Climate change and carbon pricing: overcoming three dimensions of failure

Introduction

Addressing a group of energy companies, Pope Francis recently endorsed carbon pricing as 'essential' to stem climate change[1]. His statement joins those of countless governments, businesses, and academics backing this policy option as a vital key to unlock the 'climate puzzle.' Thousands of economists, for instance, have expressed support for carbon pricing in written petitions[2, 3], and young climate activists have called for this policy option in their 'Fridays For Future' demonstrations[4].

At the same time, criticism of carbon pricing has become louder. On the global stage, the UN Climate Conference held in Madrid, Spain, in November 2019 saw political divisions prevent an agreement on rules to enable international transfers of mitigation outcomes, a form of carbon pricing based on cross-border cooperation. For the second year in a row, international negotiations on climate change almost collapsed over this issue.

Acrimony over carbon pricing also persists at the domestic level. In the United States, a major policy proposal by progressive Democrats – the Green New Deal (GND) – remains silent on the option to adopt a federal price on carbon[5], and a large coalition of GND supporters has declared that it 'vigorously' opposes certain forms of carbon pricing[6]. The most visible manifestation of acrimony, however, were perhaps the street riots led by the 'Yellow Vests' movement in France in late 2018, which were triggered, in part, by an increase in the national carbon price[7].

Even among scholars, where the idea of a price on carbon used to enjoy almost unanimous support[8-10], views have become more bifurcated. An established body of theoretical literature that affirms the economic merits of carbon pricing and dates back almost half a

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century[11, 12] has recently been joined by studies pointing to the conceptual limitations and practical failings of this policy instrument[13]. Newer economic literature has, for instance, pointed out shortfalls related to the distributional effects and transformational effectiveness of carbon pricing, while behavioural studies have explored the limiting role of human preferences and perceptions, and political scientists have shed light on the important role of political constraints and regulatory capture. An overview of such studies and the main criticisms set out therein is contained in Supplementary Table 1.

Which side is right? The question is not merely academic: the stakes are high, given that proponents of carbon pricing tend to recommend it as the backbone of any policy effort to address what is seen by many as the most daunting threat humanity has ever faced[8]. As the debate on carbon pricing has become more divided, moreover, decision makers show understandable reluctance to endorse a policy option that has consistently been unpopular with voters, even before expert communities started becoming divided about its merits. We take this backdrop as the starting point for our Perspective, which acknowledges competing views in the debate and dissects the arguments raised on both sides.

Building on this taxonomy of views, we suggest a conceptual framework that differentiates three dimensions of failure undermining or impeding carbon pricing: first, situations where the rational pursuit of pure self-interest by an ideal-typical *Homo Economicus* – the perfectly rational agent of the standard economic model – leads to results that are sub-optimal in terms of aggregate welfare; second, situations where the real-world behaviour of *Homo Irrationalis* – human beings with individual preferences and limitations – generates sub-optimal results; and third, situations where institutional barriers and capacity constraints of *Homo Politicus* – political decision makers with specific preferences, perceptions, and interests – cause sub-optimal results.

Our framework allows categorizing past and future analyses of carbon pricing, and can help to identify trade-offs and interactions between the three dimensions. Insights drawn from economic, behavioural, and political science literature form the theoretical foundation of this framework, as summarized below and synthesized in Fig. 1. We apply this framework by categorizing the criticisms raised in recent literature (see Supplementary Table 1), and draw on the framework to identify a set of principles that can help overcome the three dimensions of failure. Before proceeding to the taxonomy of failures, however, we briefly review the theory underlying carbon pricing to highlight some inherent tensions as it transitions from concept to practical operation.

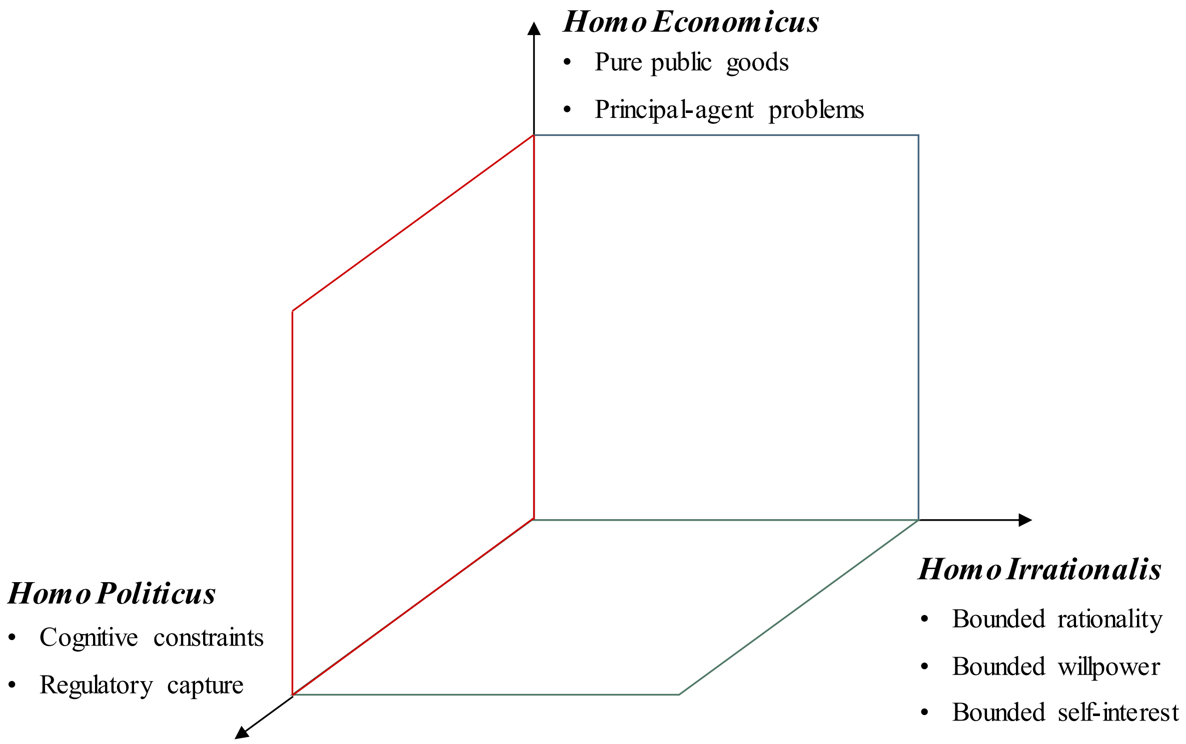

Fig. 1 | Conceptual framework with three dimension of failure and respective root causes.

Carbon Pricing: From Theory to Practice

Carbon pricing denotes a basket of policy approaches that explicitly price greenhouse gas emissions, for instance through a carbon tax or an emissions trading system[14]. In economic theory, a carbon price equal to the marginal level of damage caused by emissions yields an optimal emissions level, focusing mitigation effort where abatement costs are lowest while still allowing those emitting activities with the greatest economic benefit to continue[15]. Unfortunately, any attempt to estimate the future damages caused by current emissions is highly dependent on the choice of input assumptions, which is why such calculations tend to deliver a wide range of results[16, 17]. Uncertainty about the benefits of climate action[18], coupled with the perennial challenge of how to quantify uncertain risk[19-21] and variability across space[22] and time[15], place practical limits on such a welfare-optimal conception of carbon pricing.

This impasse has prompted governments to base climate policy on politically defined targets rather than economic cost/benefit calculations. With the Paris Agreement, for instance, most countries have committed to limiting global warming to 'well below 2°C' above pre-industrial levels[23]. Such quantified targets can be translated into a maximum concentration of greenhouse gases in the atmosphere and a remaining (cumulative) carbon budget, respectively. As a result, it is no longer necessary to estimate future climate damages and uncertain risks. Instead, the role of carbon pricing shifts from achieving a welfare-optimal outcome to securing the politically agreed carbon budget in the most cost-effective manner[24].

In practice, carbon pricing has experienced a mixed track record despite years of steady geographic and sectoral expansion[13]. As of November 2019, 56 carbon pricing initiatives had been introduced at the regional, national, or sub-national level. In total, these initiatives covered emissions of 8 $GtCO_2$ annually, equalling 14.9% of global greenhouse gas emissions[25]. Less than 5% of these initiatives imposed a price considered high enough to achieve the 2°C warming limit[14], however, and design shortfalls, political economy constraints, and an often secondary role alongside other policies in driving observed emission reductions have contributed to growing criticism of carbon pricing in the relevant literature[26]. Increasingly, such criticism is also rooted in conflicting epistemic paradigms, with perspectives rooted in evolutionary economics and sociotechnical transition studies contesting established notions of mainstream economics[27, 28]. We dissect and situate these criticisms in our mapping of the three dimensions of failure described in the next sections.

The Case of *Homo Economicus*

Climate change has been described as the "greatest market failure the world has ever seen"[15]. Mainstream economists define market failures as situations in which the rational pursuit of self-interest yields results that are inefficient from a societal point of view[29]. Greenhouse gas emissions cause climate change as they trap heat in the Earth's atmosphere. Because the resulting externalities of climate change are not reflected in the market price of products and services that result in greenhouse gas emissions, market results are inefficient in the absence of policy intervention. Carbon pricing can correct this market failure by internalizing the external costs of climate change into the activities that cause it[8].

Even if we assume that all economic agents are perfectly rational, however, as in the standard economic model of *Homo Economicus*, there are still situations where carbon pricing can fail to reduce emissions. This section focuses on the two additional categories of market failure that interfere with the theoretical efficiency of carbon pricing: pure public goods and principal-agent problems.

The first category of market failures stems from pure public goods – defined as non-excludable and non-rivalrous in use – as private actors cannot exclude non-payers from enjoying the corresponding benefits. Consequently, the benefits become positive externalities – or 'spillovers' – and private actors face a sub-optimal incentive to provide the underlying pure public goods at Pareto-efficient levels[30]. The following cases illustrate this general challenge in the context of climate policy by drawing on three examples with public goods characteristics that are necessary for deep decarbonization. These are innovation, knowledge, and infrastructure.

First, in the case of innovation, private actors might not be able to capture all the benefits of the technological advances they achieve[9, 31]. In the absence of perfect initial property protections – that could convert the public into a private good – others co-benefit from innovation through spillovers, and innovators face sub-optimal incentives to invest in research and development (R&D).

Second, in the case of knowledge accumulated through learning-by-doing, experience diffusion and leakage cap the incentives to improve processes and products. For instance, when knowledgeable employees leave a company, they are likely to benefit from earlier trial and error attempts of their employer[32, 33].

Third, in the case of infrastructure, in addition to the inability to capture all benefits, the required upfront investment frequently surpasses the financial capacity of private actors. Annual investments in infrastructure of $6.3 trillion have been called for between 2016 and 2030 to facilitate a decarbonization pathway compatible with the 2°C goal[34]. Such infrastructure needs include, for instance, electric vehicle charging stations or electricity transmission infrastructure to better integrate renewable energy.

Past progress in clean technologies and infrastructure offers abundant examples of spillovers, as the experience with solar photovoltaic (PV) technology shows (see Box 1).

Box 1 | Solar photovoltaic technology and the role of innovation and knowledge spillovers.

Solar photovoltaic (PV) technology offers a case study of market failures related to innovation and knowledge spillovers. Initial advances in solar PV were achieved by theoretical and experimental research at universities – driven by public research funding – rather than profit-motivated market participants. Subsequent learning-by-doing contributed to dramatically falling technology costs, and was again spurred by support policies rather than a carbon price[35]. In Germany, for instance, a comprehensive feed-in tariff system promoted the expansion of solar PV. Relative to the direct emission reductions achieved, this policy option appears particularly costly: one estimate suggests that, between 2006 and 2010, the feed-in tariff amounted to an average abatement cost of €537 per ton of CO_2 avoided[36]. To bridge the price differential between solar PV and conventional fuels, however, a carbon price would have had to be as high as $700 per ton of CO_2[27]. Because it would have applied to all emissions from incumbent generators, moreover, it would have imposed a considerable drag on the economy if passed through to electricity customers without some form of redistribution of fiscal revenues. Nonetheless, looking beyond static cost-effectiveness, such early support policies were critical to accelerate renewable energy progress along the technology learning curve[37-39]. Time-limited incentives in a subset of countries have thus helped make solar PV competitive around the world today[40].

The second category of market failure originates from principal-agent problems. If one party (the agent) acts on behalf of another party (the principal), problems may arise from divergent objectives and asymmetrical information[41, 42]. Agents may have private information that is ignored by the principal (cases of hidden knowledge or adverse selection), or agents may take actions that are unobservable for the principal (cases of hidden action or moral hazard)[43]. In particular, adverse selection in the case of split incentives, and moral hazard in the case of divergent time preferences, limit the ability of carbon pricing to tap into its full potential.

First, in the case of split incentives, costs and benefits accrue to different parties, and difficulties can, therefore, arise from divergent levels of information. In such constellations, investment in measures to improve energy efficiency tends to fall short[44]. Landlords, for instance, have little incentive to enhance energy efficiency if tenants pay for electricity and heat[45, 46]. A similar constellation can be found in the relationship of a ship-owner and charterer, where price sensitivity to charter rates prevents the implementation of measures in order to improve fuel efficiency[47].

Second, moral hazard can arise from divergent time horizons: and business and political cycles typically do not align well with the time horizon of climate change[48]. For instance, it is rational for agents with short term incentives to underspend on R&D, which only promises benefits far in the future. Likewise, self-optimizing agents could misprice long-term risk in order to increase short-term profits. In the case of high carbon assets, such mispricing of risk may result in large-scale asset stranding – with devastating wealth loss and distributional impacts[49]. It is worth noting that the risk of asset stranding also occurs under command-and-control policies, which, although arguably providing a clearer policy signal, may still be changed at a later point in time.

All these market failures assume that individuals are rational actors. As the next section illustrates, however, the assumption of individual rationality is rarely borne out in practice, adding further challenges for the operation of a carbon price.

The Case of *Homo Irrationalis*

Even if measures are taken to correct the market failures acknowledged in the standard economic model, behavioural failure can still cause undesirable market outcomes, as human behaviour in the real world deviates from that of the rational *Homo Economicus* assumed in the previous section. Therefore, policy design must account for both dimensions of failure, as correcting only one dimension will not ensure welfare optimal results[50].

Behavioural economists aim to account for over seven billion individual human beings who cause market inefficiencies with their individual preferences and limitations. Such behavioural failure of *Homo Irrationalis* justifies policy intervention to enhance welfare, either by protecting individuals from themselves or others from externalities that arise from their actions. In this section, we identify areas where human behaviour differs from that of perfectly rational agents due to bounded rationality, bounded willpower, and bounded self-interest[51].

Bounded rationality describes the causes of irrationality in human decision-making. Most decisions are rational because they are aligned with individual goals and preferences. Individuals only rarely make irrational decisions – decisions counterproductive to self-selected goals[52]. However, decisions perceived by the agent to be rational can be irrational from a more knowledgeable point of view. Research has amply described mistakes in human decision-making, identifying cognitive biases, predicting failures in choice, and recommending that policy-makers nudge decisions by modifying choice architectures[53, 54]. A bias to neglect opportunity cost, for instance, may explain why people favour policies with indirect cost over such with direct cost.[55] Accordingly, factors such as individual worldviews affect the optimal design of financial incentives; it matters if these are designed as subsidies or penalties, and furthermore, how they are labelled[56, 57].The example of electric vehicles (EVs) in Box 2 highlights the relevance of policy choice and incentive design.

Box 2 | Electric vehicles and the role of policy design.

The example of electric vehicles (EVs) in the transport sector illustrates that, in some situations, subsidies are better suited to achieve specific policy goals. Modelling work shows that a carbon price of \$100/tCO_2 (roughly equal to \$1 per gallon of fuel) would likely increase the global share of EVs from 0.3% (in 2017) to 15-34% by 2050[58]; that uptake is far too low to comply with the 2°C temperature goal of the Paris Agreement, which already requires at least 20% alternative-fuelled vehicles in the transport fleet by 2030[59]. By contrast, Norway used a subsidy program to achieve 60% of new car sales being electric or hybrid vehicles in 2018[60]. This example reveals the goal conflict between transformational effectiveness and cost effectiveness: an evaluation of the Norwegian subsidy program shows abatement costs of NOK 30,000-40,000 (~\$3,300-\$4,400) per tonne of CO2[61], which appears extremely high from a static perspective. As mentioned in Box 1, however, such comparisons neglect the value of dynamic network and learning effects.

Bounded willpower, the second way in which human behaviour deviates from that of perfectly rational agents, is another behavioural factor affecting how individuals respond to carbon prices. Even if individuals have the cognitive ability, perfect information, and sufficient time to reach rational decisions, they tend to be myopic[62], and self-control issues trigger choices that run counter to their long-term interest[51]. Human beings favour procrastination[51] and prefer retaining the status quo over changing it[63]. In the context of energy efficiency, for instance, people tend to discount future savings with irrationally high rates, and therefore adhere to their current, inefficient energy use patterns. For energy-efficient appliances, implicit discount rates (estimated to be up to 300% for refrigerators[64] and 825% for electric water heaters[65]) underscore the challenge. A review of studies assessing individual discount rates resulted in rates ranging from -6% to infinity[66].

The third dimension of bounded behaviour is bounded self-interest, that is, the willingness to help others at the expense of personal welfare[67]. Such selfless – or pro-social – behaviour can be observed in the intrinsic motivation to make unpaid contributions to society[68]. Once monetary incentives are introduced, individuals tend to lose this intrinsic motivation, crowding out the perceived need for action. This phenomenon of crowding-out has been observed, for instance, in the context of waste recycling and community work[69]. Crowding-out also occurs when individuals pay for certain types of behaviour, including environmental pollution; such payments – whether voluntary or mandatory – can make individuals feel entitled to pollute, diminishing the motivation to change their polluting behaviour[70],[71]. Experimental research has confirmed that environmental pricing can crowd-out environmental preferences, suggesting that a carbon price would need to be set considerably higher than if such crowding-out effects were absent[72, 73].

While irrational behaviour likely affects all climate policies, it stands to reason that carbon pricing and other policy options premised on rational price calculations are particularly vulnerable. Finally, yet another vulnerability of carbon pricing has – unlike behavioural irrationality – received ample attention in the literature and is discussed in the next section: the political economy of carbon pricing.

The Case of *Homo Politicus*

Not only markets and individuals are susceptible to failure: governments can also fail by regulating inadequately due to cognitive, organizational, and political limitations and shortfalls[74-77]. Ever since Aristotle conceived of a *Zōon Politikon,* the notion of a *Homo Politicus* has existed as a counterpart to that of *Homo Economicus*, with specific social preferences[78], contingent perceptions of justice[79], and idiosyncratic self-interests[80]. Many insights from the study of human behaviour also apply to politics: Since governments are formed by, recruited from, and serve individuals relying on cognitive heuristics[81], behavioural economists attempt to understand decision-making in politics, and identify, for instance, individual biases as sources of bad policies[82-84]. As we show in this section, information is key to cognitive constraints and regulatory capture.

Governments act through individuals, whose cognitive constraints can result in flawed policies due to information asymmetries and a failure to respond adequately to the available information[82-84]. This failure to see, seek, use, or share relevant data has been coined ‘bounded awareness’[85]. Due to its complexity, climate change incurs a significant risk of political decision makers missing relevant data, ignoring signs, and taking insufficient action[86]. Firms try to take advantage of this bounded awareness by lobbying for their vested interests, for instance by selectively providing information that supports these interests. Box 3 summarizes lobbying activities in the context of climate-related legislation.

Box 3 | Lobbying expenditures on climate-related legislation.

From 2000 to 2016, lobbying expenditures on climate-related legislation in the U.S. added up to over $2 billion, or 3.9% of the total spending on lobbying[87], with measurable success[88]. It is noteworthy that lobbying on behalf of fossil fuels outpaced renewable lobbying 10:1 in terms of spending. Where lobbying for renewable energy occurs, it tends to favour targeted support policies such as clean technology subsidies rather than carbon pricing. According to the International Energy Agency (IEA), for instance, global subsidies for renewables tripled to $140 billion from 2007 to 2016, and are predicted to rise to $200 billion by 2040[89]. Still, the challenge of lobbying is not limited to carbon pricing. Lobbying subverts all types of regulatory design and enforcement, yet to different degrees. Anecdotal evidence from efforts to introduce or strengthen carbon pricing systems suggests that, by creating an explicit price signal and thus greater transparency about the financial burden of compliance, carbon pricing is particularly vulnerable to lobbying efforts geared at its prevention or reversal. An example can be found in Washington state, where major oil companies donated millions and thrice contributed to the defeat of a proposed carbon tax[90].

Lobbying also relates to the second dimension of government failure, termed regulatory capture[91]. As seen during the design phase of the European Union Emissions Trading

System, a significant share of emitting installations succeeded in receiving more emission allowances than they needed, undermining the environmental stringency of the entire system[92]. The phenomenon of polluters shaping climate policy is evident across a majority of jurisdictions[93]. That the limited number of large emitters facing major and immediate regulatory costs will rally more effectively than the population at large, which can only expect minor benefits over the long term, might explain this phenomenon[94].

All these failures contribute to the consistently challenging political economy of carbon pricing. By rendering the cost of compliance visible and imposing it disproportionately on a limited group of articulate and politically influential emitters, while the benefit of lowered emissions is spread out among diffuse and poorly organized constituents, carbon pricing exemplifies the failure of collective action in the common interest[94]. Likewise, opinion surveys routinely show that carbon pricing is less popular with the public[95, 96] and voters[97] than alternative policies, and also less likely to build coalitions of support[98]. Claims that carbon pricing is regressive[26, 99] – although possibly unfounded even in scenarios without revenue recycling[100, 101] – make this policy option particularly vulnerable in the political process. A recurring proposal in the literature has, thus, suggested starting with more popular policy choices before shifting to a carbon price[102-104], and using carbon pricing revenue to address any perceived inequities[105, 106]. Similarly, allowance allocation decisions in emissions trading systems can be used to soften political resistance and shield any sectors that might be adversely affected by a carbon price[107].

Overcoming these failures of *Homo Politicus* will be particularly important to promote innovation in the low-carbon technologies required to achieve deep decarbonization. Political decisions pave the road towards technological innovation and system development. As the theoretical discussion of spillover and network externalities showed earlier, strategic investments are essential to promote low-carbon technologies, which require large capital flows and long-term investment horizons[108]. In practice, as the case of solar PV in Box 1 illustrates, strategic investment is key to shaping the development of the energy or transport systems in the long term. Given the high stakes involved in such investment decisions, lobbying of pressure groups represents a major challenge in prior deliberation – especially, as rational behaviour on the level of individual politicians does not necessarily eventuate in collective rationality[109].

Implications for Policy Design

Throughout history, government-imposed pricing policies have been a recurring cause of civil unrest[110]. The Yellow Vest protests in France in late 2018 and early 2019 – directed, *inter alia*, against rate hikes for fuel taxes in combination with a decrease of social welfare benefits[111, 112] – underline that policy-makers still struggle to understand and address the social and political impacts of carbon pricing, as well as the knowledge, preferences, and reactions of the public and affected stakeholder groups[7, 113].

Our human agents-based review of the three dimensions of failure corroborates the growing recognition that carbon pricing can be an important element of an ambitious climate policy portfolio to stimulate decarbonization. While it thus affirms the need for complementary policies, such as support policies with greater transformational effectiveness or regulatory policies with greater target effectiveness, it also does not support abandoning carbon pricing outright, as some critical authors have suggested[27]. Instead, the challenge lies in identifying those areas where carbon pricing can genuinely deploy its strengths as a policy instrument and those areas where targeted policies may be required.

To identify the areas where carbon pricing works best, we draw on a classification first proposed by Grubb[108]. As Grubb has observed, the effectiveness of different policy options varies along the marginal abatement cost curve. This prompts him to distinguish three domains within the marginal abatement cost curve, each of which corresponds to a 'pillar' of policy response[108]. As seen below and illustrated in Fig. 2, these domains share many similarities with the three dimensions of failure identified in this Perspective.

First, as we summarized in the section on *Homo Economicus*, neoclassical and welfare economic theory suggests market-based tools to realize CO_2 abatement particularly efficiently. Especially in the middle of the marginal abatement cost curve, carbon pricing may induce emission reductions, for instance by triggering fuel-switching in the power sector[114]. The efficiency of carbon pricing to achieve emission reductions at the margin through process optimization has been amply demonstrated[108]. Assuming a certain degree of rationality and market functioning, carbon pricing initiatives focus mitigation efforts on activities with the lowest abatement cost, and are therefore an important element in any climate policy portfolio to drive emissions reductions cost-effectively in the near term[115]. Second, as we summarized in the section on *Homo Irrationalis*, behavioural economics provides a theoretical explanation of barriers to energy efficiency, which are difficult to address with carbon pricing. On the left side of the marginal abatement cost curve, where financial incentives tend to be ineffective, information policies such as labelling and command-and-control policies such as performance standards, phase-outs, or outright bans tend to be more effective. Bans of inefficient light bulbs are a poster example[116]. Pricing mechanisms can provide incentives, but will not prevent people from engaging in certain conducts[53].

It is noteworthy that bans may also alter social norms. As seen in wake of the Covid-19 pandemic, social norms may change once certain behaviours become the new normal. For instance, wearing face masks was traditionally considered as a signal of fear. Mask requirements helped to make the norm disappear. The same might apply to mobility patterns. From Athens to Sydney, cities have rededicated public spaces from cars to cyclists in 2020, and some of these changes will likely survive the pandemic[118].

Third, as set out in the section on *Homo Politicus*, public choice theory explains challenges faced in making collective decisions, which, in turn, have vital consequences for policy making to foster innovation. In particular, at the right side of the marginal abatement cost curve, technologies can be found which require large investments and long-term horizons. It is important to identify such areas which actually require complementary policies in order to avoid supporting dead-end technologies while precluding valuable alternatives that are either unknown to policy-makers, or underappreciated in their mitigation potential. Directed policies sacrifice the availability of those technology options which are not favoured by support policies, whereas carbon pricing creates a technology-neutral incentive for all mitigation options[119, 120].

In the context of directed technology support, we must not forget the role of uncertainty in innovation and development time. Focusing on short-term cost-efficiency does not ensure that low-carbon technologies exist and are available at scale by a given deadline. If the costs of not meeting this deadline are high, delaying investment even in the most uncertain technologies needed for deep decarbonization may be costly in the long term[121].

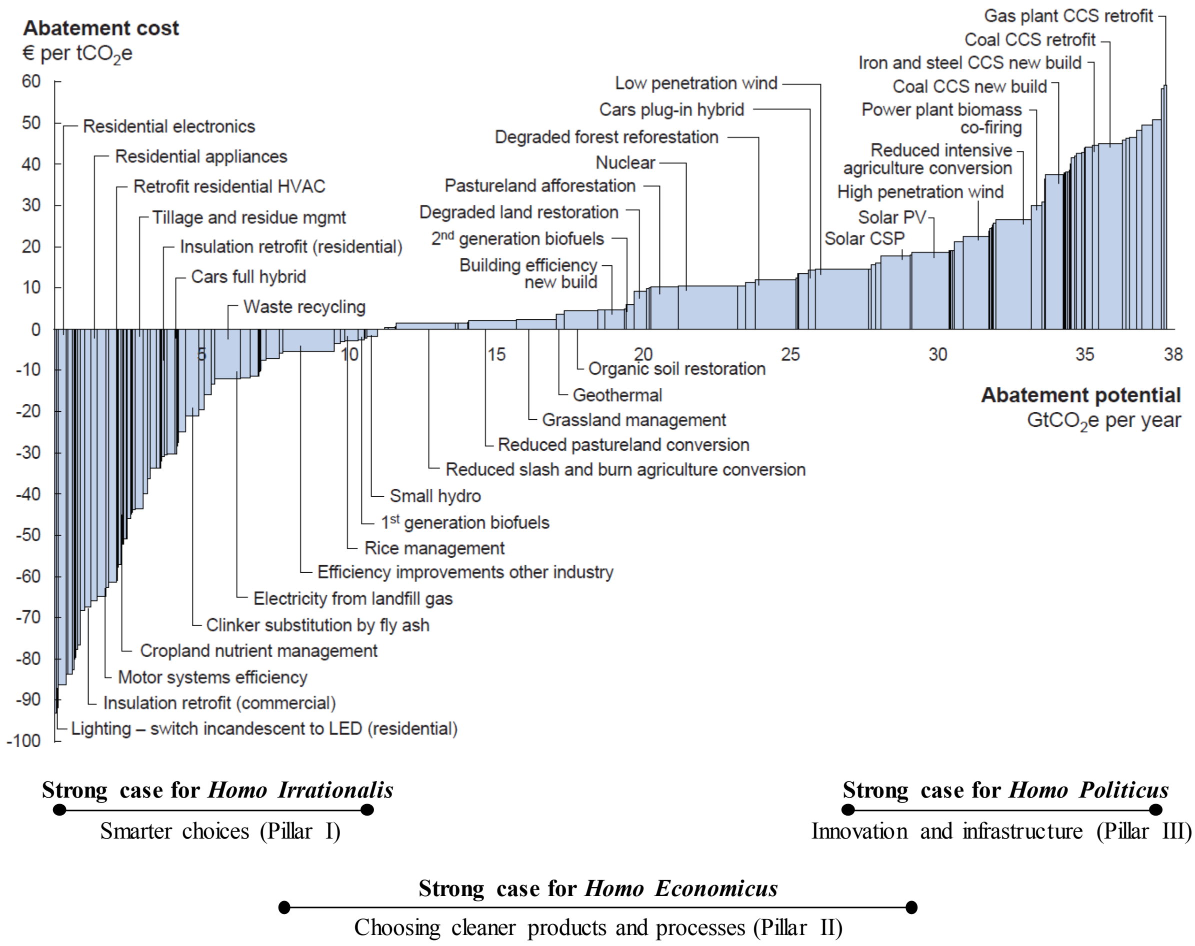

Fig. 2 | Marginal abatement cost curve identifying location of policy pillars and failure dimensions. Marginal abatement cost curves (MACCs) chart technologies and their CO_2 abatement potential, sorted by the technologies' abatement cost. Fig. 2 displays such a MACC, which estimates how much it will cost to abate a tonne of carbon dioxide in the year 2030[122]. On the left side of the MACC, one can find the technologies with the lowest abatement costs, which are negative in many cases. This means that these technologies may not only reduce emissions but also save costs compared to the alternatives in use.

The framework we suggest may also be used to identify and classify solutions to overcome the three dimensions of failure. Based on a review of recent literature in the field, we propose five principles to guide action on carbon pricing. Based on these principles, carbon pricing should be equitable, incremental, attractive, simple, and collaborative in order to overcome political and behavioural constraints that prevent its introduction and efficient operation (see Table 1). Taken together, these principles may help overcome the failures that have held back carbon pricing from achieving its full potential in the past, and facilitate a transition to the higher price levels recommended in the literature.

Table 1 | Five principles to support a shift to carbon pricing at higher levels.

Principle		Details
Equitable	×	Aside from economic efficiency, distributional effects matter[123]. If policy makers take action to achieve deep decarbonization, the redistribution of income will become a major challenge[124-126]. Unlike subsidy programs or phase-out mandates, carbon pricing generates fiscal revenues, which may be returned as 'carbon dividends'[2]. Smart use of these revenues may help overcome political and behavioural constraints[127]. To gain (and retain) public support, it is crucial to understand and consider short-term distributional effects (and long-term behavioural adaptation).
Incremental	-	Although researchers highlight the need to tackle the climate challenge sooner rather than later to avoid rising long-term costs[128, 129], implying that the time for incremental change has expired[130], abrupt introduction of a sufficiently high carbon price appears to be politically and behaviourally impossible. Therefore, long-term strategies with phased, incremental carbon pricing coupled with other more direct policies are needed[98, 103, 131]. Importantly, however, such incremental carbon pricing has to begin soon; otherwise, we lock ourselves into future dependence on radical or risky strategies, such as geoengineering.
Attractive	-	Policies cannot stop people from certain types of conduct[132]. However, the boundedness of human rationality is not only a challenge, but also an opportunity. Since most people care about the climate[133, 134], the right framing may lower efficient price levels. Economists have demonstrated the power of nudging[135], effects of energy efficiency labels[136], or benefits of green default rules[137]. In practice, efforts to leverage such tools have just begun[72, 138]. Also, communicating the environmental benefits of carbon pricing and revenue use – rather than focusing on the price itself – has been shown to increase the attractiveness of relevant policy proposals[139].
Simple	•	Political decision makers are not climate scientists. A timeline to reach net-zero emissions, for instance, is much easier to understand than arguments based on remaining cumulative emission budgets, along with scenarios such as the four representative concentration pathways of the Intergovernmental Panel on Climate Change (IPCC). Simplicity has been suggested as a key success factor in policy-making[83]. Researchers should account for that in their communication.
Collaborative	•	The consequences of climate change create a powerful incentive for sectors such as finance, insurance, and agriculture to engage in mitigation[140]. Recent coal divestments of insurance companies and pension funds underline that potential[141], which is not limited to the corporate sphere. Policy makers should seek to enter into a dialogue with communities, who may encourage pro-environmental behaviour among their members[142]. Religious leaders, for instance, can potentially reach a sizeable share of the world population[143] with their messages. In addition, the 'Fridays for Future' initiative has demonstrated the potential of influencing politics from the bottom up.

Type of success factors classified with the framework proposed in this Perspective: *Homo Economicus* (×), *Homo Irrationalis* (-), *Homo Politicus* (•).

In this Perspective, we have suggested a framework to classify the conceptual, behavioural, and political constraints that currently prevent broader, deeper, and more effective deployment of carbon pricing in a world populated by *Homo Economicus*, *Homo Irrationalis*, and *Homo Politicus*. Despite its acknowledged limitations, carbon pricing remains a valuable lever to prevent climate change – the greatest market failure ever – from also becoming the greatest government failure ever. By classifying these limitations, the analytical framework presented here can help decision makers obtain a more holistic appreciation of the factors that determine the success or failure of carbon pricing (as illustrated in Supplementary Table 2). We have further inferred principles that can guide policy action to help overcome the foregoing limitations. Future research should expand and deepen our understanding of these limitations, and also identify the interdependencies and trade-offs between the three dimensions of failure.

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