WORKING PAPERS

N° 1360

September 2022

"Fighting the war against climate change"

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FIGHTING THE WAR AGAINST CLIMATE CHANGE *

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September 15, 2022

Prepared for the *Annual Review of Economics*

* This paper is based on the climate synthesis chapter of the “Blanchard-Tirole Report” on the major future economic challenges submitted to President Macron in June 2021, as well as the specific chapter written by Christian Gollier and Mar Reguant for this report. The authors are very grateful to Mar and also thank the members of the members of the Commission in charge of elaborating and discussing this report: P. Aghion, R. Blundell, L. Boone, A. Börsch-Supan, V. Bosetti, D. Cohen, P. Diamond, C. Diehl, E. Farhi, N. Fuchs-Schündeln, M. Greenstone, H. Hoynes, P. Krugman, T. Philippon, J. Pisani-Ferry, A. Posen, C. Propper, M. Reguant, D. Rodrik, S. Stantcheva, N. Stern, L. Summers, and L. Tyson. The paper has a very strong European emphasis (and for a number of illustrations more specifically a French emphasis). However the questions raised mostly apply - up to some institutional details and emphasis- to all countries. The research leading to this paper has received funding from the Agence Nationale de la Recherche under grant ANR-17-EURE-0010.

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, and create a resentment from poor and middle-income countries that might trigger wars or other forms of conflict.

We have little time left to act (Stern, Stiglitz and Taylor, 2022). Despite the sense of urgency, there is still a sharp contrast between the officials' voluntarist political discourse and ambitious long-term pledges, and their actual behavior. Almost thirty years after the Rio summit, 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 sizeable and costly transformation of our economies that is required to achieve the Paris agreement (Conference of the Parties/COP 21) targets or the more recent "zero-net-emissions by 2050 or 2060" pledges of some major polluting countries still needs to happen.[1] The longer we wait, the more costly and disorganized 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 or 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 come up 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.

Another good news is that the environmental awareness has progressed in the polity. In a recent survey by Dechezleprêtre et al. (2022), 70% of the respondents from high-income countries and 81% of the respondents from middle-income countries believe that climate change prevails and that it is anthropogenic. The challenge is therefore to find ways that will put an end to the disconnect between speeches and behavior, to make costly actions

[1] Changing our agriculture and consumption, phasing out fossil fuel energies for our mobility (cars, trucks, airplanes), industries and living spaces, retrofitting poorly insulated buildings and using smart meters with time varying prices to rationalize our 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] Electricity storage, the very desirable complement to these intermittent productions, includes batteries, but also pumped hydro, compressed air, and green hydrogen produced either by electrolysis or by natural gas reforming plus carbon capture and storage (blue hydrogen).

politically acceptable while making sure that the cost of these actions remains as low as necessary.

We believe that, despite the grim situation, solutions exist, that combine multiple approaches. Provided that they are implemented rapidly, they will allow us to address climate change at an economic and societal cost that is small compared with the alternative. But, and this is another message of this report, we must be selective. When it comes to proposals for green policies, there is an embarrassment of riches. Our report takes a stance as to what we believe will be impactful, stresses good ideas and screens out bad ones.

In a nutshell, we argue that:

- Carbon pricing is good economics. We describe current policies and how they can be much improved, with a fair number of details and analysis.
- R&D support is good economics. Low carbon prices not only encourage current emissions, but also are detrimental to the R&D effort. But, even if carbon prices are generalized and given more substance, green R&D is still likely to be smaller than needed. Much more money must be spent on green R&D than is now the case. This money must be spent right if we want it to have an impact; we explain how to do so.
- Done well, other policies, such as standards, bans and targeted subsidies, can be good economics. But they have often been incoherent in the past 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 EU, the US 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 cuts that take place in China, India, Russia, Pakistan, the United States, and elsewhere, deliver the same benefits as a similar cut in emissions in Europe.

2. Facts and Perceptions

Despite the general support for fighting global warming, a number of perceptions hamper the design of policies that deliver the most reductions in emissions per cost to society. These

perceptions, driven by experience with actual policies, disregard for budget constraints, and distrust for 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 U.S. as in many other countries, proposals to price carbon emissions are perceived as political suicide. As documented by Dechezleprêtre et al. (2022), only one-third of the U.S. or French population would support a carbon tax at 45 $/tCO2, in spite of the fact that that level would be largely insufficient to attain the politically-determined climate ambitions of these countries[3]. This suggests that most people do not understand (or as we will later develop, do not want to take on board) the incentive mechanism behind the polluter-pay principle supported by a vast majority of the economics profession. As documented by Douenne and Fabre (2022), French households for instance feel that a carbon tax (a) is "punitive", (b) is regressive, and (c) would still be regressive if the French received an unconditional lump-sum refund from the receipts of the carbon tax (which is incorrect). The latter perception may be due to a distrust about the long-term credibility of the compensation: The compensation, once promised, can be whittled down or eliminated over time. If so, institutions must be designed, that will 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. It implies that the fraction of income spent on the tax is higher for low-income households. But observe that this critique holds for all climate policies that raise the price of energy, such as feed-in-tariffs for renewables or the ban of cheap coal for heat and electricity generation.

2.2. The relative popularity of opaque policies

In contrast, people favor, or at least do not ostensibly oppose policies whose cost is invisible to them. Yet, these policies in nature are as punitive as, or even more punitive than a carbon tax. Dechezleprêtre et al. (2020) found for example that a majority of French respondents supports green infrastructure programs (57%), a ban on polluting cars in city centers (57%), and subsidies to green technologies (56%) and for thermal insulation (64This international survey draws a similar picture for other high-income countries.

[3] The support for carbon pricing is larger when its revenue is targeted to finance environmental infrastructures (63% in France and 56% in the U.S.).

A carbon tax puts a price on carbon emissions and thus makes economic actors accountable for their pollution. The cap-and-trade system is an alternative approach to taxing carbon. Since 2005, Europe has subjected the electricity, aluminum, cement and other industrial sectors representing around 40% of the EU's greenhouse gas emissions, to this different form of carbon tax. The European cap-and-trade system is called the European Union's Emissions Trading System (EU-ETS)[4]. In an ETS, the number of allowances, also called "permits", is fixed (the lower the number, the higher the environmental ambition). The emitters must match their emissions with 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.

There are 46 cap-and-trade systems for CO_2 emissions on the five continents, from California to China and the European one. No doubt, many still lack ambition: they admit too many allowances relative to 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. For certain, the price in the EU-ETS at the time – about €20 for the emission of one ton of CO_2 in the fall of 2018[6]– lied well below the €55 of the carbon tax that brought the *Gilets jaunes* to the streets during the turmoil; but the fact that this levy on consumers occurs at the production stage has left it largely unnoticed by the citizens.

The next example makes the same observation, with a vengeance. Subsidies to green energies (wind, solar) are popular[7]. In practice, this subsidization of renewable energy often takes the form of regulation-imposed purchase obligations at some above-market, pre-specified price ("feed-in tariff") on power suppliers, and is embodied in our overall electricity bill. Again, however, while the levy is formally on producers, it is passed through to consumers, who hardly see it.[8]

[4] The price of a pollution permit fluctuates substantially depending on market and political conditions: It reached € 98 per ton of CO2 on August 19, 2022, to fall to € 67 three weeks later.

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

[6] As opposed to €99 in August 2022.

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

[8] In 2021, the cost of the feed-in tariffs for renewables energies in France has been €6.4 billion, which is also the revenue from the carbon tax.

Such policies (whether they are justified or not, we focus here on perceptions) would probably be less popular if two facts were rooted in people's minds.

First, someone's subsidy is always somebody else's tax, as illustrated by feed-in tariffs (the price at which electricity companies must purchase renewable energy produced externally); in that example it is 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 a nice distributional impact either: In the United States, the subsidies for rooftop photovoltaic (PV) power station, including net metering, burden lower income groups.[9] 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 one ton of CO_2 reached €1,000 and beyond for early generations of renewables ten years ago, 20 times the €55 per ton of CO_2 removed that brought France 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 to push wind and solar down the innovation/learning curves[10]. To take another angle at it, 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. Well-meaning, this policy has attracted some unscrupulous types driven by the opportunity for short-term profits, led to dissipative commercial efforts (e.g., the incessant phones calls for the "€1 insulation"), and interestingly done little to reduce global warming, as it provides suppliers with a generous supply of energy savings certificates ("white certificates") that are unrelated to actual savings and can be used to

[9] More broadly, Borenstein and Davis (2016) found that 60% of the income tax credits for weatherizing their homes, installing solar panels, buying hybrid and electric vehicles, and other clean energy investments were received by the income top 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.

[10] As we later discuss, 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 and those who say that pump priming was necessary because technological spillovers prevented early losses from being recovered later on through a competitive advantage. We return to learning by doing later on.

satisfy energy savings obligations faced by energy utilities (Glachant et al. 2021, Crampes and Léautier 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;[11] furthermore, they can be ill-designed and fail to reach their objective;[12] they can be regressive as well (fuel-efficiency standards cost more as a fraction of income to low-income households)[13]; finally, they often entail hidden or non-monetary costs associated to forced sobriety (time losses due to reduced speed limits on highways or to domestic flight bans, discomfort from bans on air conditioning). Yet few have ever demonstrated against a ban (with delayed effect) or a standard.

To be clear, our claim here is not that these policies are necessarily inefficient, but rather that perceptions are often more driven by appearances than by reality: the visibility of the sacrifices imposed on consumers or taxpayers often shapes attitudes towards specific policies) much more than their actual net social benefit. To function well, a democracy must provide its citizens with sufficient information about the 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 beliefs accordingly have been shown to be resistant to many forms of scientific evidence. Motivated beliefs are understandable in that they make for a nicer life (think about savoring a holiday in

[11] 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 using fossil fuel energy includes the cost of building alternative equipment (say a heat pump).

[12] In the United States, cars and trucks became less fuel efficient in 2020, because the regulation treats cars differently than light trucks/SUVs and preferences have been moving toward SUVs/light trucks (SUVs and trucks accounted for almost 76% in 2020, while they were only 49% of sales in 2012). The regulatory design flaws can be fixed (Greenstone, Sunstein and Ori 2020). Similar remarks can be made with the French system of a bonus-malus on cars. By failing to reward non-owners, it encouraged the latter to buy small cars, made cheaper by a bonus! These observations point at the importance of a proper policy design, not at an overall undesirability of fuel-efficiency standards.

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

advance or repressing thoughts about a protracted lockdown or the possibility of death or illness of our loved ones). Relevant for our context, all of us want to believe in a prosperous future.[14]

Spending vast amounts of money in the next thirty years on fighting climate change is not an exciting project. Promising "blood, sweat and tears" is a non-starter 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 even invoked to argue that we can have our cake and eat it too; but if this were true, why haven't we done it in the last 30 years?

The same observation applies to the "green-jobs" argument, also meant to soothe public opinion. Officials and the 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 on alternative uses such as healthcare or education that compete for scarce public resources?[15] Can displaced workers fill geographically and educationally the new jobs (a coal miner may not easily become a wind generator technician)? Did we consider the equilibrium effects in the respective labor markets affected with subsidies (to take a topical example, a sharp and rapid increase in the subsidies for the retrofitting of buildings would translate into higher prices for retrofitting rather than in more jobs, if there were no anticipation in the job training and certification process, thus a waste of public funds), or those associated with the funding of the policies (the taxes that enable the subsidies may make some other industries less competitive and thereby destroy jobs)?

The reluctance to say that the planet is worth enough to justify a cost has serious consequences. The problem with this political discourse is that it comforts citizens in their views 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. The first is that "the rich will pay". The rich can indeed pay more but their potential contribution is nowhere close to what is needed to fight global warming or reduce inequality, especially in countries in which redistribution is already sizeable. The second

[14] For reviews of the economics of motivated beliefs, see Epley and Gilovich (2016), Bénabou and Tirole (2016), and Golman, Loewenstein, Moene and Zarri (2016).

15 Some studies attempt to come up with an answer. Chapter 3 of the 2020 IMF World Economic Outlook and the International Energy Agency in their Special Report on Sustainable Recovery (June 2020) look at the impact of making the economy greener on jobs. There might be a small positive effects on the number of jobs.

is that people feel that there is indeed no need for anybody to pay. Both interpretations are probably relevant and equally problematic.

3. A Holistic Approach

Faced with the urgency of addressing the existential threat of climate change and the political challenges of crafting policies to do so effectively and expeditiously, we suggest a five-leg, holistic approach: leg 1: carbon pricing; leg 2: an intense R&D effort; leg 3: other actions; leg 4: compensation; and leg 5: international inspiriting.

3.1. Leg 1 – Carbon pricing done better

2.1.1 The simple case for a carbon price

The vast majority of economists think that one cannot do without a sizeable carbon price, despite its unpopularity.[16] Carbon pricing applies the polluter-pay principle[17]. Pricing has been shown to substantially alter behavior both for other pollutants as well as for carbon emissions. For example, the United Kingdom has substantially reduced its CO_2 emissions from the electricity sector almost overnight by imposing a carbon price floor (around €21 per ton of CO_2) in 2013 on top of the EU-ETS price (which remained under €10 between 2013 and 2018). This led to the phasing out of coal electricity generation, whose contribution to the U.K. electricity mix fell from 40% to 5% between 2013 and 2018 (see Leroutier, 2022). Before the energy crisis, it was estimated that a carbon price around €35 to €40 per ton sufficed to induce a switch from coal to gas, which pollutes half as much. The impact of the Swedish carbon tax, introduced in 1991 and equal to €114 in 2021, has been meaningful as well.[18]

We may dream of a society in which emission reductions would take place spontaneously without need for material incentives (another illustration of motivated beliefs), but history teaches us otherwise: time and again, we have seen that hitting economic decision-

[16] See https://www.igmchicago.org/surveys/carbon-tax/ and https://www.igmchicago.org/surveys/carbon-taxes-ii/.

[17] This principle is embodied in the *Charte de l'environnement* attached to the French constitution.

[18] The Swedish carbon tax applies to both consumers and businesses. When it was launched in 1991, the tax was €24 for consumers and €6 for companies. For fear of offshoring or unfair import competition, a lower tax rate was applied to industry (namely to sectors outside the EU Emissions Trading Scheme, the EU ETS: to avoid double taxation, sectors covered by the scheme are fully exempted from the carbon tax). From 2018 onwards, however, the carbon tax for sectors outside the EU-ETS is the same as the carbon tax applied to consumers, currently €114.

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:

- It encourages those who can eliminate their pollution at a relatively low cost to do so. For example, Metcalf and Stock (2022) estimate a cumulative emissions reduction on the order of 4 to 6 percent for a \$40/ton CO_2 tax covering 30% of emissions in the EU, with a low impact on employment and growth.
- It boosts green innovation. By monetizing the intellectual property associated with green R&D, it allows start-ups to receive financing from private investors and to reach the necessary scale.
- It requires measuring emissions (which is not always straightforward), but no other information. It therefore reduces bureaucratic red tape and discretion relative to other methods of reducing pollution.
- 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.
- Although it is not its purpose, it generates a fiscal revenue which can be used to compensate certain categories of economic agents or to fund the green transition for example.

2.1.2 The determination of the carbon price

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

The Intergovernmental Panel on Climate Change (IPCC) calculates that to keep global warming below 1.5°C, no more than roughly 700 billion tons of CO_2 (up to an uncertainty range) should be emitted looking ahead. In the absence of uncertainty, this carbon budget

can be easily achieved by mirroring the carbon budget for Europe[19] in the volume of allowances in the EU-ETS system. 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.[20] This "quantity setting" approach will ensure that the objectives are met: if countries abide by it, that there will no more pollution than planned to meet 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, about the advent and cost of green technologies, and, last but not least, about the political willingness to handle climate change. The uncertainty implies that the carbon budget will need to be revised over time as news accrue, 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 take 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.

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

- 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

[19] There is no formal carbon budget for Europe, which has selected a specific emission pathway (-55% by 2030 and zero-net-emission by 2050). We take this political decision as a given. Notice however that this pathway may not be compatible with intertemporal optimization under a carbon budget for Europe, as it is likely to lead to too little effort in the short term, i.e., too low a shadow price of carbon in the next 10 years (Gollier 2021).

[20] In practice, there are a couple of reasons why 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 SO_2 in the United States – and are bankable); they may also have received free allowances as part of a grandfathering scheme (high polluters – firms or countries – receive some allowances as partial compensation). If their production becomes greener than they had anticipated, they resell those tradable allowances. Similarly, market-makers (financial actors who obviously do not have a need for allowance) may hold allowances temporarily.

(authorities purchase allowances at the floor price), leading to a faster decrease in CO_2 emissions.[21] When the price reaches the ceiling, extra allowances are sold at the price cap, the quantity of allowances offered is increased, leading to a slower decrease in CO_2 emissions. One could for example consider a price floor that starts around €60/tCO_2 in 2021 and grows at a rate of 4% or 5% per year (and so reaches around €190-€250/tCO_2 in 2050).

- Another approach is the creation of an independent carbon board (labelled "Carbon Central Bank") in charge of adjustments, so as to 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 have kept inflation under control.[22]
- Yet another approach to securing commitment to a strong environmental effort while allowing for some flexibility is to create some skin in the game for governments to abide by their commitment. This can be achieved through the issuance by the governments 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.

2.1.3 A 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 usages, sectors, communities and regions raises the total cost of the transition. For fairness as well as for efficiency, the carbon tax that we propose must apply to all polluters without exception. When a carbon pricing mechanism exists, it is rarely universal or coherent. In France for example, the 44 €/tCO2 carbon tax covering the mobility and housing sectors differs from the price -, close to 100 €/tCO2 in the summer of 2022- on the EU ETS system 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.

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

[22] See for example Delpla and Gollier (2019).

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

- *Containing cost*. First, it is inefficient to tax some emissions and not others. A carbon price of €50 applied to some sector but not another, will lead some to spend €45 to abate, while others will not 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 emissions of the French production of electricity would be very costly as electricity generation is already mostly decarbonized in France (incidentally, that 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 usages. The latter is relatively low for electricity and light duty vehicles, higher for (older) buildings, and currently very high for sectors like airplanes, ocean transport, etc. Some of the progress will occur through switching away from fossil fuels, and some will occur through R&D instead (itself incentivized by carbon pricing). We will need alternative fuels, perhaps carbon capture and storage, negative emissions (e.g. air capture of CO_2), which are much more expensive presently.

- *Respecting fairness*. Second, exemptions are unfair. In France, *Yellow Vests* noted that, unlike them, truckers, fishermen, farmers, airlines, and taxis were not paying the full carbon tax. We realize that the no-exemption policy will add to the number of groups who might resist carbon taxation (farmers, taxi drivers, lorry drivers, real estate managers, homeowners, etc.), and that these groups are well-organized and have nuisance power- which may be why they are exempted in the first place. But a no-exemption policy has much more legitimacy than a patchwork one. Furthermore, compensation combined with a pedagogy explaining why alternatives are opaque and that subsidies are in the end taxes, might enhance the legitimacy.

  In the EU context, the limitation of the EU ETS to the industry creates another issue of fairness. In July 2021, the EU Commission submitted the “Fit-For-55” proposal which contained among many other things a package to create a second ETS market to cover the mobility and building sectors in Europe, hopefully shaped in such a way to 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

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

voted for a ban of new combustion-engine cars in 2035. The “EU trilogue” will arbitrate the disagreement.

- *Making the process lobby-proof*. Third, 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.

- *Curbing offshoring*. Fourth, the no-exemption principle[25] 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. The level playing field can be restored through a Carbon Border Adjustment Mechanism (CBAM) at the borders of Europe, which charges imports for the price corresponding to their carbon content, applying the same price for carbon emissions as for European firms[26]. Straightforward in theory, but more complex in practice; for, 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 the value chains. For that reason, economists are only mildly enthusiastic about the border tax. In the anticipation of the increasing penalties that will have to be levied on European polluters in order to attain the EU emission target, we feel that CBAM is necessary, if only to force free-riding countries to the bargaining table and generate reductions abroad that benefit the EU. Note also that it will be hard for Europe to justify abroad a border tax adjustment if it does not get its act together internally and allows for exemptions (Mehling et al., 2019).

  The EU is currently finalizing a political agreement to implement CBAM within the next few years, starting with sectors whose carbon intensity is easiest to estimate (steel, cement…). The resistance to such a policy came partly from the fact that CBAM will come as a substitute to the existing system to curb carbon leakages, which has been to distribute free allowances to the 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 in the long run. 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 when goods exit the

[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.

Union. This rebate should be equal to the carbon-price differential between the EU and the importing country.

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

- *Phasing out fossil fuel subsidies*. Fifth, another implication of a single carbon price is the end of fossil fuel subsidies that are so ubiquitous around the world. Such subsidies are equal to the difference between the total cost for society of the fuel (production and delivery cost + transportation infrastructure costs + induced cost of local air pollution and global warming – the carbon shadow price – + general-revenue-raising considerations, measured by ordinary VAT) and the price paid by the fossil fuel user. It is estimated that fossil fuel subsidies amount to a staggering 6.5% of world GDP, with China, the US and Russia by far the largest subsidizers.[27] While straight underpricing of fossil fuel (of diesel in France and Germany) 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 the shafts when they become unprofitable, generating high methane emissions), to subsidies to low-cost airlines or to subsidies linked to export finance for oil and gas exploration, pipelines, or LNG terminals. Although much smaller than those of China, the US and Russia, European fossil fuel subsidies should be phased out and the European Energy Taxation Directive still lags behind in terms of its ambitions. *Fossil fuels subsidies often amount to a negative price on carbon*.[28]

- *Rewarding negative emissions*. Sixth, negative emissions will be necessary to achieve the net zero pledges (for example, there is currently a lot of interest in a wide range of natural and other carbon removal technologies). In theory, such negative emissions,

[27] See 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 sizeable.

[28] This is so if the total cost of the fuel short of the impact on global warming (production and delivery cost + induced cost of local air pollution + general-revenue-raising considerations) exceeds the price paid by the fossil fuel user.

when certified, should be rewarded by "credits"[29] whose value corresponds to the carbon price, again to ensure 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.[30]

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 accord. 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 leg 3.

3.2. Leg 2 – An intense R&D effort

2.2.1 The case for public support to green innovation

The ecological catastrophe will not be avoided without a substantial stepping up to the R&D challenge either. There is too little green R&D investment, but the causes are not to be found in 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 current investments. Innovation is critical because it improves the trade-off between damages from the climate and damages to the economy. This current 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 to Europe by reducing global emissions far more than what Europe can generate itself.

The general R&D subsidies that are meant to compensate innovators in all industries for the partial appropriation of the fruits of their R&D efforts (that is, for the existence of technological spillovers benefiting competing firms) will not suffice, for multiple reasons (Acemoglu et al. 2012, Aghion et al. 2014, Aghion et al. 2016).

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 royalties for access to green technologies. The very low carbon prices of the past and the absence of mention

[29] 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 or hfc 23 under the Kyoto Clean Development Mechanism).

[30] For example, one should not repeat the mistakes made when setting up the Clean Development Mechanism. The latter failed the verifiability criterion; it furthermore led the credits being earned solely in the European region, and the resulting increase in the number of allowances put downward pressure on carbon prices in the EU-ETS system.

of carbon pricing in a number of official documents have created expectations of at best moderate carbon prices in the future and thereby disincentivized green R&D.

Second, and independently of too low a carbon price, some of the most important green R&D programs involve unlocking the breakthrough technologies that will in the long run enable us to achieve zero or negative emissions. While the pharmaceutical industry shows that the private sector may take long horizons in their R&D decisions, it is still the case that the public sector plays a fundamental role in supplying the required fundamental research.[31]

Considering this, R&D can be stepped up in two ways. The first is to set achievable technological goals for the private sector. Experience – not least with the recent Covid-19 vaccine – has shown that, when pushed, the private sector may do wonders: multiple vaccines were developed at yet-unseen speed and for some with yet-untested approaches.[32] The second is to create an "EU-ARPA-E", a European equivalent to the American green technology funding institution; this agency will finance high-risk, high-payoff research by the private and public sectors in Europe to unlock the key challenges for green technologies. The governance of this agency must be exemplary. More on this below.

Before concluding this section, the recent report by the IEA (2021) on the conditions necessary for 100%-renewable electricity production reminds us that the outcomes of R&D efforts are by nature uncertain, even though they condition the feasibility of certain 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. We must show humility and not pretend to know which exact technology will work; that is, we must avoid putting all our eggs in the same basket.

2.2.2 Boosting innovation through industrial policy

[31] One can further make the case that because technologies build on the shoulders of previous generations and green energies have a longer horizon than fossil fuel ones, 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.

[32] Analyses of the impact of the Covid-19 vaccine procurement process are still awaited. Public procurement was also meant to preempt other countries on the supplies and not only for speeding 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). Also, we have little information about the counterfactual; the market for a vaccine was huge and we would expect a sizeable R&D effort even in the absence of public procurement.

Innovation comes primarily from the private sector. But the impetus is often given by the state. First, through R&D subsidies and various policies encouraging innovative start-ups and subsidizing the demonstration of some key technologies. Second, by conducting smart industrial policy; not an industrial policy that is created to promote certain firms or to prop up losing industries, but one that tries to unlock technological challenges. While governments too often attempt to pick winners without having the required information, favor lobbies or just follow their favorite whim or the Zeitgeist, they can alternatively attempt to unlock technologies through a well-thought governance design. A case in point is the US defense initiative DARPA, which played a key role in the development of now widely used key technologies, such as the GPS or 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 a strict oversight of the projects. Similarly, the US National Institutes of Health have had a large impact on advanced medical and pharmaceutical research, but they have considerable financial resources (more than $30 billion per year).

For Europe, a green R&D agency could be set up which offers a larger scale and a 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-European public-private collaboration. A European version, E ARPA-E, of the Advanced Research Projects Agency–Energy (“ARPA-E”, as this spin-off of DARPA is known in the United States) would fund high-risk, high-reward research, “way out there” (“early stage”) projects. To avoid wasting public funds and to ensure a real impact, this independent agency would adopt a proper governance. Examples of desirable features include:

- A true 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 tight supervision from Nobel laureate and US Secretary of Energy Steven Chu and the first two directors were very distinguished science professors at UC Berkeley and 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 the even-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 the project delivering).

- E-ARPA-E would bet on highly promising teams and promising but high risk projects. It would be agnostic as whether the private sector or universities are best placed for solving 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 the goals. Again, the recent Covid vaccine experience is useful: it was not clear in 2020 what the best scientific and cost-effective route was.

- The agency would evaluate interventions after they have taken place, and publish the results; it would include a "sunset clause" which ensures 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 under the pressure of recipients who want to keep receiving funds or because they want 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 facilitation the termination of non-performing 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), itself modelled after the very successful National Science Foundation and National Institute of Health in the US. 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 two key researchers, Ugur Sahin and Adrian Hill, behind two of the three current Covid vaccines, that of BioNTech-Pfizer and that of Oxford-AstraZeneca, are both 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, the 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 a clean governance can be achieved in the R&D domain.

Another European undertaking, the European Space Agency (ESA), has been successful during 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 fair-return rule adds a significant factor of complexity and slowdown in the decision-making process, as well as the occasional suboptimality in the selection process. Second, ESA defines the technical specifications to be met for the projects it finances, while

DARPA and other American 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, or the industrialization of the production of certain equipment.

As we already noted, European member states have embarked in joint research support. A newcomer to this landscape is the European Innovation Council (EIC), which will distribute €10 billion over 7 years; the EIC is inspired by the way the European Research Council (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, unlike the ERC's, the EIC's strategic council is only advisory. The European Commission has kept the upper hand on the concrete decisions. Because of this "detail", Europe cannot claim to have created its own "DARPA" (in fact, DARPA has a lot of independence).

While the role of scientists in decision making and target setting could be strengthened in the management of these institutions, it should be noted that these differences are particularly important when it comes to selecting a very small number of disruptive projects and putting large sums of money on them, as the US agencies in the high-tech, environmental and medical fields have been able to do. 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 risky bets to achieve world leadership in at least a few areas. There are of course two corollaries: it is imperative to attract very high level scientists as managers, and to do so, it is necessary to know how to put the necessary means in place if necessary. Moreover, both for budgetary reasons and for having access to a broader talent pool, it is desirable to situate the agency at the European level (without imposing "fair return" constraints, or sprinkling posts according to nationality quotas).

3.3. Leg 3 – Complementary actions

2.3.1 The pros and cons of command and control

We mentioned that the carbon price may, for political reasons, be lower than needed. A second issue with carbon pricing is the measurability of emissions. Not necessarily because of the large number of economic actors: fossil-fuel products used in mobility and heating can be made subject to the overall EU-ETS system; as is currently the case for electric power and the cement and steel industries, taxes can thereby be collected early in the value chain and not from each household, firm or administration. Methane emissions from cattle breeding could be taxed at the level of the slaughterhouse. Forestry contributions to global warming (admittedly less important in the EU, which has relatively

little forest) or carbon storage from specific agricultural practices by contrast are harder to measure than a power plant's carbon emissions or the volume of gasoline produced by a refinery.

A third issue with carbon pricing is that some infrastructures (say, for electric vehicles or applications of hydrogen) must be standardized so that competing producers can serve the market[33]. The polluter-pay principle ensures that economic actors are made accountable for their emissions, but no price can guarantee that rival green companies will converge on a single standard, another market failure. The state may 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 subsidies and norms may interact with the carbon pricing instrument. For example, subsidies to exit coal from the electricity mix in Germany or to incentivize households to invest in PV panels in France reduce the demand for allowances on the EU-ETS market. This reduces the equilibrium price of CO2 in Europe, thereby increasing emissions in the steel and cement sectors for example. Due to this "waterbed effect", the net effect of these subsidies on emissions is zero, by construction. Their impact should be neutralized by an equivalent reduction of allowances on the ETS (Van den Berg et al., 2013).

Another issue is that as a rule, incentives provided by carbon pricing work better for companies (power plants, cement, aluminum, or airline companies say) than for households. For the latter, a carbon price still works well to guide *current* consumption: applied to air travel, beef consumption,[34] 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 efficient advice[35] and subsidies are not based on

[33] E.g., the recharging infrastructure for electric vehicles: charging connectors, vehicle charger vs. external charger and AC vs. DC connection, voltage…

[34] Their measurement is imperfect. An imperfect proxy for methane emissions might be the weight of the animal.

[35] And they should be wary of advice from the industry. Thermal insulation has had disappointing impact (see the next footnote). 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;

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 the 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 successive tenants are well informed about the quality of these investments (to which the energy performance certificate contributes), if they pay their electricity bills, and if the rent can be adjusted to reflect the lower energy consumption by the tenants. If any of these three conditions are not met, landlords will not make enough effort to improve energy performance. In practice, a few studies confirm that thermal renovation efforts are more sustained when landlords reside in the dwelling. Asymmetry of information problems can also reduce owners' eagerness to renovate if they are not sure about the impact of renovation investments on the value of their renovated property on 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 short-termist bias. This may well apply to energy efficiency choices, although a variety of government-sponsored zero-interest loans are often available to illiquid households.

Following Stiglitz (2019) and Rosenbloom et al. (2020) for example, these arguments call for complements to carbon pricing, such as bans and more generally standards. Examples of bans under consideration or already promulgated include the banning of single-use plastic bags and the prohibition on further sales or registration of new vehicles powered with specific fuels by a certain date or the definition of low-emissions zone not accessible by fossil-fuel 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 leg 2, innovation. A case in point is the change in lighting, which came from a combination of regulation (banning of the incandescent light bulbs in the late 2000's and early 2010's) and research and development on alternatives (LED, 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 the combustion engine cars in "low-emissions zones" will be made simpler once

consumers further face a lemons market as they cannot evaluate the competence and honesty of professionals). See Ambec and Crampes (2020).

the cost of electric cars has fallen and their range improved, which is in sight.[36] Bans and standards may also trigger innovation and learning by doing by presenting the industry with a challenge.

We favor such complementary measures but warn against treading into such interventions without ballpark numbers about their efficacy. To illustrate, it is known that rooftop photovoltaic panels (PV) are much more costly than state-of-the-art large scale grid-based PV in Southern California, Arizona, Texas, etc. Why should the US government subsidize rooftop PV 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 the really poorly insulated buildings.[37]

Ideally, the impact of such policies should be assessed whenever possible.[38] This is needed to ensure that the implicit carbon price justifying the policy not be totally out of line with the carbon price levied elsewhere. Put less technically, a standard, a ban or a subsidy that leads to spending €1,000 of consumer or taxpayer money to economize one 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 this caveat that bans, standards and subsidies must be cost-reasonable and the overall policy coherent (they must be "tested" by calculating a ballpark estimate of the implicit cost per ton removed), we think that these instruments can indeed be part of an optimal package. The bigger part of the package they constitute, the smaller the actual carbon price.

In reaction to the Yellow Vests movement (which itself originated from an opposition to a carbon tax), President Macron established 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 ambition (55% emission reduction in 2030 compared to 1990. In 2020, France had reduced emissions by 22%). The CCC submitted 150 propositions in June 2020, none of which related to carbon pricing, and many unrelated to the climate. Some of them pass easily the cost-benefit analysis even with a

[36] The Criqui report in France has examined the cost per tCO2 saved from switching to electric vehicles. Under their hypothesis, EVs will be profitable with a carbon price around 250 €/tCO2, which should be the case by the end of this decade.

[37] Fowlie, Greenstone, and Wolfram (2018) find on a US sample of low-income households that projected savings are roughly 2.5 times the actual savings. Blaise and Glachant (2019) on French data find an even worse ratio, at almost 8 times the actual savings.

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

low carbon value. For example, it proposed to ban on external heaters in bars and restaurants (it became a law in 2021). Other recommendations were more problematic. For example, the CCC proposed a ban all domestic flights when an alternative by train in less than 3.5 hours exists. The new law validated a milder version of this proposal with a threshold of 2.5 hours, and with an exemption for flyers in transit (otherwise the rule would have favored hubs in London and Amsterdam). They also wanted to limit the speed limit on highway 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 (emission and gas consumption reductions, lives saved…) is smaller than the cost (mostly time lost). These recommendations fall vastly short of the French climate ambition, and a new round of climate regulations is expected to be discussed in Parliament in the coming years.

More generally, the CCC's recommendations tended to be biased toward subsidies and bans. As we argued, a subsidy is always a tax as it needs to be financed, and bans can be costly in an invisible way. The climate urgency motivates both a sacrifice and picking our fights so as to make the most from this sacrifice. To keep the impact on the people's purchasing power reasonable, our Commission lacked a socio-economic evaluation of the proposed measures. The same need for evaluation applies also to renewable portfolio standards, a frequent policy around the world mandating a minimum fraction of electricity generated through wind and solar.[39] This process should be systematized, so that the debate be informed by the relevant data (in the United States, the Office of Management and Budget – OMB - and the Environmental Protection Agency - EPA - test regulations like this using a schedule of estimates of the social cost of carbon). More on this shortly.

25% of global greenhouse gas emissions come from agriculture and 16% of global emissions come from methane, a potent greenhouse gas. Incentives must be designed to halt deforestation and land degradation, and the promotion of land carbon sinks. To this purpose, we must improve remote sensing technologies so we can actually measure the actual impact of private efforts. Sustainable, diversified agriculture, precision cultivation and vertical farming are examples of policies that help reduce our emissions. Agriculture, which is a major source of pollution,[40] needs more focus by policymakers (Guyomard et al., 2020).

[39] The methodology for estimating properly the impact must be as state-of-the-art as possible (Greenstone and Nath, 2020). They find that the 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-$298 and is generally above $100.

[40] 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. More generally, a serious change in agriculture practices is necessary, but hard to impose for political reasons.

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 re-designed; the greening of cities strategy may also bring "co-benefits" such as better health and a reduced exposure to heat waves. These environmental policies will require complementary policies. They will raise further 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 (ban of polluting cars, suppression of parking spaces…) should ideally be captured by the community, possibly through some capital gain tax; in France such collective appropriation of the gains associated with public investment failed to take place for high-speed trains (TGVs) or urban renewal programs.

Housing policies, beyond the standard economic issues[41], have an obvious link with the fight against global warming. We have already mentioned energy renovation and the usefulness of supporting households (especially low-income ones) in their renovations through effective advice, subsidies conditional on verified energy performance (Fowlie, Greenstone and Wolfram, 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 to encourage the use of existing buildings rather than the construction of new ones. The densification of cities, despite the resistance of owners anxious to increase their land rents, is a necessary instrument, both to fight urban sprawl and its corollaries (heavy use of automobile commuting, artificialization of soils) and to reduce intergenerational inequality. Making the owners of brownfield sites accountable – forcing them to renovate the brownfields, to convert them to green spaces them or to sell them – can also contribute to the fight against global warming. Finally, the decrease in demand for office space due to Covid-19 and teleworking provides an opportunity to convert some offices into apartments, an opportunity that should be systematically exploited by empowering the market mechanism.

2.3.2 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 current technology),

[41] Actual incidence of housing subsidies, reallocation of social housing to those who need it most, liquidity of the rental market, etc.

manufacturers learn by doing. They correct engineering mistakes over time, and the production cost decreases with experience. Mandates, which for example force public utilities to have a minimum fraction of renewables in their portfolios, do not focus on future generations of the technology, but rather try to unleash incremental improvements on 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[42] and a fortiori looking ahead at new ones. Given this limited evidence, it is unsurprising that different assessments co-exist among economists.

Some view as imperative a strong push on mandates and other adoption incentives to bring down the cost of existing technologies and nascent ones: “bans and standards are essential and would benefit from careful evaluation.” There are two strong arguments in favor of this position. The first is the urgency, so many tools must be harnessed to make rapid progress. The second is that some of these technologies, in particular solar energy, will strongly benefit poor countries, where much of the increase in emissions, if uncontrolled, will take place.

Others view “bans and standards as useful but only if evaluated carefully.” They emphasize two hazards associated with mandates and other adoption incentives. The first is obvious from the previous discussion: 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. We must also carefully assess the size of the subsidy, 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, or more generally[43] mandates and subsidies are no longer needed; and yet the government often finds it hard to phase them out. It is therefore important to announce at the onset a list of criteria for the unwinding of support measures when costs come down and deployment

[42] 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 photovoltaic (PV) modules into the market. Developers, equipment manufacturers, and construction companies learn how to deploy the technology, learn from their mistake, make some profit and use some of it to support their own internal 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.

[43] For instance, if wind and solar are competitive with fossil fuel technologies, it is time to stop the subsidies.

increases. Economists agree on the nature of these arguments but differ on the weights which would be put on them.

2.3.3 Promoting a transparent and efficacious decision process

We conclude this discussion of complementary measures with two closely related policy recommendations. In view of the extreme urgency to act, cost-benefit analysis should not add an excuse for procrastination – the need for a time-consuming, complex expert assessment prior to acting – to another – the pushback from lobbies.

- *Acceptance of ballpark estimates*. Cost-benefit analysis relies on assumptions concerning uncertain variables. Some of the estimates of the cost per ton of CO_2 removed are subject to considerable uncertainty. Assessing the cost of a ban on conventional internal combustion engine cars by some year requires information about the likely learning curve for batteries, the availability of rare earth elements, the efficiency of governments in imposing standards on charging stations, or the evolution of the composition of electricity generation. Much more difficult still is the evaluation of risky research alleys and uncertain learning curves. But the existence of substantial uncertainty should not be an excuse for doing nothing. The bottom line is that ballpark estimates are needed.

- *Proactivity of evaluations*. Cost-benefit analysis, to be useful, requires expertise and is time consuming (engineering and econometric studies, randomized control experiments…). The climate urgency makes it important, though, that the rigorous analysis required for cost-benefit analysis does not slow down public decision-making.

This suggests creating a monitoring unit that uses the best available tools to produce transparent and independent estimates – themselves updated over time as data accrue, knowledge evolves, and scientific debate provides feedback. These estimates would be used in decision-making without delaying action. Representatives and public decision-makers would have rapid access to data shedding 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.

To be concrete, one can envisage, in Europe for example, the creation of a permanent commission which would benefit from the technical support of an independent body; the alternative would consist in giving a much greater weight to socio-economic assessment

in already existing structures[44]. 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 obtained would guide public decision-making, from the design of calls for tenders (see below) to the evaluation of the impact of fiscal and tax policies ("green budgeting"). At the European level, it will be necessary to ensure that the "European Climate Change Council", whose creation is planned in the European Parliament's draft European "climate law" and is intended to be composed of experienced scientists, has an important socio-economic evaluation component. In summary, while good estimates are difficult to produce, they would nevertheless make it possible to identify, for a given expenditure, promising leads in terms of environmental benefits.

3.4. Leg 4 – Compensation

Climate policies sometimes ignore the fact that they create losers, independent of whether it is based on price or non-price instruments (Levinson, 2019). The carbon tax that inflamed the Yellow Vests was economically justified,[45] but it was initially not accompanied with 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:

- As long as the total cost of decarbonized energy is larger than the one 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 our intergenerational arbitrage between current costs and future damages to our planet, we must do the least harm to abate; but the fight against climate change will not come for free. Besides, by “loser” we do not mean all economic

[44] 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), 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 Investment for the Future PIA Programs) and France Stratégie. These structures, including the High Council for the Climate, 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 socio-economic evaluation of France Stratégie permeates the French state.

[45] 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 price in the price of gasoline is justified; the price should be the “shadow price” of carbon, which correspond to the time-contingent price that will allow us 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 general-revenue-raising considerations (captured by the general VAT), congestion pricing, the emission of particles, and of course CO_2 emissions.

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 end up with stranded assets; indeed, a policy of compensation for stranded assets would disincentivize firms to adopt green technologies.

- Neither will compensation ever be fair to the entirety of the targeted populations: some in those populations will enjoy windfall gains (e.g., they do not use a car and receive a "green check" to "compensate" for the imposition of a carbon tax on gasoline) while others will still feel some net cost. Every situation is idiosyncratic, and the state has neither the information nor the personnel to enter each and every special case; and so, we must accept less than perfect solutions and not use the imperfection as 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 one had insisted on perfect compensation).

Incentives require that compensation be backward, not forward looking; that is, it should compensate for a cost inflicted upon the losers, but not be a recurrent compensation. 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). But solutions do exist. Even a single identical lump-sum transfer, the "green check", for every adult resulting from a carbon tax proceeds would benefit poorer households on average. And the redistribution can even be made more targeted and more progressive. Simply, the compensation should be as targeted as possible on actual losers – avoiding windfall effects – and keep a proper forward-looking incentive pattern.

This being said, there can be a disagreement as to what to do with the proceeds of carbon taxation. Some suggest that part of the proceeds 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 the international survey led by Dechezleprêtre et al[46]. (2022).

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

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 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, be it at the European level or elsewhere in the world. Poland and Germany for example are big coal 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 compensating losers, as has always been done historically at a more aggregate level in the form of free allowances: mid-western US states received "bribes" in the form of free emission allowances when a cap-and-trade system enabled US SO_2 and NOx emissions (which cause acid rains) to be reduced by half starting in the 1990's; eastern European countries received free allowances in exchange of their participation in the 1997 Kyoto protocol. This is the spirit of the EU "Just Transition Fund", which provides grants to member States having identified the territories expected to be the most negatively impacted by the green transition.

3.5. Leg 5 – International Inspiriting

The EU-27 by itself is only a very small piece of the climate change puzzle. It represents 9% of global emissions, France less than 1%. Future emissions furthermore will come mainly from emerging countries, further reducing the European share. So, there is little that Europe can do on a stand-alone basis. Nonetheless, Europe has a part to play, as inducing a reduction of global emissions elsewhere will deliver benefits to Europe that can be sizeable:

- First, by "leading by example". To be certain, this unconditional strategy was not that effective during the implementation phase of the Kyoto protocol.[47] Nonetheless, a voluntarist policy can have a demonstration effect – things can be done – as well as a shaming effect on countries who do not get on board. In the spirit of Nordhaus' Climate Clubs (Nordhaus, 2015), Weitzman (2017) suggests alternatively a I-do-if-you-do

[47] An unequal distribution of efforts between 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 non-compliance with the agreement) explains why Europe remained alone in carbon pricing (through the EU-ETS). Not surprisingly, its climate activism lost in intensity: The EU refused to stabilize the price of carbon when it fell below €10 per ton due to 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 experience from happening again.

negotiation strategy based on each country accepting to impose a high carbon price on its constituents if all other countries do the same.

- Second, by using a stick, the Carbon Border Adjustment Mechanism (CBAM), to ensure a level carbon price playing field between domestic firms and importers (more on this shortly) and to encourage recalcitrant countries to jump on board. If done right, the border tax eliminates the competitive advantage enjoyed by firms located in countries with lax environmental regulations. Besides leveling the playing field, 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 agreements on compliance with COP 21 nationally determined contributions and commitments on climate action set by each country, neither of which are binding as a matter of international law.

- Third, by engaging in public green R&D and making the resulting technologies available to poor countries, and by helping the demonstration of viability of existing technologies. Furthermore, the European Union (EU) can work through the multilateral development banks, the International Monetary Fund (IMF) and the development finance institutions to help emerging market and developing countries, which will represent a big share of the growth in output and emissions in the near future, to adopt low-carbon technologies. Finally, innovation is not only technological. The EU 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 would be large and would represent a relatively low-cost contribution to climate mitigation for the EU. There is not enough policy innovation in the world, and this could produce emissions reductions that benefit Europe.

- Finally, Europe must play a leadership role in promoting credible and effective international agreements.

4. Further Thoughts and Leads for Future Reflections

4.1. Electricity production

The production of electricity must be altered in level as in structure. 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 electric vehicles, 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 both electricity generation and distribution and transmission. In structure, most electricity will have to be produced from carbon-free sources. This is already largely the case in France, but not in the rest of Europe and the world. The transition requires some thinking. We already mentioned the rapid phasing out of coal, which will not create a big surge in the price consumers pay for their electricity.

Renewables will need to be widely deployed, but they may still be expensive overall due to 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, they require being supplemented by other means of production; if the latter are carbon-intensive, renewables are less green than they appear. 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. This has for example been an issue in Germany, where wind farms are in the North and much consumption is in the South, with limited high-voltage transmission capacity in-between; the shortage of transmission capacity has occasionally led to the substitution of wind energy from the North by fossil-fuel electricity produced in the South, a problem that will become much more acute in the future as renewable energy expands substantially. As for solar, which like wind has witnessed a spectacular technological improvement in the last ten years, locating photovoltaic panels in Andalusia or North Africa makes much more sense than doing so in the North of France and a fortiori further north.

Besides the unpopularity of high-voltage transmission lines, there is a second obstacle to an 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 arises 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.[48] We support such an endeavor to achieve a truly pan-European power market. Finally, it should be noted that the capacity of the high-voltage grid can be increased without building new lines, for example by installing sensors that allow more power to pass through a line without fearing a break in the line.

[48] Failing this, we should support the European Commission's Trans-European Networks for Energy (TEN-E) regulation, which tries to identify projects of common interest.

In our view, the transition phase should obey the following principles:

Regardless of opinions about this mode of production, keeping in (safe) operation existing nuclear plants, which for example provide three-fourths of the electricity production in France, is a necessity if we want to bring our contribution to the fight against climate change; nuclear is carbon free, dispatchable, and has high availability. The opposition to nuclear came historically mainly from the problem of disposing of spent material and from the fear of accident. Implications for global warming have made other considerations much more relevant. 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 (UK-style) construction of new nuclear power plants, or the choice of a specific nuclear technology if one decided in favor of such construction (third and fourth generations, including small modular reactors) be privileged? The authors of this paper feel they have insufficient technical expertise to answer such questions, and that issues related to their cost and reliability, the sequencing of the green transition, and the extension of life span of existing plants would have to be examined. In any case, the construction of new nuclear plants should not be excluded on a priori grounds given the huge increase in demand for decarbonized electricity in the years to come. When it comes to investment and R&D, and given the 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[49], 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 should be preferred 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 transition should be made as quickly as possible. A different way of expressing this is that the construction of new power plants can only be considered if there are very significant technological advances in carbon capture and storage.[50]

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

[50] 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 the knowledge of future carbon prices, the private sector can evaluate this risk; in the absence of such knowledge, investment choices are complex.

No source of electricity comes without its own problem. When determining the optimal electricity mix for the coming decades, it is important to estimate their specific Levelized Cost of Energy (LCOE) in encompassing all social costs. For example, nuclear electricity generates nuclear waste that must be safely managed, and there is a risk of accident inherently associated to the technology. In France for example, the entire stock of medium- and long-lived nuclear wastes of the entire production of electricity of the second generation of nuclear power plants (1980-2050) will be stored permanently in the Ardennes (Cigéo project), at a cost which is estimated at €25 billion, which represents 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 come from their negative externalities in terms of landscape and noise. Using real estate price data in the U.K., Jarvis (2021) suggests that the local monetized welfare impacts of wind projects have a median of around £4500/MW/year. This should be included in the LCOE of wind electricity whether or not local communities are compensated by the producer.

4.2. Diplomatic channel

We already mentioned the need for a carbon border adjustment. Many are concerned with the risk that, under the cloak of green policymaking, lobbies obtain protection against foreign competition. Aligning the import duties with the current price of carbon in effect in Europe limits the scope for such manipulation; but the tax base – the estimated emissions induced by the imports – is more discretionary. This border adjustment should be as rule-based as feasible, possibly as part of an accepted World Trade Organization (WTO) 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 proposed in the past a joint action by a small number of high emitters (such as 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. With the 2016 American 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 did not create an opportunity for Europe to rethink such an approach, together with China, the largest emitter, and one that has become over the years more and more climate conscious. There are also questions as to 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 (Nordhaus, 2015). The club’s variable geometry would make it flexible.
- For other experts, creating a new institution does not come without cost. We already have the G7 and the G20 (which covers 80% of world emissions), and the climate club might introduce more bureaucracy and disconnect between the various institutions. Climate change discussions have shortly taken place within the G7 (plus say China), which might be a better forum than the G20, which includes a number of countries that may oppose policies that diminish the reliance on fossil fuels

4.3. Environmental covenants in public contracts

It is often suggested that the award of public contracts include green criteria as important factors of choice among contenders. For example, following a citizens' climate convention (CCC)’s recommendation, a French bill alters the Public Procurement Code to make the integration of environmental clauses in all public procurement contracts mandatory, rather than optional. A priori, this idea is compatible with the concept of "economically most advantageous bid" inscribed in the European public procurement directives: this concept 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-taken concern about the greenhouse gas emissions created by the transportation of non-local production of inputs or food. A paradox arises when a government refuses to subject the airplanes’ emissions to the ETS system or the truckers’ gasoline to the carbon tax, and at the same time allows or even asks procurement officers to include environmental concerns in the tender of public contracts. Environmental criteria in procurement are (imperfect) substitutes for the taxation of emissions by the government. This passing-the-buck implies a switch from a well-defined and consistent carbon price to a series of discretionary and likely incoherent policies.

We here reiterate a warning already made: green policies will be expensive, there is no need to inflate this cost by selecting ineffective policies. Without careful assessment, the specification of the weight on environmental actions might involve an implicit amount of public funds of €5 or of €1,000 per avoided ton of CO_2. The public accounting offices (regional and national *Cour des comptes* in France) are currently not equipped to compute these implicit costs and to verify the claims of bidders made in public tenders. Furthermore, the ability to tilt procurement exposes officials to lobbying and

electioneering. A local official eager to be re-elected may over-emphasize 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), so as to protect local producers against competition, at a high cost for public finances or the consumers and a low or even negative impact on the environment.

4.4. Non-governmental actions

Regulations are never perfect for a variety of reasons, and we all should do our bit to help. First, we should try to alter ongoing 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 drastically in France when fines and legal enforcement suggested that such individualistic behavior was not widely accepted in the population and constituted antisocial behavior. For instance, 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 like Walmart or the FANGS 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, it has been noted for the US that purchasing renewable generation in states where there is a mandate dictating 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.

There cannot be too strong a divergence between the material interests of consumers, investors, suppliers and what is socially expected from them. Many of us are willing to pay a bit more for fair trade products or receive a smaller return on our savings if these contribute to a greener economy. There is no evidence however that allows us to count on massive *voluntary* sacrifices of purchasing power by a significant fraction of the population (which is 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 radically changed our carbon emission behavior, and that, although awareness has grown in the population, there is only so much that we can expect from non-incentivized private-sector behavior.

What to expect from the private sector

So far, many of the encouraging private-sector news on the technological and managerial fronts have owed more to an increasing awareness of the enormous economic shock that the end of the climate waiting game will provoke than to effective governmental action. Many corporations realize that global warming is an existential threat for their business as well as for the world. With mankind's having its back to the wall, the regulatory response will impose a large shock to their balance sheet if they are fossil-fuel dependent. Firms accordingly engage more and more in an assessment to their vulnerability to the climate risk (climate stress tests covering the transition risk and the physical risk).

Corporate leaders who want to align their businesses with the common good should implement an "internal carbon pricing" mechanism: as in the public sector, their investment decision should be guided by adjusting the NPV measure to the present value of the flow of additional CO_2 emitted valued at their stated internal carbon price, ideally being equal to the social cost of carbon net of the actual carbon price they face. This is a profit-maximizing decision procedure if and only one anticipates the emergence of an efficient carbon pricing mechanism in the economy. The concept of an internal carbon price should also be used in responsible financial markets, as discussed later on in this section. For large corporations with agency issues, a decentralized management of the decarbonation efforts would require the actual monetary transfer of the internal carbon price between the business units or subsidiaries and the center to align these units' interests with those of the corporation. Critics of the internal carbon price view however argue that firms have limited leeway to deviate from profit maximization, but that looking green (greenwashing) may actually help profits.

Shareholder insistence on knowing the carbon footprint and the exposure to regulatory risk makes good business sense, independently of any environmental consciousness. As shown for example by the behavior of some financial institutions prior to the 2008 financial crisis, corporate managers may adopt short-termist attitudes; they may cut corners to offer a flattering image of their performance at the helm of the firm, either to keep their job if the latter is imperiled, or to cash generous bonuses and exercise stock options if their compensation is not subject to clawbacks. Climate-related procrastination increases firms' short-term profits, but exposes them to a large but delayed macroeconomic shock when aggressive climate policies will be imposed. It is therefore in the interest of shareholders to curb a possible short-termism of their management and to make sure that the firm is not too exposed to climate risk, that it will not be left tomorrow with too many stranded assets.

Although climate finance and CSR governance are aimed at including extra-financial objectives on top of the maximization of the market value of firms, climate-responsible

investment funds may eventually beat the market when governments around the world will start to heavily penalize carbon-intensive corporations. Climate finance is a bet on future effective climate policies. By anticipating them, it plays a useful role to incentivize market participants to decarbonize before it is too late. But asymmetric information and measurement problems surrounding extra-financial impacts raise transparency issues and the standard critique of greenwashing. In these circumstances, green finance may be a way for financial intermediaries and investors to cash in on green obligations and on savings of climate-conscious individuals and statist or quasi-statist institutions who are imperfectly informed upon the environmental impacts of their investments. Curing this hazard, which is potentially lethal for green financial innovations, requires the enforcement of transparency rules and solid green accounting standards.

What to expect from Central Banks

There is currently much discussion about "green central banks". Let us start with the uncontroversial part, which already lies within the mandate of central banks: Climate change should be embodied in the 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 every day as we procrastinate. Various scenarios must be drawn to predict banking and insurance liabilities as the fight against global warming unfolds. Climate stress tests are about financial stability and capital buffers that reduce the occurrence of banking bailouts. Several other policies have been proposed, that in contrast consume public funds and that we now discuss.

- *Risk taking and public finances*. Today, the current 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. 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 at the end of the day greener corporations do not reap the expected revenues (for example, 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[51], 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 bunds on the ground that 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 that Germany is delaying the closure of its coal plants until 2038? Why stop there, why not purchase bonds of firms or institutions which do good for the world, reduce inequality, give large sums to charity? These actions should be left to governments, not the central bank.

- *Legitimacy*. The European political institutions have the instruments and the mandate to fight climate change. A transfer of competences to the European Central Bank 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 for this, in a completely transparent manner and without jeopardizing the finances, credibility and independence of the ECB.

What to expect from the financial sector

Public policy procrastination as we noted provides citizens, firms, and investors with incentives to do their own bit. Needless to say, we strongly favor such actions. But to be effective they require carbon accounting. Carbon accounting for a reporting company correctly emphasizes its direct and indirect emissions: direct emissions from owned or controlled sources; indirect emissions from the generation of purchased electricity, steam, heating and cooling; all other indirect emissions that occur in the company's value chain. The challenge here is to make sure that the proper information be available for these actors to direct their actions in the right direction. Current disclosures lack consistency, comparability and reliability. We should require that companies report their emissions in a

[51] 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 listed below.

verified and standardized way, with the same penalties that apply for inaccurate financial reporting.

We recommend, building on the implementation of a European taxonomy[52], to extend the reflections carried out at the European level by bringing together rating agencies in environmental, social and governance matters, central banks, financial market regulators, accounting standards specialists, financial institutions, scientists and economists in order to develop a uniform method for assessing the environmental impact of companies, based on the comparison of societal costs and (co-)benefits. Unfortunately, the task is far from simple. Indeed, our intuitions can be misleading and the adoption of "green behaviour" is much more complex than it seems: Financial investment in an installed base of 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. The plants already exist and better funding conditions amount 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. To have an impact, 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 we do not observe the counterfactual. Typically, the project developer puts an argument as to what would have occurred, absent the actions that have been taken; the regulator, lacking precise information about the counterfactual, may certify additionality if politically or administratively expedient. Moreover, green finance should 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 the optimal divestment efforts by sectors, technologies and regions supporting the 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 its emphasis on additionality, may fail to reduce carbon emissions and rather create a windfall gain for

[52] The current 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 labelling procedure should be based on the 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 substitutes for coal and has a high social value to produce electricity.

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. It allowed industrialized countries to obtain carbon credits tradable in ETS systems by investing in emission reductions where it is cheapest globally. The CDM generated high transaction costs, as there were endless debates as to whether projects were additional or not.[53] Another issue is that the conservation of a forest in Indonesia 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 vs. best in class" debate. For example, should environmentally responsible investors invest in a technology that still emits CO_2 but replaces another technology that pollutes more? Should we 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 would 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 strongly act in this matter. But, while they have strong symbolic content, there is only so much we can expect from such exclusionary policies. 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 was 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"[54]). It is not the divestment movement that weakened the tobacco industry, but the high taxes that were imposed on cigarettes in the western world. Once 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 decision by an internal carbon pricing mechanism. To value an asset, they should subtract from its market value the

[53] See World Bank (2010), p. 265 and the reference 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] Financial Times, September 17, 2019. A similar discussion re. South African stocks divestment took place during apartheid.

discounted flow of future CO_2 emissions anticipated from its current physical capital valued at the efficient 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 (efficient, best-in-class, exclusion, …), these 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 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 situation to fix the climate change problem.

5. Summing up

Four observations shape our 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, we must adopt a holistic approach to tackling the challenge. Third, green policies will be expensive, but our planet is worth more than enough that we should have the courage to admit this fact; the more we procrastinate, 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 in the past: it has been too unambitious to have the desired impact, admitted many exemptions, given way to numerous fossil fuel subsidies, raised concerns about offshoring to countries practicing environmental dumping, and offered low visibility as to future levels of the carbon price. The insufficient compensation of low-income suburban and rural dwellers has also contributed to its unpopularity. So, our first recommendation is an unambiguous endorsement of "carbon pricing done right".

But much more is needed beyond carbon pricing. First, through a rapid intensification of the green R&D effort. 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. We highlighted how such concerns can be assuaged through a proper governance of the processes and the creation of independent agencies. On the R&D front, we proposed the creation of a European agency that would use peer reviews to fund high risk/high reward

[55] Shareholder activism may be a better strategy than divestment (Gollier and Pouget, 2021).

projects. On the standards, bans and adoption incentives, we proposed the creation of an independent commission made of high-level scientists and economists, who would help rationalize public choices without slowing down 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, we view the state as a strategist that will take its responsibilities seriously (and not try to pass the buck to other actors, such as the central bank or corporations), unleash the private sector's adoption and innovation, and reconcile urgency to act and cost containment.

Finally, most countries by themselves will have a minor direct impact on climate mitigation. But, especially if 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 will benefit poor countries, and playing an intellectual leadership role in the building of international agreements.

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