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The Portfolio of Economic Policies Needed to Fight Climate Change

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Abstract

Climate change poses an existential threat. Theoretical and empirical research suggest that carbon pricing and green R&D support are the right tools, but their implementation can be improved. Other policies, such as standards, bans, and targeted subsidies, also all have a role to play, but they have often been incoherent, and their implementation is delicate.

1. INTRODUCTION

Climate change poses an existential threat. It will generate tremendous economic costs, jeopardize ecosystems and biodiversity, bring about social unrest, provoke wide-scale migration, create resentment from poor and middle-income countries, and trigger wars or other forms of conflict.

There is little time left to act (Stern et al. 2022). Despite the urgency, there is still a sharp contrast between officials' voluntarist political discourse and ambitious long-term pledges on the one hand, and their actual behavior on the other. Almost 30 years after the Earth Summit in Rio de Janeiro, emissions continue to grow, and public and private R&D on green technologies represents only 4% of total world R&D—chicken feed in view of the stakes. The sizable and costly transformation of economies that is required to achieve the targets of the Paris Agreement [adopted at the UN Climate Change Conference (COP 21)] or the more recent "zero-net-emissions by 2050 or 2060" pledges of some major polluting countries still needs to happen.[1] The longer action is deferred, the more costly the transition will be.

Fortunately, there is good news too: Despite the relatively low amount of money spent on R&D, some technologies, such as solar and wind power,[2] LED lighting, electric vehicles, and alternative proteins, have been progressing faster than expected. Furthermore, many companies realize that their fossil fuel–based assets may end up stranded, and the innovativeness of the private sector has been unleashed. Some key technologies will emerge when more money is devoted to green technologies and the private sector's incentives to turn green are reinforced by, for example, clear carbon price signals around the globe. New policies on both sides of the Atlantic—the Inflation Reduction Act in the United States and the Fit-for-55 package in the European Union—propose strategies to attain ambitious climate objectives.

Other good news is that general environmental awareness has progressed. A recent survey shows that 70% of respondents from high-income countries and 81% of those from middle-income countries believe that climate change is happening and that it is anthropogenic (Dechezleprêtre et al. 2022). The challenge is therefore to find ways to end the disconnect between speeches and behavior, to make costly actions politically acceptable while ensuring that their costs remain as low as possible.

Despite the grim situation, solutions exist, combining multiple approaches. Provided that they are implemented rapidly, they will make it possible to address climate change at an economic and societal cost that is small compared with the alternative. However, and this is another message of this article, it will be important to be selective. When it comes to proposals for green policies, there is an embarrassment of riches. We highlight what will be impactful, stressing good ideas and screening out bad ones:

- Carbon pricing is good economics. We describe, in detail, current policies and how they can be much improved.
- R&D support is good economics. Low carbon prices not only encourage emissions but also are detrimental to the R&D effort; but even if carbon prices are generalized and given more

[1] Feasible actions include changing agriculture and consumption practices; phasing out fossil fuel energies for transportation (cars, trucks, airplanes), industries, and living spaces; retrofitting poorly insulated buildings and using smart meters with time-varying prices to rationalize energy consumption for a given comfort level; redefining urban planning and land use with a green mindset; preparing for the electrification of the economy; and spending much more on green R&D.

[2] Options for electricity storage, the very desirable complement to these intermittent productions, include batteries as well as pumped hydro, compressed air, green hydrogen (produced by either electrolysis or natural gas reforming), and blue hydrogen (splitting natural gas into hydrogen and CO_2, which is captured and then stored).

substance, green R&D is still likely to be smaller than needed. Much more money must be spent on it than is now the case, and this money must be properly allocated in order to have an impact. We suggest how to do so.

- Done well, other policies, such as standards, bans, and targeted subsidies, can be good economics. However, they have often been incoherent, and their implementation is delicate. Again, there are ways to do them better, which we review.
- Domestic and international compensation is key to the acceptability of efficient policies.
- When viewed in isolation, and with the exception of some large emitters such as the European Union, United States, and China, a country's emissions will not materially alter the course of climate change. Yet individual countries can show the way ahead: They can develop technologies that can be used by other, poorer countries. They can provide leadership/momentum on global agreements and on the need to fund climate change policies in developing countries. For instance, the rationale for keeping the rest of the world in sight when thinking about, say, European policy is that every ton of CO_2 emissions cut in China, India, Russia, Pakistan, the United States, and elsewhere delivers the same benefits as a similar cut to, say, emissions in Europe itself.

The rest of the article discusses these various policies and their articulation. Before we do this, the next section focuses on the perceptions that policy makers must take into account if they are to succeed in implementing the right policies.

2. FACTS AND PERCEPTIONS

A number of perceptions hamper the design of policies that deliver the most reductions in emissions for a given cost to society or, equivalently, reduce the cost for a given mitigation objective. These perceptions, driven by experience with actual policies, disregard for budget constraints, and distrust of market mechanisms, must be addressed when designing public policies.

2.1. An Unpopular Carbon Tax

The first observation is the unpopularity of carbon taxation, as illustrated in France by the *gilets jaunes* (yellow vests) demonstrations against the carbon tax. In the United States, as in many other countries, proposals to price carbon emissions are perceived as political suicide. A recent study showed that only one-third of the US or French population would support a carbon tax at $45 per ton of CO_2 (tCO_2), even though that level is largely insufficient to achieve the climate ambitions of those countries (Dechezleprêtre et al. 2022).[3] French households feel that a carbon tax (*a*) is punitive, (*b*) is regressive, and (*c*) would be regressive even if they received an unconditional lump-sum refund from the receipts of the carbon tax (which is incorrect) (Douenne & Fabre 2022). The latter perception may be due to distrust about the long-term credibility of the compensation: Once promised, compensation can be whittled down or eliminated over time. If so, institutions must be designed to minimize the risk.

It is correct that a carbon tax without redistribution is regressive, as it is a direct consequence of the fact that, in the Western world, the demand for energy has an income elasticity slightly below unity. This implies that the fraction of income spent on the tax is higher for low-income households. However, the critique holds for all climate policies that raise the price of energy, such as feed-in tariffs for renewables or the ban of coal (a cheaper resource) for heat and electricity generation. The implication is that, if it is to succeed, any policy must have a redistribution component.

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[3] Support for carbon pricing is larger when its revenue is targeted to finance environmental infrastructures (63% in France and 56% in the United States).

2.2. The Relative Popularity of Opaque Policies

In contrast, people favor, or at least do not ostensibly oppose, nonprice policies. Dechezleprêtre and colleagues (2022) found, for example, that a majority of French respondents support green infrastructure programs (57%), a ban on polluting cars in city centers (57%), and subsidies for green technologies (56%) and thermal insulation (64%); their international survey draws a similar picture for other high-income countries. In a similar survey for Sweden, Ewald et al. (2022) also document a preference for subsidies over taxes and for a ban on flights. Yet nonprice policies may be more punitive (and regressive) than a carbon tax. A preference for policies with invisible costs and a lack of understanding of the incentive effect of a Pigouvian tax appear to be the main drivers of the protest against the carbon tax.

A carbon tax puts a price on carbon emissions and thus makes economic actors accountable for their pollution, and quantities of emissions are determined by the market. The cap-and-trade system is an alternative approach to taxing carbon, which determines the quantity of emissions while the prices are determined by the market. Since 2005 Europe has subjected the electricity, aluminum, cement, and other industrial sectors—representing around 40% of the European Union's greenhouse gas emissions—to this form of carbon pricing. In the European cap-and-trade system, called the EU Emissions Trading System (EU ETS), the number of allowances, also called permits, is fixed (the lower the number, the higher the environmental ambition). Emitters must match their emissions with the allowances. The market for allowances determines a price through the matching of supply (the number of allowances) and demand (the emissions whose marginal abatement cost exceeds the price of an allowance).[4]

There are 46 cap-and-trade systems for CO_2 emissions around the world—in the United States (California), Canada, China, Europe, Australia and New Zealand, and South Korea. However, many of these systems still lack ambition: They admit too many allowances relative to their stated environmental ambitions. Because they force polluters to own an amount of allowances in accordance with their emissions, they are formally a tax on (dirty) production rather than on final consumption. However, because the producers by and large pass the allowance price through to consumers,[5] the latter pay for the increase in the production cost. Certainly, the price in the EU ETS at the time—about €20/tCO_2 in fall 2018—was well below the €55/tCO_2 carbon tax that brought the gilets jaunes into the streets; but the fact that this levy on consumers occurs at the production stage has left it largely unnoticed by citizens.

The next example makes the same observation more strongly. Subsidies to green energies (wind, solar) are popular.[6] In practice, this subsidization of renewable energy often takes the form of regulation-imposed purchase obligations at some above-market, prespecified price (feed-in tariff) on power suppliers and is embodied in consumers' electricity bill. Again, however, while the levy is formally on producers, it is passed through to consumers, who hardly see it.[7]

Such policies (whether justified or not; we focus here on perceptions) would probably be less popular if two facts were clearer in people's minds. First, as discussed above, one person's subsidy is always somebody else's tax, as illustrated by feed-in tariffs (the price at which electricity companies

[4]The price of a pollution permit fluctuates substantially depending on market and political conditions: It reached €98/tCO_2 on August 19, 2022 and fell to €67/tCO_2 three weeks later.

[5]The magnitude of the pass-through to consumers depends on how competitive the industry is (full pass-through obtains if the industry is competitive).

[6]Unsurprisingly, US President Biden's Inflation Reduction Act relies primarily on subsidies and does not make use of the carbon tax.

[7]In 2021 the cost of the feed-in tariffs for renewable energies in France was €6.4 billion, which is also the revenue from the carbon tax.

must purchase renewable energy produced externally), which are a tax on electricity consumers. Conversely, a tax (or the sale of permits in a cap-and-trade system) creates government revenue, possibly enabling other subsidies. Furthermore, subsidies need not have an equitable distributional impact either: In the United States, subsidies for rooftop photovoltaic power stations, including net metering, burden lower-income groups.[8] In France, the regressivity of the renewables policy is equivalent to that of the carbon tax, without the possibility of using a carbon dividend to compensate the poor.

Second, the environmental performance of the policies could have been better. The cost for electricity users of economizing 1 ton of CO_2 reached €1,000 and more for early generations of renewables 10 years ago, 20 times the €55/tCO_2 tax that brought the French to the streets in 2019 and about 50 to 100 times the EU ETS price during that period. Put differently, at the time, France, Germany, and other countries may have chosen to buy 1 ton of climate protection when it would have been possible to have 50 tons of CO_2 removed for the same amount of money (of course, this reasoning ignores the fact that mandated renewable purchases contributed to the fall of wind and solar costs: Tax incentives and various green mandates helped the private sector move wind and solar along the innovation/learning curves).[9] To take another angle, the same learning could have been achieved with solar capacities installed in southern Spain rather than in Germany, with a greater environmental impact for the money spent.

Similarly, there has been little backlash against the high subsidies for insulation and boiler installation in France. Although well meaning, this policy has attracted some unscrupulous types driven by the opportunity for short-term profits, led to dissipative commercial efforts (e.g., incessant phone calls for "€1 insulation"), and done little to reduce global warming, as it provides suppliers with a generous supply of energy savings certificates (so-called white certificates) that are unrelated to actual savings and can be used to satisfy the energy savings obligations faced by energy utilities (Crampes & Léautier 2021, Glachant et al. 2021).

Two other cases in point are green standards and laws banning some technologies (e.g., phasing out thermal-engine cars or coal in the electricity mix) by a certain date. Both impose extra costs, either on consumers directly or on manufacturers who pass them through to consumers.[10] Furthermore, they can be ill-designed and fail to reach their objective,[11] they can be regressive (fuel

[8]More broadly, Borenstein & Davis (2016) found that 60% of the income tax credits for weatherizing a home, installing solar panels, buying hybrid and electric vehicles (EVs), and other clean energy investments were received by the top income quintile. A similar conclusion may be drawn for the subsidies offered to buyers of EVs, whose prices remain too high for low- and middle-income households.

[9]As we discuss below, there is a complex debate about the counterfactual: How much did purchases contribute to renewables' cost reduction? This debate pits those who argue that microprocessors have followed Moore's law despite the absence of subsidy against those who say that pump priming was necessary because technological spillovers prevented early losses from being recovered later through a competitive advantage. We return to learning by doing later.

[10]Sometimes the cost of bans is directly incurred by consumers (as opposed to indirectly through a cost pass-through by the manufacturer). The cost of a ban on airline travel when there exists a train alternative taking less than some number of hours includes the value of time lost by users. The cost of a ban on home heating systems that use fossil fuel energy includes the cost of building alternative equipment (e.g., a heat pump).

[11]In the United States, cars and trucks became less fuel efficient in 2020 because the regulation treats cars differently than light trucks/SUVs and consumer preferences have been moving toward the latter (SUVs and trucks accounted for almost 76% of sales in 2020, in contrast to 49% in 2012). These regulatory design flaws can be fixed (Greenstone et al. 2020). Similar remarks can be made about the French system of a bonus-malus on cars: By failing to reward nonowners, it encouraged the latter to buy small cars, which were made cheaper by a bonus! These observations reveal the importance of proper policy design, not the undesirability of fuel efficiency standards.

efficiency standards cost more as a fraction of income to low-income households),[12] and, finally, they often entail hidden or nonmonetary costs associated with forced sobriety (e.g., time losses due to reduced speed limits on highways or to domestic flight bans, or discomfort from bans on air conditioning). Yet few have demonstrated against a ban (with delayed effect) or against standards.

To be clear, our aim here is to show not that these policies are necessarily inefficient but rather that perceptions are often driven by appearances more than by reality: The visibility of sacrifices imposed on consumers or taxpayers often shapes attitudes toward specific policies much more than their actual net social benefit.

To function well, a democracy must provide its citizens with sufficient information about relevant trade-offs. The political costs of going against public opinion are real, but allowing these costs to exert undue influence in policy leads to unnecessarily large climate damages or unnecessary expenses of private or public money to deliver limited progress on the climate front.

2.3. Motivated Beliefs

Social scientists have documented that people hold certain beliefs in part because they attach value to them, resulting in a trade-off between accuracy and desirability. Such motivated beliefs have been shown to be resistant to many forms of scientific evidence.[13]

Spending vast amounts of money over the next 30 years on fighting climate change is not an appealing prospect. Promising blood, sweat, and tears is a nonstarter in climate politics (maybe because citizens still underestimate the size and ubiquity of the transformation that is required), and it is no wonder that following the Paris COP 21 no chief of state returning home announced that their compatriots would roll up their sleeves. Occasionally, the soothing concept of green growth is invoked to argue that "we can have our cake and eat it too." According to Pisani-Ferry (2021), "too often the transition has been pictured, if not as pathways of roses, at least as a rather benign endeavor." For example, in presenting its Fit-for-55 package, the European Commission (2021) stated that "what is good for the planet is good for people and the economy."[14] But if this were true, why hasn't it been done in the last 30 years?

The same observation applies to the green jobs argument, also meant to soothe public opinion. Officials and industry often flaunt the merits of green policies in terms of job creation. In the absence of careful investigation, the argument does not really hold water. Its validity hinges on the answers to the following questions: Are more jobs created with the money spent on green actions than with the money spent on alternative uses, such as health care or education, that compete for scarce public resources?[15] Can displaced workers fill geographically and educationally the new jobs (as, for example, a coal miner may not easily become a wind generator technician)? Have the equilibrium effects been considered in the labor markets affected by subsidies? (For example, a sharp and rapid increase in subsidies for retrofitting buildings would translate into higher prices for retrofitting rather than in more jobs, if there were no anticipation of it in the job training and

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[12] They also have had unintended effects: Fuel economy standards have not yielded the promised reductions in emissions because people have switched from cars to SUVs.

[13] For reviews of the economics of motivated beliefs, see Bénabou & Tirole (2016), Epley & Gilovich (2016), and Golman et al. (2016).

[14] Current estimates of the macroeconomic cost of the energy transition are rather reassuring. For example, according to the IPCC (2022), assessed global GDP reached in 2050 is reduced by 1.3–2.7% (67% confidence interval) in modeled pathways assuming coordinated, immediate global action to limit warming to 2°C. Costs are expected to be much larger in the absence of international coordination.

[15] Some studies attempt to come up with an answer. Chapter 3 of the special report on sustainable recovery by the International Energy Agency looks at the impact on jobs of making the economy greener, showing that there might be a small positive effect on the number of jobs (IEA 2020).

certification process, thus resulting in a waste of public funds.) Have the costs associated with the funding of the policies been taken into account (as the taxes that enable the subsidies may make some other industries less competitive and thereby destroy jobs)?

Reluctance to say that the planet is worth enough to justify a cost has serious consequences. The problem is that this palliative or evasive political discourse comforts citizens in their belief that painless solutions are available. Almost 90% of French citizens feel that the middle class should not have to pay anything to fight climate change. This may have two interpretations, both being probably relevant and equally problematic. The first is that people think there is no need for anybody to pay. The second is that the rich will pay. The rich can indeed pay more and must be stellar in the greening of their way of life; but the European climate ambition will require much more than a contribution of the rich, especially in countries where redistribution is already sizable.[16]

3. A HOLISTIC APPROACH

This existential threat of climate change has mobilized the economics profession over the last three decades. Existing research suggests that a climate policy should rely on five legs: (*a*) carbon pricing (e.g., Pigou 1920), (*b*) an intense green R&D effort (e.g., Acemoglu et al. 2012, Aghion et al. 2016), (*c*) complementary actions (e.g., Stiglitz 2019), (*d*) compensation (e.g., Douenne & Fabre 2022), and (*e*) international inspiriting (e.g., Nordhaus 2015).

3.1. Leg 1: Carbon Pricing Done Better

Although carbon pricing is not sufficient to restore economic and environmental efficiency, it is a necessary element of the optimal climate policy mix.

3.1.1. The simple case for a carbon price. Following Pigou (1920), the vast majority of economists think that one cannot do without a sizable carbon price, despite its unpopularity.[17] Carbon pricing applies the polluter-pay principle.[18] Pricing has been shown to substantially alter behavior for other pollutants as well as carbon emissions. For example, the United Kingdom substantially reduced its CO_2 emissions from the electricity sector almost overnight following the imposition of a carbon price floor (around €21/tCO_2) in 2013 on top of the EU ETS price (which remained under €10/tCO_2 between 2013 and 2018). This led to the phasing out of coal electricity generation, whose contribution to the UK electricity mix fell from 40% to 5% between 2013 and 2018 (Leroutier 2022). Before the energy crisis, it was estimated that a carbon price around €35–40/tCO_2 sufficed to induce a switch from coal to natural gas, which pollutes half as much. The impact of the Swedish carbon tax, introduced in 1991 and equal to €114/tCO_2 in 2021, has been meaningful as well.[19]

It is appealing to dream that emissions reductions might take place spontaneously without need for material incentives (another illustration of motivated beliefs), but history shows otherwise:

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[16]According to Chancel (2022), the wealthiest 10% households in Europe emit around 30 tCO_2e per year and per person, compared to 5 tCO2e for the bottom 50%. This means that asking the top 10% to go to zero-net emission would have approximately the same climate impact as asking the bottom 50% to do the same. Notice that Chancel attributes a large fraction of the industrial emissions to the capital owners rather than to consumers, which is questionable and dramatically raises the emissions of the wealthiest.

[17]Readers are referred to the surveys by the Clark Center Forum, available at **https://www.igmchicago.org/surveys/carbon-tax/** and **https://www.igmchicago.org/surveys/carbon-taxes-ii/**.

[18]This principle is embodied in the 2005 *Charte de l'environnement* appended to the French Constitution.

[19]The Swedish carbon tax applies to both consumers and businesses. When it was implemented, the tax was €24/tCO_2 for consumers and €6/tCO_2 for companies. For fear of offshoring or unfair import competition, a lower tax rate was thus applied to industry (namely, to sectors outside the EU ETS; to avoid double taxation,

Hitting economic decision makers where it really hurts, namely in their wallets, changes their behavior and unleashes innovations that can solve challenging problems.

A carbon price has at least five virtues:

1. It encourages those who can eliminate their pollution at a relatively low cost to do so. For example, a recent estimate shows a cumulative emissions reduction of 4–6% for a \$40/tCO_2 tax covering 30% of emissions in the European Union, with a low impact on employment and growth (Metcalf & Stock 2022).
2. It boosts green innovation. By monetizing the intellectual property associated with green R&D, it allows startups to receive financing from private investors and to reach the necessary scale.
3. It requires measuring emissions (which is not always straightforward) but no other information, and thus it reduces bureaucratic red tape and discretion relative to other methods of reducing pollution.
4. It is simple, in that it empowers consumers to act for the climate as the price they pay for a product captures the cost of all emissions along the value chain (they otherwise need detailed information if they want to make an informed choice; see Section 4).
5. Although this is not its purpose, it generates fiscal revenues that can be used to compensate certain categories of economic agents or to fund the green transition, for example.

3.1.2. Determination of the carbon price. How should the carbon price be set? Under the Pigouvian approach, the price of 1 ton of CO_2 should be equal to the discounted value of the flow of damages it generates. There exists no consensus among economists about how large this Pigouvian carbon price should be (Rennert et al. 2022). Indeed, this approach raises issues related to the estimation of these damages, the treatment of deep uncertainties, and the choice of the discount rate (Pindyck 2017). For these reasons, most constituencies have targeted a quantity rather than a price, for example, by capping emissions allowances on carbon markets. International negotiations have been designed to generate commitments on emissions reductions. In this context, the carbon price must be interpreted as the shadow price of the carbon budget constraint.

According to the sixth report of the Intergovernmental Panel on Climate Change, "the current central estimate of the remaining carbon budget from 2020 onwards for limiting warming to 1.5°C with a probability of 50% has been assessed as 500 Gt CO_2, and as 1150 Gt CO_2 for a probability of 67% for limiting warming to 2°C" (IPCC 2022). In the absence of uncertainty, compliance with this carbon budget can be easily achieved by mirroring the implementation of the carbon budget for Europe[20] through the volume of EU ETS allowances. The carbon price then results from market clearing: Those who find it too costly to reduce their pollution can purchase an allowance from those who hold unused allowances.[21] This quantity-setting approach ensures that the objectives are met: If countries abide by it, there is no more pollution than planned to meet

sectors covered by the scheme are fully exempted from the carbon tax). Since 2018, however, the carbon tax for sectors outside the EU ETS is the same as the one for consumers, currently €114/tCO_2.

[20]There is no formal carbon budget for Europe, which instead has selected emissions targets: −55% by 2030 and net zero emissions by 2050. We take this political decision as a given. However, these targets may not be compatible with intertemporal optimization under a carbon budget for Europe, as they are likely to lead to too little effort in the short term, that is, too low a shadow price of carbon over the next 10 years (Gollier 2022).

[21]In practice, there are a couple of reasons some players may hold unused allowances: Firms invest in allowances years in advance of their actual use to hedge against their allowance-price risk [allowances are issued long in advance—30 years in the case of sulfur dioxide (SO_2) in the United States—and are bankable]; they

the COP 21 target. If banking of allowances is allowed, and if the political authority is credible about the intertemporal carbon budget, the timing of the auction of allowances is irrelevant: The market will efficiently determine the current level of emissions and the speed at which they will be reduced.

In practice, though, there is substantial uncertainty—about the speed of global warming, the advent and cost of green technologies, and, last but not least, the political willingness to handle climate change. The uncertainty implies that the carbon budget will need to be revised over time as news come in, with consequences for carbon prices. This unfortunately creates uncertainty for firms, households, and inventors: It is hard for them to fathom how the current carbon budget will translate into future carbon prices and therefore to plan their investments. A power producer builds a plant for 30 or 50 years, a consumer buys an electric car that will last 15 years, green inventors' innovations will materialize 10 years down the road, and urban planners and builders make decisions whose effects are even longer-lasting. The financial stakes attached to such decisions hinge not so much on today's carbon price but rather on the carbon prices that will prevail in the future.

Uncertainty calls for forward guidance, that is, for informing consumers, firms, and investors about future carbon prices. This can be achieved in at least three ways:

1. One way is to set a floor and a cap for the price of carbon emissions, enabling some price stabilization. When, due to an abundance of allowances relative to the demand for them, the price hits the floor, the quantity of allowances offered is reduced (authorities purchase a fraction of them at the floor price), leading to a faster decrease in CO_2 emissions.[22] When the price reaches the ceiling, extra allowances are sold at the price cap and the quantity of allowances offered is increased, leading to a slower decrease in CO_2 emissions. The spot price of carbon should be linked to future prices to attain the emissions reduction goal at the smallest discounted value of the flow of the costs of the transition. Recognizing the uncertainty surrounding the future abatement costs, Gollier (2022) showed that this is compatible with a price floor that starts at around €65–75/tCO_2 in 2023 and grows in expectation at a rate of 4% or 5% per year.
2. Another approach is the creation of an independent carbon board—a Carbon Central Bank—in charge of adjustments. This would take such adjustments out of the political lobbying and electioneering process and thereby confer credibility on the policy, in the same way independent central banks work to keep inflation under control (see, e.g., Delpla & Gollier 2019).
3. A third approach to securing commitment to a strong environmental effort while allowing for some flexibility is to create some skin in the game for governments. This can be achieved through government issuance of securities that would compensate allowance holders if the future price of carbon fell relative to the preannounced path.[23] That would make it costly for governments to increase the number of allowances in the future; presumably, they would do so only in case of unexpectedly good news about technological progress, in which case the increase in allowances would not necessarily reflect a reduction in the climate ambition.

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may also have received free allowances as part of a grandfathering scheme (high polluters, whether firms or countries, receive some allowances as partial compensation). If their production becomes greener than they anticipated, they resell those tradable allowances. Similarly, market makers (financial actors who obviously do not have a need for allowances) may hold allowances temporarily.

[22]The UK system works differently: It adds a top-up tax to the market-determined price.

[23]In the jargon of finance, such securities are called put options (see Laffont & Tirole 1996 for the optimal such scheme).

3.1.3. Need for coherence. To reach its full potential, carbon pricing must be universal, ideally across countries but at least within each country. In the absence of other inefficiencies in the economy, any price differential across uses, sectors, communities, and regions raises the total cost of the transition. On both fairness and efficiency grounds, the carbon tax must apply to all polluters, without exception. When a carbon-pricing mechanism exists, however, it is rarely universal or coherent. In France, for example, the €44/tCO_2 carbon tax covering the transportation and housing sectors differs from the price (nearly €100/tCO_2 in summer 2022) on the EU ETS that covers the electricity and industrial sectors. The French carbon tax has many exemptions, and the agricultural sector faces no carbon price.

A carbon price should apply to all actors whenever possible, for six reasons.

3.1.3.1. Containing cost. It is inefficient to tax some emissions and not others. A carbon price of €50/tCO_2 applied to some sectors but not others will lead some to spend €45/tCO_2 to abate, while others will not even spend €5 to avoid emitting a ton of carbon because they are exempt from any payment if they pollute. This holds true at the international level as well. Drastically reducing the emissions of the French production of electricity would be very costly, as electricity generation is already mostly decarbonized in France (incidentally, this shows that an ambition of reducing emissions in the same proportion in each sector would be absurd). In contrast, low-hanging fruits can be found in the 39% of world fossil fuel emissions that still result from coal production, most of it in countries with no or very low carbon prices.[24]

A single carbon price also helps address the large variation in the cost of decarbonization across uses. The cost is relatively low for electricity and light-duty vehicles, higher for (older) buildings, and currently very high for sectors such as airplanes and ocean transport. Some progress will occur through switching away from fossil fuels and some through R&D (itself incentivized by carbon pricing). What will be needed are alternative fuels, perhaps carbon capture and storage, and negative emissions (e.g., air capture of CO_2), all of which are much more expensive at this point.

3.1.3.2. Respecting fairness. Exemptions are unfair. In France, the gilets jaunes protested that, unlike them, businesses such as trucking, fishing, farming, airlines, and taxis were not paying the full carbon tax. To be certain, the no-exemption policy would add to the number of groups that might resist carbon taxation (e.g., farmers, taxi and truck drivers, property managers, homeowners), and some of these groups are well organized and have nuisance power—which may be why they are exempted in the first place. However, a no-exemption policy has much more legitimacy than a patchwork one. Furthermore, compensation combined with explaining why alternatives are opaque and that subsidies are in the end taxes might enhance the legitimacy.

In the EU context, application of the EU ETS only to industry creates another issue of fairness. In July 2021 the EU Commission submitted the Fit-for-55 proposal, which included among many other things a package to create a second ETS market to cover the mobility and building sectors in Europe, hopefully shaped in a way that would yield an equilibrium price close to the one prevailing in the historical ETS. However, in the spring of 2022 the EU Parliament rejected this proposal on the fallacious argument that EU consumers should be protected from a carbon price. Instead, the Parliament voted for a ban on new combustion engine cars in 2035. The EU trialogue in charge of coordinating the Commission, the Parliament, and the Council will arbitrate the disagreement.

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[24]The energy crisis in Europe raised coal and natural gas prices by factors of 3 and 10, respectively, during the first six months of the Ukraine war. The switch from coal to gas to generate heat and electricity has therefore been frozen despite the relatively large carbon price on the EU ETS during the period.

3.1.3.3. Making the process lobby-proof. Like fiscal loopholes, exemptions expose the tax system to heavy lobbying. Once authorities have opened the Pandora's box of exemptions, every lobby tries to have its name added to the list.

3.1.3.4. Curbing offshoring. The no-exemption principle has another important corollary: Imports for whose emissions the producer is not held accountable should not have an undue competitive advantage over home production that is subject to carbon pricing; put differently, carbon pricing by itself should not lead to the offshoring of domestic production.[25] A level playing field can be restored through a Carbon Border Adjustment Mechanism (CBAM) at the borders of Europe, charging imports the same price for carbon emissions as European firms.[26] This may be straightforward in theory, but it is more complex in practice, as estimating the actual carbon content of imports is not that easy, especially along a value chain located abroad. Furthermore, if only intermediate goods such as cement and steel are subject to the border tax, the level playing field is not obtained for final goods such as cars. The border tax adjustment must be comprehensive, which requires information on value chains. The current framework for national and international carbon accounting systems remains inefficient and misleading, with multiple counting of the same emissions, as discussed by Heal (2022). It is therefore a strategic issue to clarify the carbon accounting rules under the leadership of a legitimate international organization such as the International Sustainability Standards Board (ISSB). In anticipation of the increasing penalties that will have to be levied on European polluters in order to attain the EU emissions target, CBAM is required to force free-riding countries to the bargaining table and generate reductions abroad that benefit the European Union. Note also that it will be difficult for Europe to justify abroad a border tax adjustment if it does not get its act together internally and continues to allow exemptions (Mehling et al. 2019).

The European Union is finalizing a political agreement to implement CBAM within the next few years, starting with sectors whose carbon intensity is easiest to estimate (e.g., steel, cement). Resistance to such a policy is partly due to the fact that CBAM will replace the existing system to curb carbon leakages, which distributes free allowances to firms most exposed to international competition. The recurrent distribution of free allowances to polluting firms is an inefficient way to fight carbon leakage, as it garbles the carbon price signal.

The principle of a level playing field should also apply to EU exporters: Symmetrically with the CBAM for imports, this principle justifies a rebate of the carbon price (or the carbon price differential if the foreign country has a lower carbon price) when goods exit the Union. This rebate should be equal to the carbon price differential between the European Union and the importing country. The EU Commission is working on this.

To be sure, the CBAM faces issues besides incomplete information about emissions along the value chain. Many countries use nonprice climate policies (e.g., bans, standards) that impose costs on producers and that will be complex to integrate in a fair carbon border adjustment. It is also subject to arbitrage (e.g., in transit through high-carbon-price countries). Finally, some high-intensity green R&D countries will claim that they put more faith in innovation than in abatement and contribute to the fight against climate change through R&D rather than through a high carbon price.

3.1.3.5. Phasing out fossil fuel subsidies. Another implication of a single carbon price is the end of ubiquitous fossil fuel subsidies. Such subsidies are equal to the difference between the total

[25] France consumes more CO_2 than it produces. Indeed, the CO_2 footprint of imports is twice as big as that of exports.

[26] If the exporting country has a carbon price, the CBAM should be equal to the carbon price differential only.

cost for society of the fuel (production and delivery cost + transportation infrastructure costs + induced cost of local air pollution and global warming + general-revenue-raising considerations, measured by ordinary VAT) and the price paid by the fossil fuel user. Fossil fuel subsidies often amount to a negative price on carbon. It is estimated that fossil fuel subsidies amount to a staggering 6.5% of world GDP, with China, the United States, and Russia being by far the largest subsidizers.[27]

While straight underpricing of fossil fuel is a very common subsidy, there exist many other forms of less obvious fossil fuel subsidies, from the absence of collateral pledging by US oil and gas companies (which leads them to not plug shafts when they become unprofitable, generating high methane emissions) to subsidies to low-cost airlines or linked to export finance for oil and gas exploration, pipelines, or liquified natural gas (LNG) terminals. Although much smaller than those of China, the United States, and Russia, European fossil fuel subsidies should be phased out. The European Energy Taxation Directive lags behind in its ambitions.

3.1.3.6. Rewarding negative emissions. Negative emissions will be necessary to achieve the net zero pledges (for example, there is a lot of interest in a wide range of natural and other carbon removal technologies). In theory, negative emissions, when certified, should be rewarded by credits[28] whose value corresponds to the carbon price, to ensure again that the same incentive applies to alternative ways of mitigating climate change. Needless to say, details matter, and one must ensure that the policy achieves the stated goals.[29]

Even if it is transparent, credible, and universal, carbon pricing is not a panacea. A carbon price is necessary but not sufficient to achieve the goals of the Paris Agreement. Furthermore, while its scope can be enlarged compared with its current perimeter, some environmentally friendly projects are not easily amenable to this approach. We will come back to this in Section 3.3.

3.2. Leg 2: An Intense R&D Effort

The mitigation efforts necessary to attain our collective goals remain costly. This raises a social and political acceptability issue. Reducing these costs is thus another necessary condition. There are strong arguments for public subsidies in favor of green R&D.

3.2.1. The case for public support of green innovation. The ecological catastrophe will not be avoided without a substantial stepping up to the R&D challenge. There is too little green R&D investment. This is not because of a shortage of loanable funds: There is a lot of money looking for investment opportunities. Rather, it is the insufficient profitability of green R&D that limits investments.

Innovation is critical because it improves the trade-off between damages from the climate and damages to the economy. This dilemma weighs heavily in particular for sub-Saharan Africa, Pakistan, India, and even China. If these countries found it more attractive to choose low-carbon technologies, they would deliver benefits, for example, to Europe by reducing global emissions far more than what Europe can do itself.

[27]Readers are referred to Coady et al. (2019). There is some uncertainty around the exact number, for methodological reasons explained in the paper, but there is no question that it is sizable.
[28]Of course, only actors who also pay for carbon emissions would be eligible for those credits; otherwise, they might emit, recapture, and claim credits, as has happened with trifluoroethane (HFC-23) under the Kyoto Clean Development Mechanism (CDM).
[29]For example, one should not repeat the mistakes made when setting up the CDM. It not only failed the verifiability criterion but also led to credits earned solely in the European region; the resulting increase in the number of allowances put downward pressure on carbon prices in the EU ETS.

Subsidies to compensate innovators in all industries for the partial appropriation of the fruits of their R&D efforts (i.e., for technological spillovers that benefit competing firms) will not suffice, for multiple reasons (Acemoglu et al. 2012; Aghion et al. 2014, 2016). We highlight two.

First, even if carbon prices are generalized and given more substance, political constraints are likely to keep them smaller than needed. With low carbon prices, it costs technology users too little to pollute, and so they will not be willing to pay much in the way of royalties for access to green technologies. The very low carbon prices of the past and the absence of mention of carbon pricing in a number of official documents have created expectations of at best moderate carbon prices in the future and have thereby disincentivized green R&D.

Second, some of the most important green R&D programs involve unlocking breakthrough technologies that will in the long run make it possible to achieve zero or negative emissions. While the pharmaceutical industry shows that the private sector may take long horizons in its R&D decisions, it is still the case that the public sector plays a fundamental role in supplying the required fundamental research.[30]

Considering this, R&D can be stepped up in two ways:

1. Set achievable technological goals for the private sector. Experience, especially with the COVID-19 vaccine, has shown that, when pushed, the private sector may do wonders: Multiple vaccines were developed at unprecedented speed.[31]
2. Create an EU ARPA-E, a European equivalent to the American green technology funding institution (more on this in the next section). This agency would finance high-risk, high-payoff research by the private and public sectors in Europe to address key challenges for green technologies. The governance of this agency must be exemplary, as we explain below.

Before concluding this section, the recent IEA (2021) report on the conditions necessary for 100% renewable electricity production offers a reminder that the outcomes of R&D efforts are by nature uncertain, even though they determine the feasibility of particular scenarios aimed at achieving carbon neutrality. This uncertainty should obviously not be a pretext for procrastination, but it must be integrated by public authorities in their strategy and in the sequencing of their actions. Governments and research agencies must show humility and not pretend to know which exact technology will work; that is, they must avoid putting all our eggs in the same basket.

3.2.2. Boosting innovation through industrial policy. Innovation comes primarily from the private sector, but the impetus is often from the state: first, through R&D subsidies and policies that encourage innovative startups and subsidize the demonstration of some key technologies; second, through smart industrial policy created not to promote certain firms or prop up losing industries but to overcome technological challenges. Governments too often attempt to pick winners without having the required information, respond to lobbies' pressure, or just follow their own

[30]One can further make the case that because technologies build on the work of previous generations and green energies have a longer horizon than fossil fuels, even if the latter are made cleaner through innovations such as carbon capture and storage, overall spillovers are larger for clean energy research, motivating higher subsidies than for alternative R&D tracks.

[31]Analyses of the impact of the COVID-19 vaccine procurement process are still awaited. We note that public procurement was also meant to preempt other countries on supplies, not only to speed up the advancement of technology (indeed, the lack of international cooperation, except for the COVAX coalition, suggests that preemption was a major goal, even though no one will ever say so). Further, there is little information about the counterfactual; the market for a vaccine was huge and we would have expected a sizable R&D effort even in the absence of public procurement.

whim or the zeitgeist. Instead, they should attempt to unlock technologies through a well-thought governance design.

A case in point is the US Defense Advanced Research Projects Agency (DARPA), which played a key role in the development of now widely used key technologies such as GPS and the Internet. DARPA distributed money to the private sector, universities, and government labs with much discretion (due to its insulation from politics and lobbying), an eye on outcomes, and strict oversight of the projects. Similarly, the US National Institutes of Health have had a large impact on advanced medical and pharmaceutical research (they also have considerable financial resources—more than $30 billion per year—from the federal government).

For Europe, a green R&D agency could be set up to offer a larger-scale and wider array of competences than a single member state. European alliances for batteries (since 2017) and for clean hydrogen (since 2020) have already started to foster cross-EU public–private collaboration. A European version of the Advanced Research Projects Agency–Energy (ARPA-E, as this DARPA spin-off is known in the United States) would fund high-risk, high-reward research and "way out there" (early-stage) projects. To avoid wasting public funds and to ensure a meaningful impact, proper governance would need to be established for this independent agency, with desirable features such as the following.

- A high-level manager would be appointed, with substantial operational flexibility to oversee the allocation of funds and insulation from interest group politics. ARPA-E started in 2009 with close supervision from Nobel laureate and US Secretary of Energy Steven Chu, and the first two directors were very distinguished science professors at the University of California, Berkeley and the University of Maryland.
- Grants would be subject to a rigorous peer review process, in which independent, highly qualified experts would assess the technological feasibility and even the distant market prospects of the project and would compare not only the projects but also the scientific standings of the teams (a very important feature for project delivery).
- In its support for highly promising teams and promising high-risk projects, EU ARPA-E would be agnostic as to whether the private sector or universities are best suited to solve a particular problem.
- The agency would not pick the solution in advance; it would set goals (e.g., battery capacity and longevity) rather than the way to achieve them. Again, the COVID-19 vaccine experience is useful: It was not clear in 2020 what the best scientific and most cost-effective route would be.
- The agency would evaluate interventions afterward and publish the results. A "sunset clause" would ensure that support can be withdrawn if the project is not working or is no longer needed—a feature that is often missing when the public sector undertakes industrial policy: Whether pressured by recipients who want to keep receiving funds or a desire to prove they were right in the first place, officials too often keep throwing money at projects that show little chance of succeeding. Relatedly, because a good R&D portfolio has some failures, failures need to be tolerated and recognized, but lessons must be learned.
- A requirement of co-funding by the private sector might be of further help (as is the case for the US ARPA-E), both at the project screening stage and to help facilitate the termination of nonperforming projects.

Is this feasible? It may be useful to compare EU ARPA-E with existing European institutions with similar objectives.

A European role model for this, albeit in the academic research sector and with too small a scale, is the European Research Council (ERC), modeled after the very successful National

Science Foundation and National Institutes of Health in the United States. It selects a small number of high-risk, high-promise projects; is protected from political intervention; and conducts a clean, peer-reviewed allocation of grants. The key researchers behind two of the three current COVID-19 vaccines, Uğur Şahin of BioNTech-Pfizer and Adrian Hill of Oxford-AstraZeneca, are ERC laureates whose grants were for then-exotic forms of vaccination or therapies that they were able to transform quickly when COVID-19 appeared. Needless to say, a European agency in charge of green projects would face a different environment and have different goals and processes, but the ERC example shows that European cooperation and clean governance can be achieved in the R&D domain.

Another European undertaking, the European Space Agency (ESA), has been successful for quite a long time despite two features that have made the agency difficult to run. First, it has applied an unwritten fair-return rule that contributing countries must receive a volume of orders for projects supported by the agency in proportion to their contributions. This rule adds significant complexity and slowdown in the decision-making process as well as occasional suboptimality in the selection process. Second, ESA defines the technical specifications of the projects it finances, whereas DARPA and other US agencies have moved to a logic that defines performance objectives and leaves it to the contractor to find solutions. The European system has been less conducive to breakthrough innovations such as reusable launch systems and industrialization of the production of certain equipment.

As noted above, EU member states have embarked on joint research support. A newcomer to this landscape is the European Innovation Council (EIC), which will distribute €10 billion over seven years. It is inspired by the way the ERC operates: A fraction of its budget will even be used to take over where the ERC's proof-of-concept program ends, to bring innovations closer to industrial or societal use. The EIC also has thematic priorities in the tradition of DARPA. Unfortunately, the EIC's strategic council, unlike that of the ERC, is only advisory; the European Commission has kept the upper hand on concrete decisions. Because of this detail, Europe cannot claim to have created its own DARPA (which, in the United States, has a lot of independence).

Thus, the role of scientists in decision making and target setting could be strengthened in the management of these institutions. These differences are particularly important when it comes to selecting a very small number of disruptive projects and putting large sums of money into them, as US agencies have been able to do in the high-tech, environmental, and medical fields. Committing such sums with a high risk of failure is not in the European administrative culture for understandable reasons, but it is indispensable to make such investments to achieve world leadership in at least a few areas. There are of course two corollaries: First, it is imperative to attract very high-level scientists as managers, which will require a mechanism to ensure the necessary means. Second, for both budgetary reasons and access to a broader talent pool, it is desirable to situate the agency at the European level (without imposing fair-return constraints or sprinkling positions according to nationality quotas).

3.3. Leg 3: Complementary Actions

In this section, we discuss various issues that have been proposed for and against carbon pricing and public subsidies for green R&D.

3.3.1. Pros and cons of command and control. We mentioned that the carbon price may, for political reasons, be lower than needed. Another issue with carbon pricing is the measurability of emissions. This challenge is not necessarily due to the large number of economic actors. Fossil fuel products used in mobility and heating can be included in a cap-and-trade scheme such as the EU ETS; as is currently the case for electric power and the cement and steel industries, taxes can thereby be collected early in the value chain rather than from each household or firm. Methane emissions from cattle breeding could be taxed at the level of the slaughterhouse. However, forestry contributions to global warming (admittedly less important in the European Union, which has relatively little forest) and carbon emissions from agricultural practices are harder to measure than those of a power plant or the volume of gasoline produced by a refinery.

A third issue with carbon pricing is that some infrastructures (say, for EVs[32] or hydrogen applications) must be standardized so that competing producers can serve the market. The polluter-pay principle ensures that economic actors are held accountable for their emissions, but no price can guarantee that rival green companies will converge on a single standard. This is another market failure. The state can help with this standardization; it should be as neutral as possible regarding the choice of technologies, but it cannot be entirely neutral.

A fourth issue is that, as a rule, incentives provided by carbon pricing work better for companies (e.g., power plants, cement and aluminum producers, airlines) than for households. For the latter, a carbon price still works well to guide current consumption: Applied to air travel, beef consumption,[33] gasoline, and fossil fuel–generated electricity, it leads consumers to substitute the train for the airplane, eat less beef, increase car sharing and telecommuting or teleworking, and use less air conditioning. Carbon pricing may function less well when consumers invest for the long run. There are three reasons for this.

First, households are poorly informed about the future costs and benefits of their green actions. A case in point is energy retrofitting, especially in France where, unlike in Germany, consumers do not receive good advice[34] and subsidies are not based on realized energy savings. For carbon pricing to have the intended incentive effects, households must be properly advised regarding their private cost-benefit analysis.

Second, those who decide are not always those who will pay the bill. Despite energy performance certificates, tenants and landlords do not always agree on energy savings. In theory, landlords have the right incentives to invest in the energy renovation of their buildings and apartments if tenants are well informed about the quality of these investments (energy performance certificates can contribute to such awareness), if they pay their electricity bills, and if the rent can be adjusted to reflect the tenants' lower energy consumption. If these conditions are not met, landlords will not make enough effort to improve energy performance. A few studies confirm that, in practice, thermal renovation efforts are more sustained when landlords reside in the dwelling. Asymmetry of information problems can also reduce owners' willingness to renovate if they are concerned about the impact of renovation investments on the value of their property in the housing market in the event of a sale. Finally, there are coordination issues in condominium structures.

Third, empirical evidence shows that households may underinvest in the quality of durable goods, either because of liquidity constraints or because of a bias toward the present. This may well apply to energy efficiency choices, although a variety of government-sponsored zero-interest loans are often available to illiquid households.

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[32]The EV recharging infrastructure includes charging connectors, vehicle charger vs external charger, AC vs DC connection, voltage, and so on.

[33]This measurement is imperfect. An imperfect proxy for cattle-related methane emissions might be the weight of the animal.

[34]They should also be wary of advice from the industry. Thermal insulation has had a disappointing impact (see footnote 37). Households face both moral hazard (insulation suppliers can cut on the quality of material and work) and adverse selection (performance insulation benefits depend on many parameters, and consumers further face a lemons market as they cannot evaluate the competence and honesty of professionals). Readers are referred to Ambec & Crampes (2020).

Following Stiglitz (2019) and Rosenbloom et al. (2020), for example, these arguments call for complements to carbon pricing, such as bans and standards. Examples of bans under consideration or already promulgated include those on single-use plastic bags and on the sale or registration of new vehicles powered with specific fuels by a certain date, and the definition of low-emissions zones not accessible by fossil fuel–powered cars. An international illustration of a standard in the environmental realm is the successful 1987 Montreal Protocol on Substances that Deplete the Ozone Layer, which set targets for countries and burden sharing.

Such policies are easier to put in place when combined with the second leg discussed above, innovation. A case in point is the change in lighting, which came from a combination of regulation (the banning of incandescent light bulbs in the late 2000s and early 2010s) and R&D on alternatives (LEDs, from the theory in the early twentieth century to the breakthrough on blue LED in the 1990s). Similarly, banning new sales or restricting the use of combustion engine cars in low-emissions zones will be simpler once the cost of electric cars has fallen and their range improves, which is in sight.[35] Bans and standards may also trigger innovation and learning-by-doing by presenting the industry with a challenge.

Such complementary measures can be useful but require ballpark numbers about their efficacy. To illustrate, it is known that rooftop photovoltaic (PV) panels are much more costly than state-of-the-art large-scale grid-based PV panels in Southern California, Arizona, and Texas. Why should the US government subsidize such panels with direct subsidies and net metering subsidies? To meet a decarbonization goal, it is preferable to subsidize grid-based PV or take the money and put it into R&D for hydrogen or long-term storage. Retrofitting, a very popular policy, is another case in point: The evidence shows that the price per ton of CO_2 removed can be very high, except for very poorly insulated buildings.[36]

Ideally, the impact of such policies should be assessed whenever possible.[37] This is needed to ensure that the implicit carbon price justifying the policy is not out of line with the carbon price levied elsewhere. Put less technically, a standard, ban, or subsidy that leads to spending €1,000 of consumer or taxpayer money to economize 1 ton of CO_2 is not a green policy: Under a carbon price of €50, say, the same amount of money would have removed 20 tons instead of a single one. Subject to the caveats that bans, standards, and subsidies must have reasonable costs and that the overall policy must be coherent (it must be tested by calculating a ballpark estimate of the implicit cost per ton removed), we think these instruments can indeed be part of an optimal package. The bigger the part of the package they constitute, the smaller the actual carbon price.

In reaction to the gilets jaunes movement, President Macron established in October 2019 a Convention Citoyenne pour le Climat (CCC), composed of 150 randomly selected citizens, with the mandate to make recommendations about how to attain the French climate goal: 55% emissions reduction by 2030 compared to 1990 (as of 2020, France had reduced emissions by 22%). The CCC submitted 150 propositions in June 2020, none related to carbon pricing and many unrelated to the climate. Some of them easily pass the cost-benefit analysis even with a low carbon value. For example, the CCC proposed a ban on external heaters in bars and restaurants; it became a law in 2021. Other recommendations were problematic. For example, the CCC proposed a ban

[35]The Criqui (2021) report in France examines the cost per tCO_2 saved from switching to EVs and hypothesizes that EVs are beneficial with a carbon price around €250/tCO_2, which should be the case by the end of this decade.

[36]Fowlie et al. (2018) find, in a US sample of low-income households, that projected savings are roughly 2.5 times the actual savings. Blaise & Glachant (2019), using French data, find an even worse ratio, at almost 8 times the actual savings.

[37]Also, such policies should not be undertaken in sectors where a high-enough carbon price prevails already, as they would duplicate carbon pricing.

on all domestic flights when an alternative by train in less than 3.5 hours exists. A new law validated a milder version of this proposal, with a threshold of 2.5 hours and an exemption for flyers in transit (otherwise the rule would have favored hubs in London and Amsterdam). The CCC also wanted the highway speed limit to be reduced from the current 130 km/h to 110 km/h. This was rejected by the government on the basis of a technical report demonstrating that the benefit of the measure (e.g., in terms of lower emissions, lower gas consumption, and lives saved) was smaller than the cost (mostly, time lost). These recommendations fall vastly short of the French climate goal, and a new round of climate regulations is expected to be discussed in Parliament in the coming years.

The CCC's recommendations tended to be biased toward subsidies and bans. As we noted earlier, a subsidy is always a tax as it needs to be financed, and bans can be costly in an invisible way. Climate urgency motivates both making a sacrifice and choosing battles in order to make the most from the sacrifice. The CCC lacked a socioeconomic evaluation of the proposed measures, an assessment that could help ensure a reasonable impact on people's purchasing power.

The same need for socioeconomic evaluation applies to renewable portfolio standards, a frequent policy around the world mandating a minimum fraction of electricity generated through wind and solar.[38] This process should be systematized, so that the debate is informed by the relevant data (in the United States, the Office of Management and Budget and the Environmental Protection Agency test regulations using a schedule of estimates of the social cost of carbon). This point is further discussed below.

One quarter of global greenhouse gas emissions come from agriculture. Incentives must be designed to halt deforestation and land degradation and to promote land carbon sinks. Remote-sensing technologies must be improved to measure the actual impact of private efforts. Sustainable, diversified agriculture, precision cultivation, and vertical farming are examples of areas in which policies help reduce emissions. Agriculture, a major source of pollution,[39] needs more attention from policy makers (Guyomard et al. 2020).

Ambitious city planning and public transportation schemes are also called for. Cities, land use, and transportation systems (including park-and-ride facilities) must be designed or redesigned; green city strategies may also bring co-benefits such as better health and reduced exposure to heat waves. These environmental policies will require complementary policies. They will raise the land rent enjoyed by owners of city-center property, especially as localities vote against densification (which is unpopular with owners, who want to preserve and increase their rent). The increase in property prices brought about by green policies (e.g., a ban on polluting cars, reduction in the number of parking spaces) should ideally be captured by the community, possibly through some capital gains tax; in France such collective appropriation of the gains associated with public investment failed to take place for high-speed trains or urban renewal programs.

Housing policies, beyond the standard economic issues,[40] have an obvious link with the fight against global warming. We have mentioned energy renovation and the usefulness of supporting households (especially low-income ones) in their energy-reducing renovations through effective

[38]Greenstone & Nath (2020) make the point that the method for properly estimating the impact must be as state-of-the-art as possible. They find that US renewable portfolio standards have had a substantial impact on CO_2 emissions, and that the cost per ton of CO_2 abatement ranges from \$58 to \$298 and is generally above \$100.

[39]Emissions of ammonia, a serious threat to health, from the agricultural sector continue to rise, posing a challenge for EU member states in meeting EU air pollution limits. Other serious changes in agriculture practices are necessary but hard to impose for political reasons.

[40]Such issues include the actual incidence of housing subsidies, reallocation of social housing to those who need it most, and liquidity of the rental market.

advice, subsidies conditional on verified energy performance (Fowlie et al. 2018), and an increase in the skills of craftsmen in the sector. These policies make it possible to reduce the energy consumption of buildings and encourage the use of existing structures rather than the construction of new ones. The densification of cities, despite the resistance of owners, is a necessary instrument, both to combat urban sprawl and its corollaries (e.g., heavy use of automobile commuting, expansion of paved surfaces) and to reduce intergenerational inequality. Making the owners of brownfield sites accountable—requiring them to renovate brownfields, convert them to green spaces, or sell them—can also contribute to the fight against global warming. Finally, the decrease in the demand for office space due to COVID-19 and the associated increase in teleworking provide an opportunity to convert some offices into apartments, an opportunity that should be systematically exploited by empowering the market mechanism.

3.3.2. The case of learning-by-doing and public procurement. Taking as an illustration the sharp decrease in the costs of wind and solar power over the last 40 years, governments often use mandates—the requirement imposed on electricity companies to procure at least some percentage of their electricity from renewables—and other incentives for the adoption of existing green technologies in order to bring down the cost of alternative energy. The argument is that independently of any R&D (which is promoted by R&D subsidies rather than incentives to adopt technology), manufacturers learn by doing. They correct engineering mistakes over time, and the production cost decreases with experience. Mandates do not focus on future generations of the technology but rather try to spur incremental improvements in existing technologies.

While there is no question about the existence of a virtuous circle of R&D, learning, and economies of scale, researchers have found it difficult to put numbers on the relative influence of each in achieving cost reductions, even on existing technologies[41] and a fortiori looking ahead at new ones. Given this limited evidence, it is unsurprising that different assessments coexist among economists.

Some view as imperative a strong push for mandates and others prioritize the adoption of incentives to bring down the cost of existing technologies and nascent ones: The reasoning is that bans and standards are essential, although they can benefit from careful evaluation. There are two strong arguments in favor of this position. The first is the urgency of climate change: Many tools must be harnessed to make rapid progress. The second is that some technologies, in particular solar energy, will greatly benefit poor countries, where much of the increase in emissions, if uncontrolled, will take place.

Others view bans, mandates, and standards as useful but only if evaluated carefully. They emphasize two hazards associated with them. The first is obvious from the discussion above: Estimating future learning curves is difficult, and no one wants to create an open bar that might divert public money from green actions with a much stronger impact on climate. In addition, the size of the subsidy must be carefully assessed, as it is for example not clear that installing PV panels everywhere in Europe is an efficient use of public funds to promote learning-by-doing in solar energy. The second issue is one of commitment: At some point the cost reductions level off, and mandates and subsidies are no longer needed (for instance, if wind and solar are competitive with

[41]The reason for this is simple. The effects of R&D (public and private), scale economies, and learning-by-doing are simultaneous and inherently interdependent. For example, government R&D, subsidies, and mandates get wind turbines or PV modules into the market. Developers, equipment manufacturers, and construction companies learn how to deploy the technology, learn from their mistakes, make some profit, and use some of it to support their R&D to make a bigger and better wind turbine or more efficient PV modules and trackers. At some point, consolidated markets become more concentrated and demand increases, so remaining producers benefit from returns to scale.

fossil fuel technologies, it is time to stop the subsidies); and yet, as noted earlier, the government often finds it hard to phase them out. It is therefore important to announce at the onset clear criteria for unwinding support when costs come down and deployment increases. Economists agree on the nature of these arguments but differ on the weights to be put on them.

3.3.3. Promoting a transparent and efficient decision process. A major issue is that firms, having to take irreversible investment decisions under uncertainty, have a private incentive to wait for more information to invest (the usual option value of waiting; see Dixit & Pindyck 1994). If they do not invest soon however, global warming will steadily get worse, an effect individual firms ignore in taking their decisions. As shown by Ulph & Ulph (1997) and Gollier et al. (2000), a counteracting option value prevails at the collective level due to the quasi-irreversible nature of emitting CO_2 in the atmosphere. There is an option value to postpone these emissions to learn more about the intensity of the climate sensitivity or the damage function, two sources of deep uncertainty (Pindyck 2017, Lemoine 2020). This has three implications suggesting the need for (*a*) collecting as much information now as feasible, (*b*) engaging in some form of forward guidance to help firms understand what they will be exposed to in the future, and (*c*) giving financial incentives to firms to move earlier.

This is a hard balancing act, and it suggests the need for a monitoring unit that uses the best available tools to produce transparent and independent estimates that are updated over time as data accrue, knowledge evolves, and scientific debate provides feedback. These estimates could then be used in decision making without unduly delaying action. Representatives and public decision makers should have rapid access to data that could shed light on the impact of their decisions, for the sake of both transparency and efficiency. Transparent calculations of the marginal cost of removing a ton of CO_2 from the atmosphere should be required for all government subsidy or mandate programs.

One can envisage, in Europe for example, the creation of a permanent commission that would benefit from the technical support of such an independent body; alternatively, much greater weight would be given to economic assessment in existing structures.[42] Economists, scientists, and other high-level experts would regularly update their estimates of current and future carbon prices and costs per ton of CO_2 not emitted. The results would guide public decision making, from the design of calls for tenders (see below) to evaluation of the impact of fiscal and tax policies (i.e., green budgeting).

At the European level, it is necessary to ensure that the European Climate Change Council—whose creation is planned in the European Parliament's draft climate law and is intended to be composed of experienced scientists—has an important economic evaluation component.

3.4. Leg 4: Compensation

Climate policies, whether based on price or nonprice instruments, sometimes ignore the fact that they create losers (Levinson 2019). The carbon tax that inflamed the gilets jaunes was economically

[42] In France there are already several bodies with jurisdiction over climate policy, including the High Council for the Climate (HCC, an independent authority), the General Council for the Environment and Sustainable Development (CGEDD), and the Economic Council for Sustainable Development (CEDD), as well as several cross-functional bodies such as the General Secretariat for Investment (SGPI, responsible for implementing the Investments for the Future programs) and France Stratégie. Most of these generally do not have the means to carry out the economic assessments that would maximize the ecological impact for a given expenditure. It seems important to us, therefore, that the strong culture of socioeconomic evaluation of France Stratégie permeate the French state.

justified,[43] but it was not initially accompanied by measures that would have offset at least partly its impact on poorer households and rural and suburban drivers with few public transportation opportunities. For the sake of clarity, a couple of considerations are necessary.

- As long as the total cost of decarbonized energy is larger than that of fossil fuels, not everyone in the current generation can be compensated without raising debt. There must be a net cost to climate change mitigation, and it must be borne by at least a subset of the population. In intergenerational arbitrage between current costs and future damages to the planet, abatement efforts should inflict the least harm, but the fight against climate change will not come for free. Besides, by losers we do not mean all economic agents who are hurt by the green transition. Workers should be compensated, not shareholders, especially those of corporations that had opportunities to change their technologies and that end up with stranded assets; indeed, a policy of compensation for stranded assets would disincentivize firms from adopting green technologies.
- Compensation will never be fair to all targeted populations: Some will enjoy windfall gains (e.g., those who do not use a car but receive a "green check" to compensate for the imposition of a carbon tax on gasoline), while others will experience some net cost. Every situation is idiosyncratic, and the state has neither the information nor the personnel to accommodate each and every case. Less-than-perfect solutions must be accepted, and imperfection cannot be an excuse not to act (an analogy can be useful here: Antismoking policies, which in many countries are regressive, would never have been enacted if policy makers had insisted on perfect compensation).

Incentives require that compensation be backward, not forward, looking: It should compensate for a cost inflicted on the losers but not be recurrent. The compensation system should not weaken the strength of the price signal. For example, a recurrent compensation to workers who live in a rural area very distant from their workplace would not induce them to find a nearer job or move closer to their workplace if they have an opportunity to do so (not everyone has). However, partial solutions do exist. Even a single identical lump-sum transfer, the so-called green check, for every adult (resulting from carbon tax proceeds) would benefit poorer households on average. The redistribution can even be made more targeted and more progressive. Simply, the compensation should be as targeted as possible to actual losers—avoiding windfall effects—and keep a proper forward-looking incentive pattern.

That said, there can be disagreement about what to do with the proceeds of carbon taxation. Some suggest that part of the proceeds should fund green actions rather than redistribution. This has the benefit of showing that the state puts its money where its mouth is and that it is convinced that the carbon tax really serves to fight climate change, rather than just being another source of public funds or of redistribution. This may explain the surprising finding that a carbon tax appears more acceptable if it is used to finance the green transition than if it is redistributed, as shown for many Western countries in a recent international survey (Dechezleprêtre et al. 2022).[44]

[43]It can be argued, though, that buying gas at a station already carries an implicit effective CO_2 taxation rate that is above the EU ETS value. There is no question that including a carbon tax in the price of gasoline is justified; the price should be the shadow price of carbon, which corresponds to the time-contingent price that will make it possible to meet the COP 21 emissions objective and far exceeds the EU ETS price. In practice, the gasoline price includes not only the price of oil and the cost of refining and distributing it, but also a variety of levies that reflect other revenue-raising considerations (captured by the general VAT), congestion pricing, the emission of particles, and of course CO_2 emissions.

[44]We find it surprising that people want the money to be invested in R&D rather than go to them. Two possible hypotheses are that people believe that a tax whose revenue is redistributed is meaningless (mixing

While all countries must spend money to reduce their carbon footprint, they differ in both how costly it will be and how they will be impacted by climate change. Therefore, compensation is also crucial at the international level. Stopping the use of coal, which emits much more CO_2 than even rival fossil fuel energies, is a low-hanging fruit. Yet it has happened on an insufficient scale, in Europe and elsewhere in the world. Poland and Germany, for example, are big coal producers and consumers. The closure of their coal plants will generate a substantial human cost; displaced workers deserve strong support. Delaying closure, however, only delays those costs and in the meantime leads to very high emissions. There is no other way to proceed than to compensate losers, as has been done historically at a more aggregate level in the form of free allowances: Midwestern US states received "bribes" in the form of free emissions allowances when a cap-and-trade system enabled US SO_2 and nitrogen oxides (NOx) emissions (which cause acid rain) to be reduced by half starting in the 1990s; eastern European countries received free allowances in exchange for their participation in the 1997 Kyoto Protocol. This is also the spirit of the EU Just Transition Fund, which provides grants to member states that have identified the territories expected to be the most negatively impacted by the green transition.

3.5. Leg 5: International Inspiriting

The European Union by itself is only a very small piece of the climate change puzzle. It represents 9% of global emissions (France represents less than 1%). Furthermore, future emissions will come mainly from emerging countries, further reducing the European share. So, there is little that Europe can do on a standalone basis. Nonetheless, its efforts to reduce global emissions elsewhere will deliver benefits to Europe that can be sizable. It has a part to play in the following ways.

- First, it can lead by example. To be sure, this unconditional strategy was not that effective during the implementation phase of the Kyoto Protocol.[45] Nonetheless, a voluntarist policy can have a demonstration effect—showing that things can be done—as well as a shaming effect on countries that do not get on board. In the spirit of William Nordhaus's (2015) "climate clubs," Martin Weitzman (2017) suggests alternatively an "I-will-if-you-will" negotiation strategy in which each country agrees to impose a high carbon price on its constituents if all other countries do the same.
- Second, the European Union can use a stick, the CBAM, both to ensure a carbon-price level playing field between domestic firms and importers (more on this shortly) and to encourage recalcitrant countries to get on board. If done right, the border tax eliminates the competitive advantage enjoyed by firms in countries with lax environmental regulations. It also puts pressure on these lenient countries, as their competitive advantage on the export market vanishes (indeed, they are better off collecting the carbon tax on exports themselves). Border tax adjustments are arguably more efficient than conditioning bilateral or multilateral trade

up a tax proportional to emissions and a lump-sum tax), or that a green tax that is not used to fund the green transition must be an attempt to raise fiscal pressure on a false argument.

[45] An unequal distribution of efforts among countries (offering countries like the United States a good excuse to deviate from the agreement), combined with the absence of a sanction tool (such as a carbon adjustment mechanism at the borders in case of noncompliance), explains why Europe remained alone in carbon pricing (through the EU ETS) during the period. Not surprisingly, the EU climate activism lost in intensity: The EU refused to stabilize the price of carbon when it fell below €10 per ton because of the financial and sovereign crises and the development of renewable energies in Germany and elsewhere in Europe. That said, the EU ETS recently introduced a market stability reserve system to prevent this from happening again. Notice that China has recently introduced a centralized market for permits, but the equilibrium price of carbon on this market remains low.

agreements on compliance with the COP 21 contributions and commitments on climate action set by each country, neither of which are binding as a matter of international law.

- If countries use the same tools, say, carbon taxes, then a carbon border tax that equalizes the price paid by domestic and foreign exporters achieves efficiency and does not affect competitiveness. If, however, as seems to be increasingly the case, countries use different tools—for example, the United States relying mostly on subsidies and the European Union relying mostly on taxes—the pursuit of efficiency in abatement will lead to large differences in competitiveness. Suppose, for example, that the subsidy in one country is equal to the tax in the other. Then the price of carbon emissions is the same in both countries, and so no border tax adjustment is needed to equalize the incentive to abate across countries. However, the firms in the subsidy country have a competitive advantage over the firms in the tax country. These differences in competitiveness have to be addressed with other tools, such as targeted tariffs aligned with the WTO rules. Absent these tools, carbon border taxes, to the extent that they exacerbate competitiveness issues, may be difficult to put in place. Finally, the European Union can lead by engaging in public green R&D and making the resulting technologies available to poor countries and by helping demonstrate the viability of existing technologies. Furthermore, it can work through the multilateral development banks, the International Monetary Fund, and the development finance institutions to help emerging market and developing countries—two categories of countries that will represent a big share of the growth in output and emissions in the near future—adopt low-carbon technologies. Moreover, innovation is not only technological. The European Union could, for example, offer 5% of carbon revenues to developing countries to set up CO_2 verification and markets. The benefits from an Indian cap-and-trade, for example, would be large and would represent a relatively low-cost EU contribution to climate mitigation. There is not enough policy innovation in the world, and this could produce emissions reductions that benefit Europe.

4. FURTHER THOUGHTS AND LEADS FOR FUTURE REFLECTIONS

4.1. Electricity Production

As a key sector of greenhouse gas emissions and decarbonization, the production of electricity must be altered in level as well as structure. There is a growing literature (see, e.g., Cole et al. 2021, MIT Energy Initiat. 2022) that attempts to characterize the least-cost low-carbon electricity mix for the decades to come. These studies share similar conclusions: Although the global consumption of primary energy is expected to go down thanks to sobriety and energy efficiency, much more electricity will need to be produced to match the increased demand associated with EVs, green buildings (heat pumps, for example), or the production of green hydrogen (which uses CO_2-free energy to power electrolysis that splits water into hydrogen and oxygen) for mobility and higher-temperature industrial processes. This will create challenges for electricity generation, distribution, and transmission. In terms of structure, most electricity will have to be produced from carbon-free sources.

Renewables will need to be widely deployed, but they may still be expensive because of electrical system balance and transmission problems. First, these are intermittent sources of energy and, in the absence of cheap battery or other sources of storage, have to be supplemented by other means of production. Second, in Europe the best wind resources are in the North, especially offshore, while the best solar resources are in the South. Bringing renewable electricity to where consumption takes place poses a challenge for high-voltage transmission grids, for both economic and not-in-my-backyard reasons. Besides the unpopularity of high-voltage transmission lines, there is a second obstacle to the efficient localization of renewables. Developing such lines across Europe requires cooperation among a number of grid owners and dispatchers with divergent interests (the same problem exists in the United States). A long-awaited solution would be to create a single European transmission and dispatching system that would enable a single European electricity market and thus facilitate the deployment of renewables (Wu et al. 2021).[46] Due to the high cost of electricity storage, the marginal abatement cost in the electricity sector grows asymptotically to attain zero-net emission. Cole et al. (2021) estimated that switching from 99% to 100% renewable electricity mix in the United States would yield a marginal abatement cost of \$930/tCO_2. The report of the MIT Energy Initiative (2022) estimates a marginal abatement cost of \$644/tCO_2 for a 99% reduction of emissions of the Northeastern power grid. These studies emphasize the key role of a carbon-neutral dispatchable source of electricity, such as the nuclear technology, to attain zero-net emission. A 2021 report by RTE (Réseau de transport d'électricité, the French grid company) shows that the least-cost zero-net electricity mix for 2050 allocates a sizeable production share to nuclear electricity (RTE 2021). Regardless of opinions about this mode of production, maintaining safe operation of existing nuclear plants, which for example provided in 2021 three-quarters of the electricity production in France, is a necessary piece of EU contributions to the fight against climate change: Nuclear is carbon free, is dispatchable, and has high availability. Large refurbishment operations can, at a reasonable cost, extend the life of these power plants up to 60 years (some even argue 80 years). Should construction of new nuclear power plants, or the choice of a specific nuclear technology (third and fourth generations, including small modular reactors), be privileged? Issues related to the cost and reliability of nuclear plants, the sequencing of the green transition, and the extension of the life span of existing plants should be examined. The literature suggests that the construction of new nuclear plants should not be excluded on a priori grounds, given the expected huge increase in demand for decarbonized electricity. When it comes to investment and R&D, and given technological and societal uncertainties, it is important not to put all our eggs in the same basket.

During the transition, the use of gas may be a lesser evil. Indeed, gas generates half as much CO_2 emissions as coal, although this difference is reduced in the event of methane leaks (methane leaks due to gas production and extraction must be closely monitored). In addition, its cost is relatively low,[47] keeping the price of electricity at a reasonable level. It should be noted, however, that a more intensive use of existing gas-fired power plants is preferable to the construction of new gas-fired power plants, as new investments with long lifetimes could have a lock-in effect on the energy mix; gas is still too polluting, and the full transition should be made as quickly as possible. A different way of expressing this is that the construction of new gas-fired power plants should be considered only if there are very significant technological advances in carbon capture and storage.[48]

No source of electricity comes without problems. When determining the optimal electricity mix for the coming decades, it is important to estimate the levelized cost of energy (LCOE)

[46] Failing this, governments should support the European Commission's Trans-European Networks for Energy (TEN-E) policy, which works to identify projects of common interest.

[47] We ignore in this discussion the impact of the 2022 invasion of Ukraine and its long-term geopolitical consequences for European access to gas.

[48] We do not see here any argument for policy intervention if the carbon price is high enough: The recommended carbon-pricing mechanism should solve the problem efficiently, provided it is put in place. A ban on coal (which will meet the same resistance as a carbon price) will be necessary if the carbon price remains too low; but this again raises the issue of predictability of the carbon price. New investment in gas is risky, given that it will have to be phased out relatively rapidly. With knowledge of future carbon prices, the private sector can evaluate this risk; in the absence of such knowledge, investment choices are complex.

accounting for social costs. For example, nuclear electricity generates nuclear waste that must be safely managed, and there is a risk of accident inherently associated with the technology. In France, for example, the entire stock of medium- and long-lived nuclear wastes from the electricity production of second-generation nuclear power plants (1980–2050) will be stored permanently in the Ardennes (Cigéo project), at an estimated cost of €25 billion, which represents however less than 0.1 euro cent per kWh generated. This is included in the nuclear LCOE. Estimating the social cost of a nuclear accident is obviously more difficult. On the other side, the strongest resistance to wind turbines is based on their negative externalities in terms of landscape issues and noise. Real estate price data in the United Kingdom suggest that the local monetized welfare impacts of wind projects have a median value of around £4500/MW/year (Jarvis 2021). This should be included in the LCOE of wind electricity whether or not local communities are compensated by the producer.

4.2. Diplomatic Channels

In a world with differentiated climate ambitions and carbon prices, carbon border adjustments will have to be implemented to fight the carbon leakage problem (Marcu et al. 2020, Garicano 2021, Pizer & Campbell 2021). Many are concerned about the risk that, under the cloak of green policy making, lobbyists will obtain protection against foreign competition. Aligning import duties with the current EU price of carbon limits the scope for such manipulation; but the tax base—the estimated emissions induced by imports—is more discretionary. This border adjustment should be as rule based as feasible (Garicano 2021), possibly as part of an accepted World Trade Organization process.

In view of the constraints inherent in the United Nations process (obtaining the signatures of 196 countries gives each a veto right and necessarily leads to least-common-denominator decisions), a number of economists led by Nordhaus (2015, 2021) proposed in the past a joint action by a small number of high emitters (e.g., the United States, China, Europe, Russia, India, Brazil, and Japan). These countries would agree on a core of common actions and put diplomatic pressure (and economic pressure through the border tax) on other countries to join the club. Following the 2016 US presidential election and, more broadly, the rise of populist governments often unwilling to tackle climate change, the idea lost momentum. Contrary to initial hopes, the election of Joe Biden in the United States did not create an opportunity to rethink such an approach. There are also questions about the nature of the appropriate forum: Some experts argue in favor of a "coalition of the willing"; the voluntary nature of such a climate club would facilitate progress on an agreement (e.g., Nordhaus 2015, 2021; Falkner et al. 2022). The club's variable geometry would make it flexible.

However, creating a new institution does not come without cost. The G7 and G20 already cover 80% of world emissions, and a climate club might introduce more bureaucracy and disconnect between the various institutions. Climate change discussions have taken place in the G7, which (if China is included) might be a better forum than the G20, which includes a number of countries that may oppose policies that diminish reliance on fossil fuels.

4.3. Environmental Covenants in Public Contracts

It is often suggested that public contracts should include green criteria as important selection factors among contenders. For example, following a CCC recommendation, a French bill has altered the Public Procurement Code to make the integration of environmental clauses in all public procurement contracts mandatory rather than optional. This is compatible with the concept of the "economically most advantageous bid" inscribed in European public procurement directives, which could be understood as including an evaluation of the environmental damage caused by production processes. The relevant data in this case are emissions and their implicit subsidy (the difference between the social cost of carbon emissions and the actual price of carbon).

Consider the well-founded concern about greenhouse gas emissions created by the transport of nonlocal production of inputs or food. A paradox arises when a government refuses to subject airplane emissions to the ETS or truckers' gasoline to the carbon tax, while at the same time allowing or even asking procurement officers to include environmental concerns in the tender of public contracts. Environmental criteria in procurement are (imperfect) substitutes for the taxation of emissions. This passing-the-buck implies a switch from a well-defined and consistent carbon price to discretionary and likely incoherent policies.

We reiterate our warning: Green policies will be expensive. There is no need to inflate this cost by selecting ineffective policies. Without careful assessment, the new environmental covenants in public contracts might involve an implicit amount of public funds, whether it is €5 or €1,000 per avoided ton of CO_2. The public accounting offices (regional and national, such as the Cour des Comptes in France) are not equipped to compute these implicit costs and to verify the claims of bidders in public tenders. Furthermore, the ability to tilt procurement exposes officials to lobbying and electioneering. A local official eager to be reelected may overemphasize the benefits of local production or voluntarily ignore some relevant dimensions (say, the heating of local greenhouses to grow vegetables) while including others (say, transportation) to protect local producers against competition, at a high cost for public finances or consumers and a low or even negative impact on the environment.

4.4. Nongovernmental Actions

Regulations are never perfect for a variety of reasons, and all countries should do their bit to help. First, it is important to try to alter social norms. This is no easy task, but norms-based interventions can be effective, especially when coupled with material incentives. Tobacco smoking in public spaces is a case in point: Attitudes changed dramatically when fines and legal enforcement suggested that such individualistic conduct was not widely accepted in the population and constituted antisocial behavior (Gruber 2003). In the context of the environment, combining maluses on high-emission cars with a ban on advertising their glamorous features, or outright awareness campaigns, would mimic what was done for tobacco. Banning lights for closed shops and supermarkets at night is another visible demonstration of a changing norm.

Second, citizen and corporate initiatives (socially responsible investment and consumption, for example) can contribute to a better outcome. Whether on their own initiative or under stakeholder pressure, firms such as Walmart or the FAANGs (Meta, Amazon, Apple, Netflix, and Alphabet) contract some of their electricity from wind and solar producers. Whether such initiatives have a real impact has to be looked at with care, though; for example, in the United States, the purchase of renewable generation in states where a mandate dictates the share of renewable generation in electricity companies' production portfolio often leaves total renewable generation (and CO_2 emissions) unchanged: It does not generate more investment in renewables. Impact is what matters, not posture and greenwashing (Moisson 2022).

There cannot be too great a divergence between the material interests of consumers, investors, and suppliers and what is socially expected from them. Many people are willing to pay a bit more for fair trade products (Berger 2019) or receive a bit smaller return on savings if doing so contributes to a greener economy. There is no evidence, however, that a significant fraction of the population will be willing to make massive voluntary sacrifices of purchasing power (as confirmed by the perceptions reported above). Relatedly, private initiatives should not absolve governments from acting, and governments should not ask the private sector to do their job. It should be borne in mind that 30 years of injunctions have not significantly changed carbon emissions behavior and that, although awareness has grown in the population, there is only so much that can be expected from nonincentivized private-sector behavior.

4.4.1. What to expect from the private sector. Externalities create a wedge between profits and value creation of economic activities. In the absence of extrinsic motivations organized by the Pigouvian pricing of these externalities, prosocial behaviors driven by intrinsic motivations such as image concerns and self-esteem may contribute to reducing emissions. Bénabou & Tirole (2010) discuss the benefits, costs, and limits of socially responsible ways of life and production as a means to improve collective welfare.

So far, much of the encouraging private-sector news on the technological and managerial fronts has owed more to an increasing awareness of the enormous economic shock that the end of the climate waiting game will trigger than to effective governmental action. Many corporations realize that global warming is an existential threat for their business as well as the world. Firms accordingly engage more and more in an assessment of their vulnerability to the climate risk (climate stress tests cover the transition risk and the physical risk).

Corporate leaders and managers who want to align their businesses with the common good could implement an internal carbon-pricing mechanism (Trinks et al. 2022): As in the public sector, their investment decisions should be guided by adjusting their measure of value creation, i.e., their profit, by the present value of the flow of additional CO_2 emitted. This flow should be valued at the stated internal carbon price, ideally equal to the social cost of carbon, net of the actual carbon price they face. For large corporations, decentralized management of decarbonization efforts would require the actual monetary transfer of the internal carbon price between business units or subsidiaries and the center to align the units' interests with those of the corporation.

Critics of the internal carbon price, however, argue that firms have limited leeway to deviate from profit maximization. By raising production costs, a voluntary internal carbon pricing not followed by competitors could be counterproductive for the environment by transferring production and market shares to the least responsible producers. Even in the presence of climate-concerned consumers, the presence of greenwashing producers raises a credibility issue for this approach of incentivizing firms. This calls for stronger and more reliable carbon accounting standards, as discussed below.

An internal carbon-pricing mechanism could still be a profit-maximizing procedure if a firm anticipates the emergence of an efficient carbon-pricing mechanism. Although climate finance and corporate social responsibility (CSR) governance are aimed at including extrafinancial objectives on top of maximization of firms' market value, climate-responsible firms may eventually be more efficient than their brown competitors when governments around the world start to heavily penalize carbon-intensive corporations. Internal carbon pricing is a bet on future effective climate policies. By anticipating them, it plays a useful role in incentivizing market participants to decarbonize before it is too late.

4.4.2. What to expect from central banks. There is much discussion about green central banks. Let us start with the relatively uncontroversial part, which already exists in the mandate of central banks: Climate change should be embodied in central banks' economic forecasts, banking stress tests, and assessments of the quality of the collateral they accept from banks. Climate change will create macroeconomic shocks (damages, properties under water, energy transition, high carbon prices, and stranded industrial assets) whose likely size grows with every day of procrastination. Various scenarios must be drawn to predict banking and insurance liabilities as global warming continues.[49]

Climate stress tests are about financial stability and capital buffers that reduce the occurrence of banking bailouts. Policies have been proposed that, in contrast, consume public funds and that we now discuss.

4.4.2.1. Risk taking and public finances. The problem with green projects is not the availability of financing but the lack of associated income prospects. The central bank can potentially boost the profitability of green projects in several ways. Two of them, well-meaning, have been recently suggested. To the extent that central bank profits go to the treasury, both involve the use of public money. They are in our view misguided.

First, the central bank could promote green projects by relaxing prudential standards: It has been proposed that capital requirements be loosened for banks' climate-friendly lending. However, green projects are subject to substantial macro (political and technological) risk. One cannot help being concerned about such a policy increasing the risk of a banking crisis. Green finance should not be the new subprime, if greener corporations do not reap the expected revenues (e.g., because governments fail to impose the relevant carbon price) or specialize in a technology that does not deliver.

Second, the central bank can reduce spreads on bonds in a discretionary manner; it does so, for example, to shore up countries that face a speculative attack on their currency. It has been proposed that the central bank purchase green bonds to reduce their spreads, if any. In contrast with the relaxation of prudential standards, such a policy would induce direct risk taking by the central bank[50] rather than an indirect one associated with the specter of new bailouts of the financial sector. Leaving aside the fact that a proper, impact-related definition of green bonds is still in the making, green spread reductions would open an environmental and political Pandora's box. For example, could the European Central Bank (ECB) refuse to buy German bonds on the ground that the country's per capita emissions of CO_2 from the burning of fossil fuels for energy and cement production are 75% higher than those of France, or because Germany is delaying the closure of its coal plants until 2038? Why stop there, why not purchase bonds of firms or institutions that do good for the world (for example, by reducing inequality) or give large sums to charity? These actions should be left to governments, not the central bank.

4.4.2.2. Legitimacy. The European political institutions have the instruments and the mandate to fight climate change. A transfer of competences to the ECB should at the very least be explicit. It would, however, provide governments with an excuse to make the ECB responsible for their environmental policies. Since these climate actions have a cost, the state spends public money, even if the operation is done through the ECB. It is the states that must take responsibility, in a completely transparent manner and without jeopardizing the finances, credibility, and independence of the ECB.

4.4.2.3. Sense of mission. Finally, there is a concern that the Central Bank, voluntarily or under political pressure, might engage in "mission creep." Authorities like central banks and competition authorities have been relatively efficient—at least relative to their ministerial predecessors—at fulfilling a narrow mission (control inflation, supervise banks, defend consumer interests against

[49]Not everybody agrees. Cochrane (2020) argues that climate-related financial risks are relevant only over a very long horizon, longer than the relevant horizon for assessing financial stability.
[50]Some proposed measures, such as not accepting collateral from dirty energy firms, do not involve higher risk, but they are subject to the same problems discussed here.

monopoly power and product misrepresentations). Becoming jacks of all trades and being given a fuzzy mission may not make them deliver on what is expected of them.[51]

4.4.3. What to expect from the financial sector. Public policy procrastination may incentivize citizens, firms, and investors to do their bit. Needless to say, we strongly favor such actions. To be effective, however, they require carbon accounting. Such accounting for a reporting company correctly emphasizes its direct and indirect emissions: the former from owned or controlled sources, the latter from the generation of purchased electricity, steam, heating, and cooling, as well as indirect emissions that occur in the company's value chain. The challenge is to make sure that the necessary information is available for these actors to direct their actions in the right direction. Current disclosures lack consistency, comparability, and reliability. Companies should be required to report their emissions in a verified and standardized way, with the same penalties as those that apply for inaccurate financial reporting.

Building on the implementation of a European taxonomy,[52] methods used by CSR rating agencies, central banks, financial market regulators, accounting standards, and financial institutions should converge to science-based tools for assessing the environmental impact of companies, based on a comparison of societal costs and (co)benefits. Unfortunately, the task is far from simple. Intuitions can be misleading and the adoption of green behavior is much more complex than it seems: Financial investment in existing hydroelectric plants, or in a renewable energy that would have occurred anyway thanks to high-enough subsidies, does nothing for the planet, however green these energy sources may be. Such funding amounts to a mere windfall gain to the corresponding energy producers.

Green financiers have an impact through the reduction of the cost of capital to the socially responsible firms in which they invest (Gollier & Pouget 2022). To make a difference, green projects must not have taken place in the absence of lower interest rates paid to environmentally conscious investors. Such "additionality" is difficult to assess, as it is not possible to observe the counterfactual. Typically, the project developer puts forward an argument as to what would have occurred absent the actions taken; the regulator, lacking precise information about the counterfactual, may certify additionality if it is politically or administratively expedient to do so. Green finance should also calibrate the benefit it offers to responsible firms in order to provide the efficient incentive to decarbonize. In the absence of any other incentive, the benefit generated by the lower cost of capital should be equal, at the margin, to the social benefit of the carbon not emitted compared to a reference production process in the sector. We are not aware of any study attempting to measure optimal divestment efforts by sectors, technologies, and regions that support efficient global decarbonization allocation.

Similarly, well-meaning private policies such as carbon offsets and public ones such as the Kyoto Clean Development Mechanism (CDM), despite their emphasis on additionality, may fail to reduce carbon emissions and instead create a windfall gain for projects that would have taken place anyway or whose direct impact is nullified by carbon leakage. The Kyoto CDM rewarded carbon-saving projects in developing countries while allowing industrialized countries to obtain

[51]Readers are referred to Tirole (2023) for an assessment of the desirability of multi-mission agencies.

[52]The EU taxonomy is a work in progress. In early 2022, the political deal between France and Germany to label natural gas and nuclear electricity as green left many experts, activists, and politicians very skeptical about the future of this label. An efficient climate labeling procedure should be based on a comparison of the social costs and benefits of each technology. For example, as long as the electricity storage problem remains unsolved, making a drastic expansion of solar and wind generation costly, and in the absence of alternative carbon-free sources of production, natural gas is used as a substitute for coal and has a high social value for electricity production.

carbon credits tradable in the ETS by investing in emissions reductions where they are cheapest globally. The CDM generated high transaction costs, as there were endless debates as to whether projects were additional or not.[53] A further issue is that the conservation of a forest in Indonesia, for example, would raise (slightly) the price of soy or timber, leading to substitute deforestation elsewhere—the leakage problem once again.

Another case in point is the "exclusion versus best-in-class" debate. For example, should environmentally responsible investors invest in a technology that emits CO_2 but replaces one that pollutes more? Is it appropriate to encourage firms in industries that pollute but cannot be phased out in the short run to reduce their pollution? For example, if oil is still going to be used in the short term for, say, driving, incentivizing oil companies to reduce their emissions at the extraction, transportation, and refining stage has environmental benefits. The question is clearly more complex than one might initially think.

Finally, there is much discussion about divestment of carbon-intensive assets from portfolios, starting with immediate divestment from coal-related assets, in response to political authorities' failure to act clearly and decisively on this matter. However, while such exclusionary policies have strong symbolic content, only so much can be expected from them. Their efficacy is limited by yet another leakage problem: They have little impact if other investors jump at the opportunity of buying undervalued fossil fuel stocks and bonds. This has been expressed—albeit in too extreme a form—by Bill Gates, who argued that campaigns to ditch fossil fuel stocks are a "total waste of time" (cited in Edgecliffe-Johnson & Nauman 2019).[54] It is not the divestment movement that weakened the tobacco industry, but the high taxes imposed on cigarettes in the Western world. Again, social responsibility is about impact, not posturing.

In the presence of unregulated externalities, the market value of a firm does not measure its social value creation, and asset prices do not support an efficient allocation of capital. Responsible investors should be guided in their portfolio decisions by an internal carbon-pricing mechanism. To value an asset, they should subtract from its market value the discounted flow of future CO_2 emissions anticipated from its current physical capital valued at the effective carbon price. Standard quantitative finance models could then be used on the basis of the risk/return structure of these social asset values to determine the efficient greenness of portfolios and divestment strategies.[55] However, independent of the divestment strategy (e.g., efficient, best-in-class, exclusion), responsible investors face a financial carbon leakage problem, as other investors will rebalance their portfolio to take advantage of bargain prices of brown assets by divesting from the more expensive green ones. The sacrifices of the responsible investors will be mostly undone through this equilibrium effect. Compared to political institutions, green financiers are in a much worse position to fix the climate change problem.

Shareholder insistence on knowing the carbon footprint and the exposure to regulatory risk makes good business sense, independent of environmental consciousness. As shown, for example, by the behavior of some financial institutions before the 2008 financial crisis, corporate managers may adopt short-termist attitudes: They may cut corners to offer a flattering image of their performance, either to keep their job if the firm is imperiled or to cash generous bonuses and exercise stock options if their compensation is not subject to clawbacks. Climate-related procrastination

[53] Readers are referred to World Bank (2010, p. 265) and the references therein. These debates of course subsided when the currency of the payment (allowances in the EU ETS system) collapsed. A related issue is that of "carve-outs": A firm that otherwise has high carbon emissions, either directly or indirectly through its supply chain, can select a subset of assets that are clean and issue green bonds against them. Similarly, Poland, a high CO_2 emitter, was the first issuer of sovereign green bonds.

[54] A similar discussion of South African stock divestment took place during apartheid.

[55] Shareholder activism may be a better strategy than divestment (Gollier & Pouget 2022).

increases firms' short-term profits but exposes them to a large but delayed macroeconomic shock when aggressive climate policies are imposed. It is therefore in the interest of shareholders to curb possible short-termism in a firm's management and to make sure that the firm is not too exposed to climate risk, so that it will not be left with too many stranded assets.

5. SUMMING UP

Four observations shape the economists' views on the climate challenge. First, the climate urgency calls for swift and large-scale action. There is rapid change, but nowhere near fast enough. Second, a holistic approach must be adopted to tackle the challenge. Third, green policies will be expensive, but our unique planet certainly warrants the courage to admit and deal with this fact; the longer action is deferred, the more costly it will be. Fourth, there is no need to inflate this cost by selecting low-impact policies.

Carbon pricing has many virtues. Unpopular for good as well as bad reasons, it is nonetheless an essential piece of the puzzle. It has been poorly implemented: It has been too unambitious to have the desired impact, has admitted many exemptions, has given way to numerous fossil fuel subsidies, has raised concerns about offshoring to countries practicing environmental dumping, and has offered low visibility as to future levels of the carbon price. Insufficient compensation of low-income suburban and rural dwellers has also contributed to its unpopularity. So, the first conclusion of this article is an unambiguous endorsement of carbon pricing done right.

However, much more is needed: first, through a rapid intensification of the green R&D effort, and second, through standards, bans, and targeted adoption incentives where carbon pricing is less adequate. These interventions are more discretionary than carbon pricing and therefore more prone to lobbying, regulatory capture, and red tape. Such concerns can be at least partially addressed through proper governance of the processes and the creation of independent agencies. On the R&D front, a European agency could be created to fund high-risk/high-reward projects, that would use peer reviews. On standards, bans, and adoption incentives, it would also make sense to create an independent commission of high-level scientists and economists who would help rationalize public choices without slowing public decision making. In both cases, sunset policies would phase out subsidies when projects do not perform and when subsidies are no longer needed. In sum, the state should be a strategist taking its responsibilities seriously (and not trying to pass the buck to other actors, such as the central bank or corporations), unleashing the private sector's adoption and innovation, and reconciling urgency to act and cost containment.

Finally, most countries by themselves will have a minor direct impact on climate mitigation, but especially if the policies are designed at the European level, their indirect impact can be substantial: leading by example and showing that things can be done, putting pressure on free-riding countries through border tax adjustments, promoting technological and policy innovation that can be used by poor countries, and playing an intellectual leadership role in the building of international agreements.

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