npj | climate action

Article

https://doi.org/10.1038/s44168-025-00284-9

Pricing instruments in environmental and climate policy when polluters are boundedly rational

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The use of pricing instruments in environmental policy has been argued to have certain advantages, notably related to static and dynamic efficiency as well as effectiveness due to economy-wide scope. This paper adopts a broad perspective to provide a complete set of arguments in favour of price-based instruments in environmental policy, illustrated for climate policy. Pricing instruments are still not used to their full potential. The reason is that there is still considerable unfounded scepticism, including by researchers in the social environmental sciences, about their functioning and performance. Different disciplines express distinct and partly inconsistent ideas on the desirability of pricing instruments. An important recent criticism is that traditional economic arguments for pricing instruments are based on rational agents and are inconsistent with findings of behavioural economics. We examine this argument by assessing how instruments behave under various realistic behavioural assumptions in line with bounded rationality and other-regarding behaviour. We find that the case is strengthened for cap-and-trade versus environmental taxation. We also discuss additional instruments to effectively counter environmental and climate challenges under bounded rationality and social interactions.

After decades of studies on environmental policy, there is no definite agreement between the various disciplines involved about what policy instruments are to be preferred. This is well illustrated by the recent literature on climate policy. Propositions from various disciplines, such as economics, environmental studies, sociology, political science and psychology, do not articulate a consistent view on what is the best policy design for climate change mitigation. As a result, policymakers and practitioners are confronted with a vast number of policy propositions broadly classified as economic or market-based approaches (e.g., pollution and energy taxes, renewable energy tariffs and permit trading), direct regulation or command-and-control (e.g., performance- and technology-based standards and mandatory phasing-out of energy-intensive products such as incandescent light bulbs), enabling (feed- in tariffs for renewable electricity, subsidies for electric vehicles, heat pumps or rooftop solar PV) and information-based instruments (e.g., education campaigns, energy-efficiency labelling schemes, and voluntary energy conservation)[1]. Others have focused on more radical policy proposals, including the stimulation of direct action (environmental movements), or have expressed a strong belief in voluntarism and associated local solutions[2], including holding companies responsible for their own and even their customers' ("Scope 3"; see, e.g., ref. 3) emissions. Not surprisingly, this plurality of perspectives can cause much confusion among policymakers about whether and where to put one's priorities in the instrument mix. To this one can add uncertainty about the positive and negative synergies of instrument combinations[4].

While the Kyoto Protocol meant an important advance in the debate on international economic instruments, notably about cap-and-trade systems to reduce emissions like the EU's ETS, there is an ongoing debate about the adequacy of market-based or tax-based solutions for climate policy. Environmental economists and various international organizations have repeatedly called for price-based solutions[5–7]. This approach is based on the economic theory of environmental policy according to which pricing of negative environmental externalities means internalizing the market failure and thus assuring that private and social costs coincide. This will result in private decisions by all producers and consumers that generate the best outcome in terms of social welfare[8].

In recent years, much attention has been given to bounded rationality and social interactions, and what this means for the design of environmental and climate policy. It has been suggested that these deviations from rationality imply that pricing instruments will not work well. We will examine if this is true, and if so under what conditions. We will conclude

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that environmental pricing is able to handle, and that some forms can even perfectly deal with, non-rationality. Nevertheless, there remains room for employing additional instruments, notably information provision and behavioural nudges.

To set the stage, Section 2 will sketch the main reasons for using pricing instruments in environmental policy, while Section 3 will summarize and provide brief responses to main criticisms of pricing instruments. Along the way, we will illustrate specific points made for the context of climate policy and carbon pricing. Section 4 examines what bounded rationality and social interaction mean for the role of traditional pricing and other instruments in the design of environmental policy. Section 5 concludes.

Arguments for using pricing in environmental and climate policy

Eight key arguments in favour of pricing as an instrument of environmental and climate policy are:

1. Pricing of negative environmental externalities means that private and social costs are made equal, which guarantees private decisions to be in line with net social benefits, or more generally, social welfare. This assures more socially desirable decisions by all agents in the economy, including firms, consumers, investors and innovators, as all of these are influenced by costs and prices.
2. A main advantage of price regulation over other instruments is that it can address heterogeneity of polluters, thus reducing the cost of pollution control. Heterogeneity might take the form of firms having different sizes, production (and thus polluting) technologies or organization structures, which at an abstract level would translate into distinct marginal cost curves of pollution reduction (abatement). This results in a relatively low cost of pollution reduction under a price incentive because all polluters will reduce pollution until the associated marginal cost equals the pollution price (charge, levy, tax or tradable permit price). The marginal abatement cost will then result to be identical among all polluters (in the ideal case of fully rational firms), implying that a particular overall pollution goal will be met against least costs.
3. Pricing of pollution at the "source" means that all other prices in the economy will adapt to reflect the indirect external cost. So, for example, pricing $^{CO}2$ emissions in the form of putting taxes on fossil fuels (petroleum, natural gas and coal) that generate carbon emissions will make sure that all goods and services in the economy will have higher market prices as their cost will reflect their pollutive character, and moreover over their entire lifecycle (including resource extraction, production, consumption, recycling and waste stages) as all prices of all intermediate products will reflect direct and indirect pollution. In other words, both direct and indirect emissions of all decisions will then be discouraged. The entire economy can thus quickly become more sustainable as all consumers and producers will adjust their decisions to the changed, "sustainable" prices, opting for cleaner inputs, process technologies, intermediate products, and final goods and services.
4. Pricing is dynamically efficient, that is, it stimulates innovation and adoption of new technologies that are more efficient (cost-effective) in reducing pollution. For example, a carbon tax increasing the prices of fossil energy will create incentives for consumers and producers to invest in energy-efficient or renewable-energy technologies, in turn limiting $^{CO}2$ emissions. Empirical evidence suggests a positive relationship between higher energy prices and the development of (green) innovation technologies[9,10], and similarly between carbon prices and innovation[11,12]. In comparison with a price instrument, a uniform standard provides a weaker economic incentive (benefit) for the adoption and R&D of improved abatement technologies because the potential cost savings are smaller[13]. If prices reflect environmental impacts, any innovation trajectory will better take into account all direct and indirect "environmental costs" and thus be more likely to arrive at a definite, sustainable solution to environmental problems than without such externality pricing.
5. No other instrument than pricing can reach emission mitigation at a similar effective and detailed level. One study confirmed this by comparing policy options to reduce emissions, finding that only an emission price on $^{CO}2$ is able to control and reduce emissions at a lower cost than any other policies[14]. Another study makes a similar case for carbon pricing[15].
6. Pricing will make sure that there are no leakages like rebound, i.e. indirect unintended and unwanted production, consumption, innovation and diffusion effects that create more pollution elsewhere. Because of consistently higher prices for all products in the economy proportional to the total (direct and indirect) pollution there are no escape routes: higher prices will stimulate economic agents to search for cheaper and thus environmentally better performing close alternatives, while if they choose to purchase very pollutive alternatives, the pollution price means less income will be available for purchasing other pollutive goods and services. Tradable permits may function better in this respect than taxes as they will lead to higher prices if rebound tends to occur, which will then discourage the rebound-causing actions.
7. Pricing represents a form of regulation that allows for flexibility and freedom on behalf of the polluters which means decentralization of policy, with associated low information needs. This matches well the liberal character of our society. In addition, pricing—instead of, e.g., carbon- labelling—means that no separate life-cycle analysis (LCA) is needed to account for all the environmental effects of products and services over their life-cycle. Instead, firms will integrate energy taxes or a CO_2 price in existing cost-accounting systems of their products and services. As a result, information needs of pricing instruments are low.
8. Most people are not environmentally conscious but simply search for cheap deals when making purchasing decisions—effective policy evidently should reach out to this majority: price regulation will be capable of doing this, without restricting individual freedom too much and without assuming that people are altruistic (showing voluntary environmentally benign behaviour) or can handle much information (like ecolabels). Hence, the best way forward is to assure that "dirtier is more expensive" and "cheaper is greener"—both of which environmental pricing will achieve.

Responding to arguments against pricing in environmental policy

There is still considerable resistance to pricing in environmental and climate policy[16–18]. Here we discuss some widespread concerns and counter-arguments[19].

Pricing environmental externalities is often seen as raising costs in general. In line with this, there is widespread concern that consumers will lose purchasing power and producers' profits. This is not true if taxes are shifted from labour to energy and materials. Indeed, the main goal is not to raise prices in general but to alter the relative prices of cleaner and dirtier alternatives to the advantage of the former, so that choices are motivated to shift from dirtier to cleaner options. Especially concern that a carbon tax will place a tremendous competitive burden on carbon-intensive sectors in an open economy has been influential. The fear of trade effects and carbon leakage drives such sentiments[20]. This has motivated the complementary instrument of border carbon tariffs which are discussed in the literature as a serious option and currently implemented by the European Union[21].

A reason why getting social-political support for pricing instruments in environmental policy has not always been easy is that other disciplines than economics within the social sciences, in particular policy sciences, political sciences and sociology, have contested pricing instruments as these are considered to be associated with neoliberal ideology. The vague alternative solution offered is to move away from markets and competitive firms, rather than adapt market economies through externality pricing[22–24].

Another important concern relates to the distributional impacts of pricing instruments. For example, "energy poverty" is often invoked in discussing a carbon tax[25]. But this neglects that evidence shows carbon pricing tends to be progressive in low-income countries, and regressive in only some high-income countries[26,27]. It also ignores the many proposals in

the literature to use pricing revenues to compensate low-income households[28,29]. This does not deny the potential role of adapted or complementary instruments, such as correcting for unwanted distributional impacts in the design of pricing policies—e.g., through block-pricing or relatively high environmental taxes on expensive status goods that are disproportionally consumed by the rich. Nevertheless, it should also be recognized that any policy which is effective in combating climate change will have severe distributional consequences—whether it concerns pricing, standards or quotas. The basic problem is that all environmental policies operate in a world characterized by existing inequalities, which means that if prices of polluting commodities go up due to whatever environmental regulation, then some will suffer more from this than others. While pricing or tax solutions are often criticized in this regard, adoption subsidies are generally presented as not having these problems. However, they often tend to be inequitable too: think of subsidies for electric vehicles or rooftop solar photovoltaic panels—both tend to benefit mainly well-off households, who can afford an expensive car and own a house[30].

A more fundamental objection is that pricing amounts to assigning an instrumental valuation to nature, legitimizing polluting activities and neglecting any intrinsic value of nature[31]. However, the same holds for any policy, as none can (immediately) erase all activities that directly or indirectly contribute to environmental pressure. Moreover, a problem with the notion of intrinsic value is that it cannot be made explicit, since by definition it is devoid of human interference. Hence, anything said about it—by humans—will not just be subjective and debatable but inconsistent with the meaning of 'intrinsic', and in fact move towards the instrumental notion of existence value (reflecting psychological benefits people derive from knowing something exists, even if they do not use it).

Standard economic theory of environmental policy uses notions of optimality, suggesting that Pigouvian taxes (with a value equal to the marginal external costs in the hypothetical social welfare optimum) can bring the economy to the socially optimal point. However, if certain conditions are not satisfied (other market failures such as imperfect competition, asymmetric information, public goods or bads, and bounded rationality of agents) then this result is not precisely true. Many theoretical studies have been undertaken to examine the various second-best solutions if the first-best world is not attainable[32,33]. However, it should be said that the qualitative arguments above generally still hold if the assumption of bounded rationality (and other- regarding preferences or social non-market interactions between economic agents) is accepted. What changes, though, are precise pricing rules.

To further motivate this latter point, note that the basic issue here is price sensitivity of all consumers and producers who will adjust their decisions to the changes in product prices reflecting environmental costs. Many empirical studies indeed show that energy prices are an important factor of behaviour, of both producers and consumers[34]. Besides changing consumption patterns, a carbon tax (ultimately increasing energy prices) will create incentives for consumers and producers committing to invest in new and more energy-efficient technologies that are able to considerably reduce $^{CO}2$ emissions in their activities. In fact, empirical evidence suggests a positive relationship between higher energy prices and the development of "green" innovation technologies[35,36]. One study finds on the basis of patent data that price instruments have the largest inducement effect on innovation[37]. Another shows, using an empirical model with a range of environmental and technological policy instruments, that a price on $^{CO}2$ emissions is the most efficient single policy to reduce GHG emissions[38]. The reason is that this simultaneously stimulates consumers to conserve energy, fossil energy producers to reduce emissions, and renewable energy producers to increase production and reduce costs.

A combination of price regulation and technology policy instruments is even better, as they serve complementary roles, and deal with two types of externalities[39], namely environmental (negative) and knowledge (positive), and possibly even a third, namely related to lock-in (also negative)[40]. Indeed, technological policy aims to create incentives for innovation and keep options open that are not attractive currently (high costs) but may be the best performing in the future (i.e. lowest cost of reaching environmental goals, such as lowest cost of abatement, or of renewable electricity production). With only environmental regulation (with prices or standards) but without technological support—e.g., in the form of subsidies or price guarantees for expensive but promising technological options—the currently cost-effective technology would outcompete the more expensive technologies, even if some of these might perform better in the long run. Such a myopic solution should be avoided—therefore technological policy is needed as well.

Implications of bounded rationality for pricing and complementary environmental-policy instruments

Behavioural economics, an emerging subfield of economics, aims to provide a more accurate and realistic picture of human behaviour. This has given rise to various alternative theories to describe consumers and producers[41,42]. Empirical and experimental studies have examined a wide variety of behavioural factors, including decision biases and heuristics, conformity, status-seeking and social norms, behaviour under uncertainty and risk, and hyperbolic discounting. This has already seen considerable application in studies of environmental policy[43–46]. Next, we examine the most relevant behavioural implications for environmental policy design.

There is now broad support for the idea that human behaviour in many economic settings is often characterized by bounded rationality[47]. In many situations individuals are faced with complex decision-making processes (e.g., a vast amount of offered products which need to be compared) and instead of maximizing their utility very quickly they deviate from optimal, rational decisions. Behavioural economics has proposed a set of explanations for such behaviour including cognitive limitations, inattention, and framing. Yet, if consumers and producers are boundedly rational, it is likely that there is not a straightforward prediction of how they respond to a policy (and subsequent price increases) which is, moreover, typically embedded in a complex set of pre-existing policies. There is experimental evidence suggesting that individuals may ignore taxes on goods if they are hidden, i.e. not labelled in the price tag[48]. Such behavioural responses then lead to low tax (price) elasticities and consumers are likely to continue purchasing the same amount of the taxed goods (while income constraints may mean they will save less in the end). The authors attribute this reaction to the "salience effect" which explains that the less salient and transparent a tax is, the more likely are consumers to underreact to it.

For carbon taxation, such insights might imply less than optimal responses as predicted by rational agent theory. Non-transparency is relevant here as carbon taxation is ideally applied at the source, that is, to fossil fuel suppliers and processors ("upstream"). Producers will pass on the increased costs of carbon-intensive goods to consumers, but these will not necessarily know about the cause (taxation). One approach to increase carbon tax salience in order to avoid behavioural under-reactions to taxation is to invest in education campaigns which inform about the environmental tax cause of price increases in all goods and services. The significance of this approach is underscored by widespread public concern regarding the transparency of the impact of carbon taxes on prices and the allocation of generated revenue[49]. One can, anyway, expect producers and investors to considerably invest in private advertising and information provision to explain higher product prices to consumers. Another approach involves separating tax information from the displayed price to increase tax awareness during purchases. Nevertheless, some find small effects in studying the efficacy of a Pigou tax (sugar tax)[50], while studies on environmental taxes have yielded mixed results: some demonstrate the efficacy of visible carbon taxes on gasoline in reducing demand compared to market-driven price increases[51], while others find that hidden taxes may outperform salient carbon taxes in reducing consumer demand[52].

As is well known from the literature on behavioural economics, framing and labelling of information can influence decision-making in many contexts. Framing effects describe an inconsistency in individual decision making, violating standard rationality assumptions[53]. While the same choice (situation) can be described or framed very differently,

according to rational choice theory framing should not affect individuals' choices. Yet, numerous studies in economics and psychology have shown framing effects, such as attitudes towards environmental policy proposals[54,55]. The framing of public policy is clearly an important concern, considering its potential large influence on public opinion. For example, One study find more negative reactions to levies called 'tax' as compared to 'fee' (while being economically equivalent)[56]. Others tested the importance of such labelling (tax vs. fee) for Pigouvian taxation, obtaining similar results and observing that acceptance was negatively influenced by labelling the Pigouvian instrument as a 'tax' in case of tax revenues not being earmarked[57]. The latter indicates a general harsh reaction towards environmental taxes, which possibly can be offset if its revenues are targeted and redistributed to environmental purposes. These findings suggest that policymakers may benefit from designing carbon taxes in a way that mitigates behavioural responses. One approach is to partially determine the use of tax revenues, allowing for investments in environmental projects and innovations (R&D) to create social-political acceptability, even if such earmarking may seem unattractive from a pure social welfare perspective (since corrective externality pricing already restores the social optimum in the rational-agents-cum-general-equilibrium world). This might need to be complemented by campaigns informing individuals about what is done with the revenues of a carbon tax, such as reducing other (distortionary) taxes labour taxes, funding public services like education, or reducing public debt. However, environmental taxes are meant to merely regulate and not generate new funds. Therefore, earmarking of funds generated by such taxes violates the purpose of such taxes and their welfare optimality. An entirely different policy reaction to the sensitivity of the 'tax' label is to opt for carbon pricing based on cap-and-trade (emissions trading)—where perhaps the related label "carbon market' should be avoided as it might generate resistance as well.

Another widely discussed issue is the interaction of social preferences and policy incentives[58,59]. Social preferences assume that individuals are not only self-interested but also value the utility and well-being of others. Some prominent examples are preferences for fairness, altruism and reciprocity[60–62]. It has been argued that typical economic incentives may crucially interact with social preferences and may lead to perverse and opposite outcomes[63]. If, as expected by conventional theory, individuals behave exclusively motivated by (material) self-interest, economic incentives would lead to a change in behaviour through altering basic economic variables, such as income and prices.

A growing literature finds that prices and payments are able to crowd out (or reduce) the intrinsic motivation for environmentally benign behaviour[64–68]. This means that the optimality of pricing policies is not guaranteed. For example, one study demonstrates that collective rewards—i.e. payments made to a group of resource users—can undermine pro-social norms underlying any conservation effort and are thus a cost and environmental ineffective instrument for conservation matters[69]. Others have focused on the question of which environmental policy instrument is more likely to minimize and contain motivational crowding. One study uses experiments to study crowding effects for two equivalent policy instruments that control environmental externalities, namely environmental taxes and standards[70]. Their results show that emission taxes (price instrument) are more likely to lead to crowding-out effects than simple emission standards (quantity instrument). However, in opposition to these findings, considerate evidence suggest that economic incentives can initiate crowding-in effects (i.e. raise intrinsic motivations) in the context of pro-environmental actions[71–73]. Additionally, for other pro-social actions, like vaccinations, incentives have led to crowding-in effects rather than crowding-out effects[74,75].

Some have raised serious doubts on the economic relevance of the crowding-out issue, pointing to the fact that even if crowding effects partially unfold, it may still be quite efficient to use economic incentives as the first-order effect (changing prices and thus behaviour) dominates the second-order effect (less voluntarily changed behaviour due to less intrinsic motivation). Evidently, the total sum or net effect of the two effects matters, which is likely to be positive[76]. It is also not clear that the evidence for crowding is solid, as countervailing cases are not observed. This could mean that distinct interpretations, such as incentive versus motivation crowding-out, are possible[77]. More fundamentally, without a pricing instrument one relies on voluntary behavioural change, which is far from sufficient to solve the environmental problem (otherwise it would not have been necessary to devise such policy).

Another important issue to consider is that taxation and subsequent price increases are likely to support even boundedly rational agents in making desirable (or even close to optimal) decisions. For example, it has been pointed out that a common behavioural bias like myopia or impatience can explain underinvestment in energy-efficient equipment. In fact, consumers with high discount rates are less likely to make such investment[78,79]. This is also referred to as the "energy-efficiency gap". Yet, higher energy prices due to carbon pricing policies will shorten pay-back times of such investments and thus make them more attractive. This means that the effect of bounded rationality will then be smaller, and a more rational decision is likely[80]. Additional strategies can be employed to counteract other cognitive biases. For instance, leveraging default options, such as setting renewable energy or high-efficiency products as defaults, proves advantageous for individuals who tend towards passive decision-making[81]. Furthermore, reminders and prompts play a crucial role, particularly through notifications that signal when efficiency upgrades are due. These interventions are designed to overcome limited attention, serving as timely cues to prompt individuals to consider and act on energy-efficient choices[82].

Environmental or carbon tax levels can in principle be set higher or lower to address specific cases of bounded rationality[83]. Since this is politically difficult, another option is to add instruments to make carbon taxation more effective. Table 1 illustrates how this can work out for different cases of bounded rationality and social interactions. In addition, it is important to recognize that there is no empirical basis for thinking that we can decide about an optimal tax level—witness the diversity of estimates of the "social cost of carbon"[84]. In addition, an immediately optimal and high carbon price will be impossible politically and risky economically. Instead, the literature suggests a gradually rising carbon price until emissions reduction is sufficient—e.g., consistent with a temperature target or carbon budget. Another relevant insight is that the presence of bounded rationality suggests that carbon markets (cap-and-trade or emissions trading) will be more effective in reducing emission than carbon taxes. The reason is that the cap or ceiling to emissions will result in prices going up (down) if boundedly rationality of agents translates into lower/higher emissions than rational agents, such as lower due to habits or higher due to seeking status. In addition, a carbon market may train and discipline market participants, possibly resulting in them making more rational decisions over time.

In the context of social influence, carbon pricing can gain effectiveness versus a situation of atomistic, isolated agents. In effect, the social interactions give rise to a social multiplier of the emissions reduction impact of carbon pricing[85]. One can understand this as carbon pricing stimulating many agents to shift to lower-carbon consumption, which is subsequently copied through repeated social interactions, resulting in additional emissions reduction. This social multiplier might be strengthened through additional information provision instruments. An extension of the social multiplier is the "cultural multiplier" of climate policy. This captures the long-term effects of changes in multiple consumption choices simultaneously—what one could call 'lifestyles'—while also considering people belonging to fluid social groups or sub-cultures with distinct lifestyles[86]. Hence, while the social multiplier focuses on spillovers between individuals, the cultural multiplier extends this to spillovers between lifestyle components and social groups. In line with this, the concept of social tipping has emerged as a proposed strategy[87,88]. Social tipping refers to the idea that a minor change in a social system parameter can trigger sudden, nonlinear shifts through self-reinforcing feedback. Suggested as a policy tool, social tipping interventions can then facilitate widespread behaviour change[89–91]. Since a price increase of energy and carbon-intensive goods is likely to increase market shares of new low-carbon intensive technologies and

Table 1 | A summary of findings on carbon pricing and other instruments under non-rationality

Behavioural theory	Behavioural factor	Implications for carbon taxation	Impact on carbon tax effectiveness	Complementary instruments
Bounded rationality	Salience and attention	Consumers may underreact to hidden carbon taxes.	Negative	Education campaigns clarifying that price changes are due to environmental taxes. Separate tax information from displayed prices at point of purchase.
	Framing	Consumers tend to be less receptive to a carbon price when it is explicitly labelled as a tax, and their acceptance is contingent upon how the generated revenue is utilized	Negative	Frame as fee and earmark revenues. Campaigns on environmental taxation and revenue uses (e.g., reducing other taxes, funding public services).
	Decision biases	Carbon pricing has the potential to mitigate biases such as myopia and facilitate consumers in making optimal decisions	Positive	Information: Provide energy efficiency ratings, lifetime cost comparisons, and payback period. Defaults: Set renewable energy or high-efficiency products as default options for passive decision-makers. Reminders: Send notifications for efficiency upgrades to overcome limited attention and prompt timely action.
Social preferences	Motivational crowding	Carbon taxes (and subsidies) are likely to generate more crowding-in of pro- environmental norms than crowding-out	Negative/Positive	Employ instruments that reinforce rather than diminish intrinsic motivations, avoiding feelings of coercion or over- justification, including effective communication of policy rationale and community participation in solutions (e.g., citizen deliberation or climate assemblies).
	Social interactions and peer effects	Carbon pricing has social and cultural multiplier effects	Positive	Complement with social tipping interventions including normative information provision.

products, social interaction and conformity behaviour of consumers can spur the uptake of such technologies. Here, the provision of normative information can serve as a valuable complementary policy instrument.

Many studies show that normative information interventions regarding personal energy use, such as giving information about the average energy consumption of one's neighbours, can support voluntary energy conservation measures in households and thus effectively complement traditional pricing strategies[92–96]. Similar results have been shown for other conservation behaviours, for example, residential water consumption[97–99]. Yet, most of the mentioned studies only show significant reductions in energy and water usage over a limited time period, while effects appear to fade over time. In some instances, interventions even had counterproductive effects, that is, consumption savings in one domain like water were offset by an increase in another domain like energy[100]. The latter warrants attention when exclusively relying on information strategies. As opposed to economic incentives, persistent effects are more difficult to realize with such strategies only.

While in some circles hope is high that behavioural nudges are a useful and effective complement to more traditional instruments of climate and environmental policy, there are several reasons to be pessimistic. Reviews and meta-analyses indicate that overall emission-reduction effects tend to be modest[101,102] although there is debate on the exact magnitudes[103]. In addition, nudges sometimes fail due to habits being difficult to break, may rebound or "counter-nudges" like advertising for high-carbon products may be at work[104]. Moreover, reliance on nudges might divert attention from the need for more systemic and structural changes in policies[105]. Finally, the combination of carbon pricing and behavioural instruments may also be needed to overcome special challenges related to energy and carbon rebound[106,107].

Conclusions

If after reading the pros and cons of pricing approaches to environmental policy one is convinced that we need to get the prices right, then the main question is: how do we know the right prices? One way is to value environmental damage and translate this (using market models) in optimal externality prices. This is difficult for methodological reasons—witness the diversity of estimates of $^{CO}2$ damage costs in the literature. Another approach is more pragmatic, also known as adaptive policy. It means that prices (or taxes) are adapted until they do the job, that is, until they have reached a reduction of the goal pollutant to a desirable, safe level. The difficulty here is in the political resistance. Note that tradable permits have an advantage in the sense that one does not have to set, correct or adapt prices, but instead must decide about the total level of emissions (and monitor and control this evidently). The system of tradable permits will then produce a permit price that reflects the appropriate "scarcity or externality", provided polluters are sufficiently rational. The problem here is how to assess the appropriate ceiling to total emissions allowed by all permits. Information from the natural and health sciences (chemistry, biology, medicine) can provide the basis for setting safe levels—from environmental, ecological and health perspectives—to pollutant emissions or concentrations. We do not want to play down the difficulties involved in getting the prices right. This paper is intended to contribute to improving the political feasibility of such policies.

Carbon markets have several advantages over carbon taxes. They automatically adapt carbon prices if emissions exceed the cap in case of bounded rationality or social interactions of emitting consumers or producers. In addition, they represent the only instrument so far able to harmonize climate policy (notice, e.g., that the EU-ETS covers 30 countries). They moreover have turned out to be a stable institution that is difficult for national governments to cancel. Witness the recent high energy prices due to Russia's invasion in Ukraine—it led to many national energy taxes to be lowered or cancelled, whereas the EU-ETS remain fully in place. Carbon markets further tend to have higher prices than carbon taxation[108]. Last but not least, the cap limits rebound through the endogenous carbon price going up if behavioural fashions or technological innovations stimulate additional emissions.

Complementary instruments to deal with bounded rationality and social interactions can take various forms. They are more important in the case of carbon taxation as it is more sensitive than carbon markets to deviations from rationality. Here a range of nudges and informational instruments is available to deal with unwanted effects of tax salience, framing, decision biases like myopia, and motivational crowding. A key opportunity is offered by social interactions, where adequate information provision can help to achieve a large social multiplier effect of carbon taxation.

Data availability

No datasets were generated or analysed during the current study.

Received: 31 July 2025; Accepted: 8 August 2025;
Published online: 18 October 2025

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Acknowledgements

This work contributes to the 'María de Maeztu' Programme for Units of Excellence of the Spanish Ministry of Science and Innovation (CEX2024-001506-M). This study received funding under the Horizon Europe programme through project CAPABLE (grant agreement 101056891) and an ERC Advanced Grant for the project CLIMGROW (grant no. 101097924).

Author contributions

E.G. and J.v.d.B. wrote and revised the paper.

Competing interests

The authors declare no competing interests.

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