemic 'contractual failures', principal-agent failures, individual diversity, experimentation; vicarious learning, malleable preferences, altruism	**Behavioural and organisational economics**
2. *Optimising*: deliberative economic trade-offs	Economic optimisation based on relative prices, 'representative agents' with 'rational expectations', stable preferences and tech trends	**Neoclassical and welfare economics**
3. Transforming: Strategy, systems & structure	Strategic judgement, collective deliberation on risks and opportunities arising from structural, technological, institutional and behavioural change, including innovation, infrastructure and institutional developments	**Evolutionary and institutional economics**

Figure 3: Three domains: decision-making characteristics and underpinning theories. *Source*: Developed from Grubb *et al.* (2014, ch. 2).

existing and emerging technology, including by enhancing understanding, confidence, and new norms around cleaner technologies and practices.

Engagement policies aim to increase awareness of energy-related information to facilitate better choices. Since the early 1990s, mandatory labels have been applied to energy-using appliances and products to guide consumers towards more energy-efficient choices. Since the mid-2000s, across the European Union, minimum energy performance regulations (standards) have been applied to largely the same products, to remove the least efficient models from the market. Both have iteratively increased in scope and stringency, with their effects accumulating over time as capital stock is replaced. By 2018, these together reduced EU electricity consumption equivalent to 15 per cent of annual consumption (Lane *et al.*, 2021), which was inconceivable with price effects alone, given the observed elasticities.[8]

Such policies also help tackle the consequences of 'deep' market failures which are almost intractable to 'fix' directly, and interact with first-domain decision-making, as observed with household energy efficiency. The economic efficiency and effectiveness of standards in many areas of energy end-use are widely acknowledged in policy, including the IPCC's finding that 'building energy codes represent the main regulatory instrument to reduce emissions from both new and existing buildings (*high confidence*)' (IPCC, 2022, technical summary).

The energy efficiency literature is replete with other types of measures which have also successfully expanded and accelerated the take-up of more efficient technologies and practices. Some deliver by shifting the onus from end-users to other agents. In the UK, for example, the 'CERT' energy efficiency obligation required energy supply companies—agents with resources, knowledge, and delivery capacity—to achieve a given level of carbon savings from their sales. At its peak, in 2011, the system supported energy efficiency measures in over a million homes a year; total emission savings resulting from its operation (over 5 years) were estimated at about 300 million tonnes of CO_2 over the lifetime of the associated investments (Ofgem, 2013). Other measures also enhanced business energy efficiency, with approaches that combined behavioural with economic incentives.[9]

(ii) Pillar 2: markets and pricing to incentivize cleaner products and processes

Prices and market structures shape the choices of market actors to buy, sell, or invest in cleaner products and processes. Since Pigou's *The Economics of Welfare* (1920), when faced with an externality, the recommended response is to reflect the marginal social damage in prices so as to 'internalize external costs', principally through taxation to correct for the disparity between private and social costs of consumption.

This policy pillar aims to ensure that the structure of markets and taxation reflects damages and thereby encourages the adoption of low-carbon technologies—including removal of fossil fuel subsidies and carbon pricing. These policies are typically 'horizontal' economy-wide or at least sector-wide measures that embody a technology-neutral approach. In relation to the corresponding domain, the primacy of carbon pricing seems clear; a comprehensive price on carbon (and other GHGs) equivalent to the social cost of carbon corrects the acknowledged market failure. With adequate foresight, the market and actors within it should respond to the immediate and anticipated future carbon price by reallocating resources 'from dirty to clean'.

From this perspective, carbon pricing should deliver emissions reductions at least cost, at each point in time and over time. Revenue-neutral recycling of tax revenues can lower some existing taxes to decrease labour costs (Bovenberg, 1999; Goulder, 2013; Stern and Stiglitz, 2017) or capital taxation (Rausch *et al.*, 2011), and/or can be used to provide funds for public R&D investment (e.g. Klenert *et al.*, 2018)), justified with reference to the 'other' acknowledged market failure of knowledge spillovers (Jaffe *et al.*, 2005). Revenues could also be used to offset distributional or other adverse impacts—if revenue is redeployed equitably, carbon pricing in theory can be progressive rather than regressive. In fact some literature finds that if source-side (e.g. wage and capital) as well as

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[8] Aside from literatures on energy elasticities more broadly (note 4), Zhu *et al.* (2018) find that 'residential electricity demand is almost inelastic in the short term'.

[9] Two particular measures targeted business energy efficiency. The Climate Change Levy (CCL), a tax on business energy use, combined the direct price incentive with sector-specific 'Climate Change Agreements' (CCAs), which offered energy-intensive industries derogations from the tax in return for delivering negotiated improvements in energy intensity. An evaluation of the CCL overall (Martin *et al.*, 2009) concluded it had a 'strong impact' in reducing energy intensity and electricity use; for a full set of micro and macro evaluations see https://www.gov.uk/government/publications/second-climate-change-agreements-scheme-evaluation. However it became clear that the less energy-intensive sectors (e.g. service and public sectors) largely passed through the CCL with little or no impact on behaviour—confirming the micro-econometric evidence of very low price elasticities. Consequently, the CCL was complemented by the UK business CRC (formerly the Carbon Reduction Commitment) energy-efficiency scheme, a tradeable certificate scheme which also required precise monitoring and publication of emissions (direct and electricity-related) (Grubb, 2009), prompting much greater response. *Ex-post* evaluation concluded that the CRC cut emissions from the sectors covered by 6–8 per cent (much greater than the 2 per cent estimated *ex ante* on the basis of energy elasticities) (DECC, 2015). The behavioural dimension was further enhanced by introducing comparative performance metrics, originally used as a basis for revenue recycling, but when revenue recycling was withdrawn, the complexity and controversial nature of the 'league tables' provoked business opposition which led to the scheme being later terminated.

use-side (products, services) impacts are taken into account, carbon pricing can be progressive even without revenue redeployment (Rausch *et al.*, 2011; Goulder *et al.*, 2019).

The paradigmatic assumption is that, with these 'supplementary' measures, carbon pricing may operate as theoretically intended. This propagates the extension of carbon pricing as 'first best' priority for climate policy (Hepburn *et al.*, 2020; Parry, 2020).

Reflecting this philosophy, in 2005 the EU emissions trading system (EU ETS) introduced a carbon price to all electricity generation and industrial emitters across the EU. It was generally plagued by low prices for most of the subsequent 15 years, until reforms in the late 2010s, and as such had relatively little direct impact on the electricity generation mix and associated emissions across Europe (Bel and Joseph, 2015). In response, in 2013 the UK unilaterally introduced a carbon price floor to underpin the EU ETS price. The combined price was initially around €11/tCO_2, rising to €45/tCO_2 by 2020, and was sufficient to encourage rapid fuel-switching from coal-fired to gas-based generation (Leroutier, 2022), with coal decreasing from 40 per cent of generation in 2012 to under 2 per cent in 2020 (BEIS, 2021).

As noted in the previous section, the evidence is that carbon pricing does influence innovation (Calel and Dechezleprêtre, 2016) but mostly in rather incremental ways—improving the performance and efficiency of incumbent industries and technologies, rather than more radical innovation (Grubb *et al.*, 2021). Tvinnereim and Mehling (2018) find this to be true even in Sweden, one of the few countries to have implemented a carbon price from the 1990s with a price rising to US$140/t$CO_2$—the highest in the world: Swedish emissions have stayed flat, far from the deep decarbonization required to approach net zero emissions.

While the practical progress on carbon pricing has been limited (see section IV), it remains the main focus of economics and related modelling literatures. While if pressed, modellers clarify that such results actually reflect the marginal cost of constraints, in practice this reinforces a discourse framed almost entirely around carbon pricing as the best and default policy. This has potential drawbacks in terms of narrowing the focus of enquiry, particularly given the practical difficulties discussed in section IV.

(iii) Pillar 3: strategic investment for innovation and infrastructure

The nature of third-domain economics implies a clear need for *strategic investment* to drive innovation across a broad spectrum of interrelated technologies and infrastructure, in which public value exceed any conceivable returns to private investors. This involves direct public support or another policy that looks to enable the longer-term evolution of low carbon energy systems, as well as governance reform within relevant sectors to ensure that established decarbonization goals are appropriately and consistently reflected in public decision-making. While carbon pricing can steer innovation towards low-carbon alternatives in general, all the third-domain empirical and related literatures around innovation systems, multi-level transitions, and complex systems theories, discussed in section II(iii), indicate why more directed measures are required to accelerate innovation and deeper transitions.

The policy experience of the past few decades in renewable energy illustrates this. Beyond the R&D investments of the 1970s and 1980s, the major cost reductions in renewable energy technologies have been increasingly associated with technology-specific 'demand pull' policies, along with policies to enhance shared learning and supply chain developments at scale (Nemet, 2009). Germany's feed-in tariffs—notably, fixed-price contracts for electricity from wind and solar—are the most prominent example, though of course this is part of a much bigger story, including the multiple international policy dimensions of developments in wind and solar (e.g. Nemet, 2019; IPCC, 2022, chs 13, 16).

The UK example is telling in its evolution from a more technology-neutral philosophy. This started with an auction-based 'non-fossil fuel obligation', initially spawned from efforts to protect nuclear as well as support renewables. In 2001, the UK moved to a renewable obligation (RO) which required electricity suppliers to source an increasing proportion of their electricity from renewables, through buying renewable obligation certificates (ROCs) from renewable generators, thereby subsidizing new renewables. The initial technology-neutral design, however, resulted in most subsidies going to the most mature renewable energy, namely onshore wind. Notwithstanding visceral criticism from high-profile economists (note 6), in 2009 ROC 'banding' was introduced to give more support to less developed renewables—reflecting a strategic recognition by government that the UK's biggest low-carbon resource was offshore wind energy. Alongside wider initiatives, and particularly the offshore wind accelerator, the reform induced investment, collaboration, and scale in this challenging technology arena (Jennings *et al.*, 2020). Recognizing that the uncertain revenues added financial risk to a programme of investment still developing capital-intensive and risky technologies with complex supply chains, the RO then began to be replaced by 'contracts-for-difference' (CFDs), offering a fixed electricity price for 15 years—incentivizing improved output—with competitive pressures introduced by auction (Grubb and Newbery, 2018). In subsequent auction rounds, offshore wind represented 95 per cent of new capacity.

The auction prices fell from around £170/MWh in 2008, to around £40/MWh for offshore wind projects coming online in the UK in 2023 (Mercure *et al.*, 2021)—the latter being effectively subsidy-free. The cost reductions are attributed to four main factors: induced R&D (government and private); learning-by-doing; scale economies; and reduced financing costs, as confidence in the financial community grew (Jennings *et al.*, 2020). This has opened up huge zero-carbon energy resource (Ofgem, 2022), accounting for 13 per cent of generation already by 2020 (from <1 per cent in 2010 (BEIS, 2021)), and it now forms the backbone of the UK's decarbonization and energy security strategies, with a five-fold increase in capacity targeted by 2030 (CCC, 2020; BEIS, 2022).

Contrary to the common prescription to begin with the low-cost abatement options and incrementally increase efforts and costs over time, consideration of transition dynamics implies that the most cost-effective strategy may instead be targeted funding of certain key technologies with large potential and prospects for cost reductions (e.g. solar, and offshore wind), and long-lived capital investments critical to a low-carbon future (Vogt-Schilb *et al.*, 2018). The same seems broadly true of other technologies, such as the development of electric vehicles fostered by a wide range of government policies, necessarily including investment in charging infrastructure.

None of these developments would have happened solely due to carbon prices—certainly, not the ones that governments have in practice been able to muster (section IV). However, the interactions remain important. Figure 4 illustrates a conceptual cost–benefit evolution for a new, low-carbon technology. An emerging technology may cost several times that of incumbents, and strategic deployment can bring down costs through the mechanisms noted above. Once a new technology reaches the point of competitiveness, it no longer needs direct public support. The presence of a rising carbon price amplifies the net benefits of investment and low-carbon innovation, though this alone would not be sufficient to overcome the initial private investment barriers.

While each pillar has a most direct impact on the economic processes within its respective domain, this example also illustrates important interactions with the others. These interactions and their evolution over time are central to the argument of the three domains framework, and are explored in section V.

IV. Political economy challenges and government failures across the pillars

All policies require political initiative, agreement on the implementation, and subsequently effective monitoring and compliance mechanisms, as well as continued management and refinement. Policy is never perfect, and concerns about market failure—and other deviations from the first-best world of second-domain ideals—need to be balanced against the risks of government failure. In the following we illustrate how these challenges are relevant in all, but different across the domains.

In pillar one, challenges include public acceptance of new norms, and the implementation and enforcement of standards (Schütze and Stede, 2021). Easily assimilated information (e.g. labels) can help to pave the way for standards (in terms of product information systems, and public awareness—few people object to demonstrably inferior options being removed from the market). In turn, the codification in a standard and sanctions for non-compliance

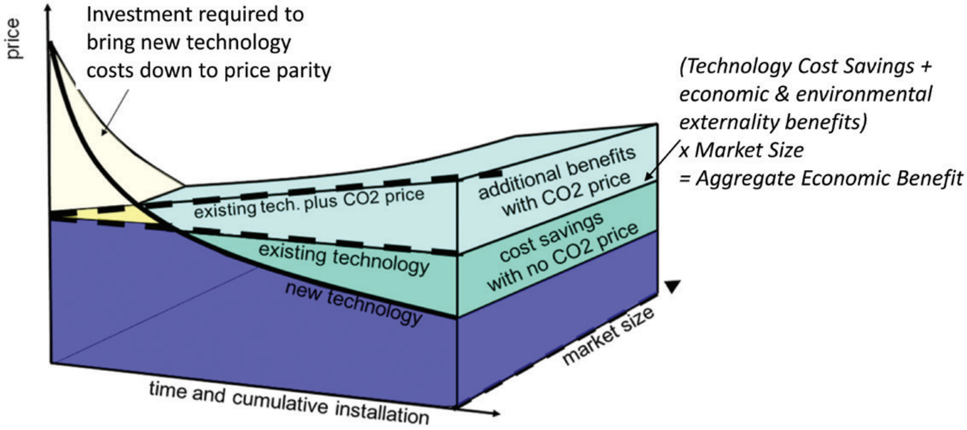

Figure 4: The cost–benefit structure of strategic investment. *Source*: Grubb *et al.* (2014, ch. 9).

can help to reinforce a societal norm (Ostrom, 2009). The implementation of standards thus requires political skills in order to ensure acceptance and effectiveness.

In fact, the greatest government failures in this arena can be ascribed to mis-diagnosis of the primary decision-making domains at play. Based on data demonstrating the cost-effectiveness of home energy efficiency improvements, in 2011 the UK government abandoned existing policies and introduced the 'green deal', which offered property owners public loans for energy efficiency investments. The loans would be tied to the buildings, rather than occupants, with repayments added to bills on a pay-as-you-save economic logic, buttressed by a 'golden rule' that the estimated energy savings should always exceed the loan repayments. Based on impeccable second-domain economic logic, it was heralded as 'Europe's most innovative and transformational energy efficiency programme', with the UK Department of Energy and Climate Change projecting that it would support the retrofit of 14 million homes by 2020.

The advice of energy efficiency experts, that it would not work (Rosenow and Eyre, 2013), was ignored, given the compelling economic logic and political appeal of putting energy efficiency in the hands of home owners themselves. In the event, the green deal led to the collapse of the UK energy efficiency market on all fronts, and retrofits plummeted, to only about 6,000 homes a year, despite public expenditure of £240m. The 'biggest failure in the history of UK energy policy' can be ascribed to many detailed explanations of barriers, behaviours, and failures in design (Rosenow and Eyre, 2016),[10] but a more concise explanation is that it applied second-domain economic logic to a first-domain behavioural and structural problem.

In pillar two, policy-makers internalizing externalities with pricing mechanisms face consistent public opposition, driven in part by feared distributional impacts.

As a result, after three decades of economic advocacy, the use of carbon pricing remains very constrained, in both scope and price levels, as illustrated in Figure 5. With the advent of the Chinese ETS, the global coverage rose to about 31 per cent of fossil fuel CO_2 emissions (about a quarter of global GHG emissions), and the EU ETS price has risen sharply; nevertheless, most realized prices, and the global average, remain far below recent estimates of the 'social cost of carbon' at over $\$100t/CO_2$ (e.g. Rennert *et al.*, 2022), or levels plausibly required for carbon pricing to be a major driver of global decarbonization (e.g. Stern and Stiglitz, 2017; Harmsen *et al.*, 2021).

As noted, in theory distributional issues can be tackled, but in practice it can be difficult, without undermining the desired investment incentives. In Germany, for example, a disproportionally high share of tenants and of low-income households living in badly insulated buildings require up to 10 times the amount of heat per square metre of the best-performing buildings, and would thus be highly exposed to high energy or carbon costs (Kröger *et al.*, 2023). Average reimbursements would not compensate for such a cost increase, but tailored reimbursement risks undermining the desired incentive effect.

The distributional effects may in theory be of lesser concern regarding industry, as expenditure on industrial outputs is progressive (Stede *et al.*, 2021). In practice, however, concerns about international carbon leakage (Grubb *et al.*, 2022) have led to carbon pricing in industry so far being accompanied by free allowances or exemptions; even the much-vaunted Swedish carbon tax has numerous derogations.

After three decades of sustained lobbying by economists, the primary US legislation on climate mitigation has in fact adopted the opposite course, in the *Inflation Reduction Act*. The fact is that carbon pricing has thus encountered numerous failures regarding the ability or willingness of governments to implement economic recommendations, leading Rabe (2018) to pessimistically ask, '*Can* we price carbon?'.

In pillar three, challenges include identifying appropriate arenas and technologies to support, and avoiding the 'pork barrel' of mutually reinforcing vested interests and regulatory capture. Nevertheless, governments have played a critical role in fostering large-scale transformations of the technical systems. Typical cases of this include investments in port infrastructures, the railways revolution, or the French nuclear programme. In all cases, governments must make long-term strategic choices for their country but must balance their perception of long-term interest with short-term political constraints to retain public support.

In principle, a distinction can be made between the *long-term visions* and *specific choices* on technologies. The former include, for example, level of energy autonomy, date and pathway of carbon neutrality, export-oriented versus inward-oriented industrial strategies, to provide a shared vision to mobilize a large portfolio of policies as well as private initiative. Technological choices ultimately imply a decision between technical controversies in a context of strong uncertainty, and strategies for reflexive evaluation or progress. Given unavoidable uncertainties, this may involve an element of 'arbitrariness' from a pure economic point of view, which may however be necessary

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[10] One aspect of design failure stemmed from the presumption that if there was a guaranteed loan that would generate a net-positive NPV, it would be attractive—the government consequently set the loan at 7.5 per cent, more expensive than loans available from banks. One unknown is whether the programme would have been more successful at lower rates, notwithstanding the historical lack of self-generated efficiency investments based on bank loans.

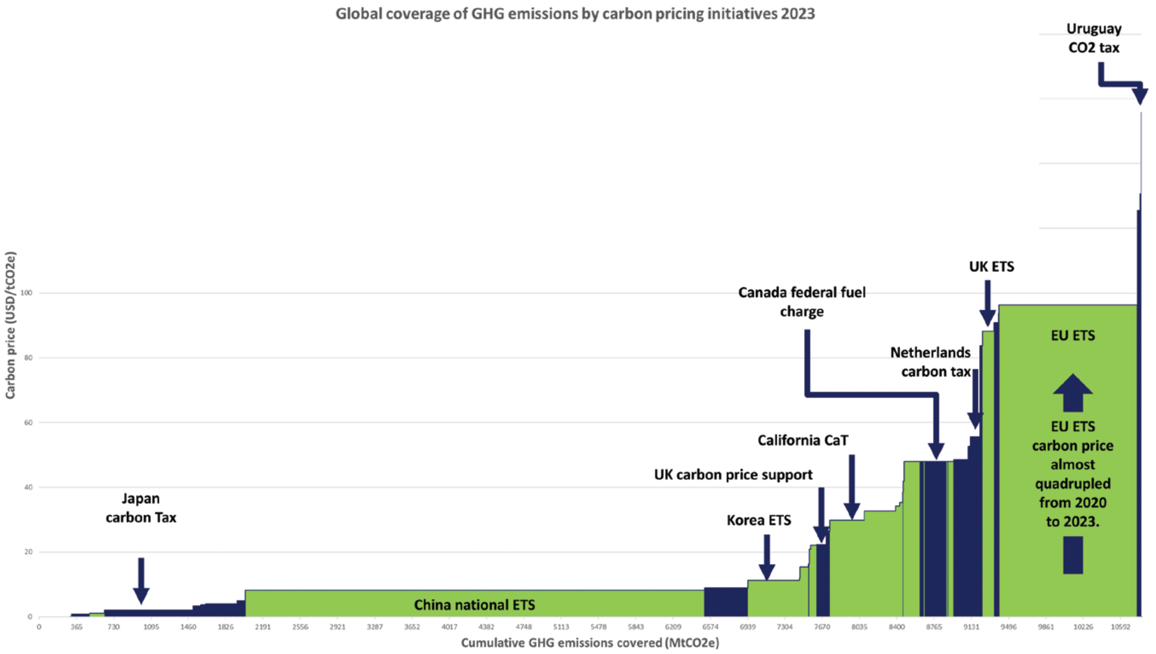


Figure 5: Carbon price in different systems, plotted against emissions coverage, 2020 (World Bank, 2020). *Source*: Produced with data from World Bank Carbon Pricing Dashboard and Coverage Data 2023, https://carbonpricingdashboard.worldbank.org/. *Notes*: For detail of the individual countries and regions see data source. The lighter shade (green) represents emissions trading systems while the darker shade (dark blue) represents carbon taxes. 301.6 $MtCO_2e$ accounted for by the Mexico pilot ETS and Oregon ETS are priced at 0 USD/tCO_2e. The dataset identifies some regions in which carbon pricing systems overlap. This graph removes the potential of double-counting arising from overlap between provincial emissions trading systems and the China national ETS, approximately 850 $MtCO_2e$. Other potential sources of double-counting of emissions (less than 500 $MtCO_2e$) arising from overlap of carbon taxes and emissions trading systems, notably in the UK and Mexico, and carbon taxes in some EU countries, which have larger prices differences, which we have retained for simplicity. The Indonesia ETS, accounting for approximately 300 $MtCO_2e$ is not shown due to lack of price data.

as a tool to achieve the learning required to improve and to assess technologies and practices, for the coordination of a great diversity of actors, and to overcome inertia.

Any strategic choice on technologies inherently selects one future among many others under country-specific methods of organizing the relations between science, expertise, and policy-making processes. Public strategic choices may also both reflect and affect preferences over time (Mattauch and Hepburn, 2016).

The key challenge is to balance the stability of legal, institutional, and financial settings with risks of regulatory capture. Credible public-funding commitments (subventions, grants, guarantees) are needed to encourage researchers and firms to risk dedicating their career and innovation capacity to a new technology. But there are also clear risks of regulatory and policy capture by interest groups (e.g. Nemet *et al.*, 2018*b*) which has been strongly emphasized in development economics (Krueger, 1990) and in infrastructure policies (Button and Hensher, 2005).

This requires procedures to be put in place to encourage revision in accordance with experience, while minimizing the risks of time inconsistency of decisions (Nemet *et al.*, 2018*b*). With stable strategic choices (e.g. climate goals, broad goals for energy resources), some policy instruments can prioritize learning, and iterative upscaling and progressive revisions of initial contracts can minimize the risks of government capture by rent-seeking processes (Helm, 2010), reducing risk of both market and government failure (Wolf, 1987). Interestingly, the IPCC sixth assessment (IPCC, 2022, ch. 15) insists on the importance of new forms of risk-sharing mechanisms in public–private partnerships like public guarantees that open fewer 'capture' risks than subsidies, while mobilizing the private sector and the banking system (Gropp *et al.*, 2014).

The conclusion is simple: all policy pillars carry challenges of potential 'government failure'. The rational response is not to do nothing, or to assume that governments can price carbon better than they can do anything else, but to pragmatically learn lessons and improve policies across all three—and to understand their potentially positive interactions.

V. Pillar complementarities

Compared to common economic positioning of carbon pricing as ‘the best’, with inadequate progress and a narrative now facing significant backlash, the three domains approach offers two potential advantages. First, it represents the multiple theories and associated policies not as competing, but as distinct processes that operate primarily at different social and spatial scales, and over different timeframes. Second, once we delineate these domains and associated policy pillars, it becomes apparent that there are inherent and mutually-supporting complementarities between carbon pricing, at the core of pillar 2, and the other pillars.

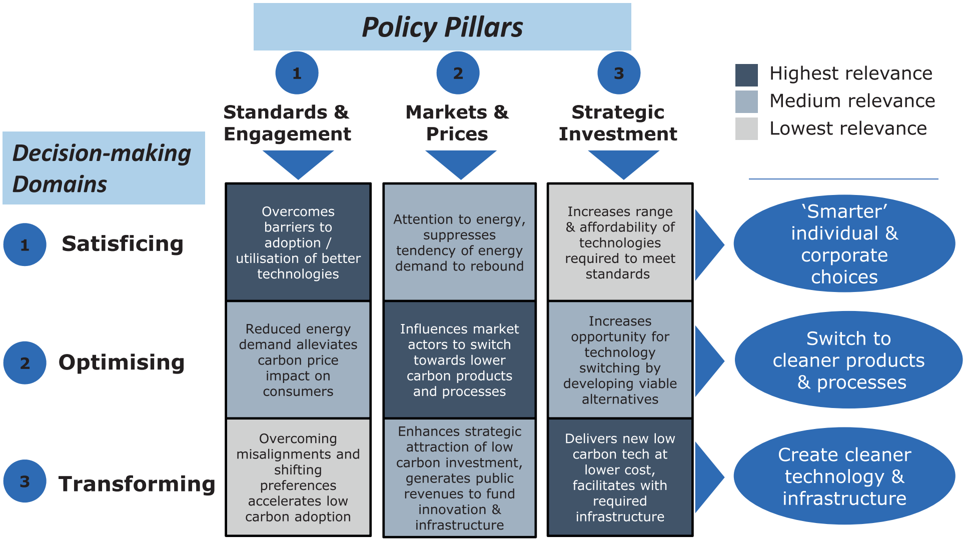
Pillar 1 policies support individuals and organizations in choosing efficient, low-carbon technologies and behaviours, thereby reducing the cost of energy consumption. Such measures are also crucial for tackling potential distributional and competitiveness concerns associated with carbon pricing (and broader energy price rises), improving the political acceptability of new or increasing prices. There is a common understanding that subsidy removal and carbon pricing advance energy efficiency. However the reverse is also true, for example reflected by (Bashmakov, 2017)’s ‘energy cost constancy’, finding that in the long run the total energy cost as a fraction of GDP—the product of real energy prices times energy intensity—tends to converge in a relatively narrow range, as enhanced energy efficiency facilitates subsidy removal.

Carbon pricing can counter the potential rebound effect from increasing energy efficiency (Baranzini *et al.*, 2017). It also generates revenue that could be earmarked for energy efficiency and innovation programmes or to mitigate the economic and social consequences of the propagation of higher energy costs throughout the economic system (Stern and Stiglitz, 2017) which can otherwise lead to a rejection of carbon prices as illustrated by the *gilet jaunes* revolt in France (Combet and Hourcade, 2017).

Pillar 3 policies generate and drive down the price of new and immature low-carbon and energy-efficient technologies, pushing forward the best-practice frontier by improving the range of affordable technology options to switch to in response to carbon price signals (pillar 2), as well as allowing a more effective response to energy efficiency policies (pillar 1). In turn, a credible carbon price enhances the incentive for private innovation activities through demand-pull, increasing the potential return from investment in low-carbon innovation. By reducing the cost differential between high-carbon incumbents and low-carbon innovations, the point of price parity is advanced as cost reductions continue, meaning targeted support can be removed more quickly.

In addition, it is not unusual for some policy designs to embed a hybrid approach within one instrument. While the use of revenues from carbon pricing instruments to fund strategic investments are the most obvious example, there are more direct hybrid instruments, for example the UK instruments for business energy efficiency which combine direct price with behavioural incentives (see note 9).

Figure 6 summarizes key reinforcing impacts among policy pillars and domains, including how pillars 1 and 3 can help to advance carbon pricing. These complementarities demonstrate the need for an integrated policy mix that pursues all pillars simultaneously.



	1 Standards & Engagement	2 Markets & Prices	3 Strategic Investment
1 Satisficing	Overcomes barriers to adoption / utilisation of better technologies	Attention to energy, suppresses tendency of energy demand to rebound	Increases range & affordability of technologies required to meet standards
2 Optimising	Reduced energy demand alleviates carbon price impact on consumers	Influences market actors to switch towards lower carbon products and processes	Increases opportunity for technology switching by developing viable alternatives
3 Transforming	Overcoming misalignments and shifting preferences accelerates low carbon adoption	Enhances strategic attraction of low carbon investment, generates public revenues to fund innovation & infrastructure	Delivers new low carbon tech at lower cost, facilitates with required infrastructure

Figure 6: Summary of pillar and domain complementarities. *Source*: The authors.

The UK experience is again instructive. Between 1990 and 2020 the UK reduced territorial CO_2 emissions by 47 per cent (BEIS, 2021), an average rate of decarbonization faster than anywhere else in the G20 (PWC, 2021). The UK experience was of a consistent, cross-party commitment on climate change since the early 1990s, with a great deal of policy experimentation and learning-by-doing.

Around two-thirds of CO_2 reductions in the UK over this period were delivered by a decarbonizing power sector (BEIS and ONS, 2022), where elements of all three policy pillars have been clear.

- On pillar 1, notwithstanding the 'green deal' failure (section IV), the UK benefited not only from the earlier success of the CERT programme and hybrid measures to enhance non-domestic energy efficiency (see section III(i)) but also EU standards on appliance efficiency (and cars): over the period, energy consumption reduced by 18 per cent while GDP grew by 60 per cent (down from 80 per cent in 2019, due to Covid-19), and UK consumer expenditure on electricity (and energy more broadly) declined over time as a proportion of GDP (2.2 per cent in 1990 to 1.82 per cent in 2020, remaining largely constant as a share of total energy expenditure).[11]
- On pillar 3, after the shaky start, policy became more effective as indicated (section III(iii)), and ultimately delivered dramatic expansion and cost reductions in offshore wind energy; wind alone produced 25 per cent of electricity in 2022, and renewables overall more than 40 per cent of electricity.
- On pillar 2, the UK was also among the most ambitious countries on use of economic instruments, including the hybrid measures for energy-efficient use, and carbon pricing on producers; the floor price/carbon price support in electricity generation drove coal to the margin of power generation—where, with the progress on both electricity demand and renewables, it was no longer needed.

The up-front costs of the renewables programmes were not trivial and were borne by consumers, as were the costs of the carbon price support. The enhancement in electricity efficiency thus contributed to making the other two policy pillars politically acceptable; third pillar progress has opened up a whole new low-carbon resource; while the second pillar carbon price has squeezed coal from the system, helps to constrain rebound, and reassures low-carbon innovators of a market-based, ultimately subsidy-free landing point for their investments.

VI. Conclusions

Human decision-making is complex. For climate change, the scope ranges from the individual actions of eight billion people through to transformation over decades of some of the most complex socio-technical systems ever created.

Given that, this paper has argued the need to understand three distinct domains of decision-making. In economic terms this distinction allows for better understanding of the distance from the 'technology best practice frontier', by incorporating lessons from three theories of decision-making relating to different scales: individual and often short-term satisficing and habituation; more conscious and calculated economic optimization; and the strategic processes associated with transformation of technologies and systems.

Deeply embedded in the structure of modern economic thinking is a reference point of 'perfect markets'. This identifies climate change as 'simply' an externality to be solved by internalizing a carbon price, with first- and third-domain behaviours seen as market 'failures', to be 'fixed'. While in practice policy-making recognizes the need for broader and deeper policy intervention in order to tackle such a multi-faceted issue as climate change, the belief still lies at the core of most Western economic advice and dominates much of the academic economic discourse and modelling on climate change. We have argued that this framing is inadequate—and that, on its own, it demonstrably has not, and cannot, deliver the transformations required.

Even from a theoretical standpoint, the dominant economics framing neglects some of the foundational principles of economics itself, as noted by top economists. There is no reason why 'tastes, technology, the governmental and institutional framework' should be excluded from economic analysis (Samuelson, 1983). Compared to the abstract neoclassical ideal, we clearly live in a 'second best' world (including, the inadequacy of carbon pricing)—yet the classical prescription neglects the fundamental insight of Lipsey and Lancaster (1956) that the best policies in a second-best world are not the same as in abstract first-best equilibrium theory. Most recently, the Nobel laureate Akerlof (2020) warned about the 'sins of omission' arising from a focus on elements that are easily quantified and modelled, compared to other important dimensions in economic systems and policies.

The evidence and theories underpinning the three domains of decision-making highlight three distinct areas of opportunity for respective 'pillars' of energy/decarbonization policy, predominantly: (i) standards and engagement,

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[11] Calculated using DUKES data on energy expenditure by final user (Table 1.1.6) (BEIS, 2021) and GDP, current prices.

(ii) markets and pricing, and (iii) strategic investment. The mapping from domains to pillars is not unique—there are many cross-interactions—but presenting these domains and pillars within one integrated framework allows us to move past their representation as competing explanations of the same phenomena, or policies 'ranked' as better or worse. Instead, they are revealed as distinct processes in their own right, operating within different social, spatial, and temporal scales. This allows us to identify deep complementarities between pillars, and to argue the paradox of the title: that carbon pricing can only be effective if the boundaries of its effective operating space are well understood, and carbon pricing is paired with pillar 1 and 3 policies which can enlarge the political scope for carbon pricing, and enhance responses to it.

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