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Carbon pricing design: Effectiveness, efficiency and feasibility: An investment perspective

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Carbon Pricing Design: Effectiveness, efficiency and feasibility

An investment perspective

By Florens Flues & Kurt Van Dender

Abstract

Carbon pricing helps countries steer their economies towards and along a carbon-neutral growth path. This paper considers how the design of carbon pricing instruments affects their effectiveness, efficiency and feasibility. Design choices matter both for taxes and Emissions Trading Systems (ETSs). Considering the role of carbon price stability for clean investment, the paper shows how volatile carbon prices can cause risk-averse investors to forego clean investment that they would have undertaken with more stable prices. The paper then evaluates the effectiveness and efficiency of policy instruments to stabilise carbon prices in ETSs, which tend to produce more volatile carbon prices than taxes. The paper analyses the auction reserve price in California, the carbon price support in the UK, and the market stability reserve in the EU ETS. Considering feasibility, the paper discusses the tax (or emissions) base, how revenue use can affect support from households and firms, and administrative choices.

Table of contents

FIGURES

TABLES

1 Introduction

1. Carbon pricing helps countries steer their economies towards and along a carbon-neutral growth path. Carbon prices can improve resource efficiency and boost investment in clean energy and low-emission goods and services (OECD, 2018[1]; OECD, 2017[2]). Carbon pricing also adds flexibility to the fiscal policy toolkit. A carbon price with well-designed rates, base and revenue use is good climate policy and good fiscal policy.

2. Carbon prices reduce emissions effectively. The carbon price support in the United Kingdom increased carbon prices in the electricity sector from EUR 7 per tonne of CO_2 to more than EUR 30 between 2012 and 2016. Emissions in the United Kingdom´s electricity sector fell by 58% in the same period and continue to decline. Overall CO_2 emissions in the United Kingdom decreased by 25%, of which 19 percentage points are due to cleaner electricity generation (OECD, 2018[1]).

3. Carbon prices reduce emissions efficiently, i.e. they maximise the amount of emission reductions for each Euro invested in decarbonisation and encourage energy users to refrain from carbon-intensive activities that are only of low value to them. The exceptional return to carbon prices is due to three reasons. First, emitters have an incentive to cut emissions as long as it is cheaper than paying the price.[1] This ensures that all low-hanging fruit is harvested, before more expensive options are considered. Second, carbon prices decentralise the decisions of where to cut emissions. This overcomes the asymmetry of information between the government and emitters: regulators do not need to stipulate which emissions should be reduced using which technologies or which behaviours should be adapted. Emitters are generally better informed about options and their costs than the government. Third, carbon prices provide an ongoing incentive to cut emissions, thus stimulating innovation. The exceptional return to carbon pricing is not just theory. Comparing different emission reduction policies, OECD (2013[3]) finds that a price on carbon is the policy tool with the lowest cost of emission reductions, i.e. carbon pricing is cost-effective.

4. Looking across countries, there are many examples of where it has been feasible to implement carbon prices throughout the economy. For example, Finland, the Netherlands, Sweden and Switzerland price nearly all emissions from fossil fuels in the household and commercial sectors already above EUR 60 per tonne of CO_2.[2] The carbon price support has stabilised carbon prices in the United Kingdom´s electricity sector and reduced domestic emissions effectively. While carbon prices in industry are often low, Finland, Norway and Slovenia price about 50% of fossil fuel emissions above EUR 60 per tonne of CO_2. In road transport, many countries price all emissions above EUR 60 per tonne of CO_2, but road use gives rise to a range of damages including congestion, noise, accidents and local air pollution in addition to climate change. Thus, current levels of fuel taxes are not necessarily high enough to account for all the

[1] For example, if the carbon price is EUR 60 per tonne of CO_2 and the emitter has an investment opportunity that cuts emissions for EUR 20 per tonne of CO_2, she makes a profit of EUR 40 per tonne from pursuing the investment opportunity.

[2] See Table 3.A.4 in (OECD, 2016, p. 67[9]). Switzerland has increased the rate of its carbon tax since 2015 (Swiss Federal Office for the Environment, 2018[62]).

damages caused by road transport.[3] The Canadian carbon pricing backstop sets an example of how to ensure that all emitters pay at least a benchmark price (CAD 50 per tonne $CO_{2\text{-equivalent}}$ in 2022) for their emissions (Environment and Climate Change Canada, 2017[4]).

5. This paper considers how the design of carbon pricing instruments affects their effectiveness, efficiency and feasibility. Design choices matter both for taxes and emissions trading systems. For exposition, this paper often considers a *simple tax*, which sets the same rates for all emissions and a *simple Emissions Trading System* (ETS), which consists of a cap on emissions and tradeable permits.[4] In practise, however, taxes and emissions trading systems are generally more complex than their *simple* exposition version, and this paper discusses the implications of various design features.[5]

6. In addition, the paper looks at carbon pricing from a clean investment perspective. Aiming to limit global temperature increases to 1.5°C and well below 2°C as called for in the Paris Agreement requires decarbonisation by about mid-century (Rogelj et al., 2018[5]; Rogelj et al., 2015[6]).[6] and decarbonising economies requires substantial investment in low- and zero-carbon assets. Carbon prices also reduce emissions by encouraging energy-users to abstain from carbon intensive activities that are only of low-value to them. Carbon prices thus encourage replacing carbon-intensive activities by low- and zero-carbon activities, as well as reducing carbon-intensive activities as such. While the narrative focuses on the first, and especially those that require an investment, carbon prices cause additional emission reductions that will not always be mentioned in this paper.

7. In the following, Section 2 considers what carbon prices are, how they can be measured, and how they reduce emissions. While the focus of the paper is on carbon price design choices, the level of carbon prices significantly determines the amount of emission reductions. Section 2 closes with a discussion of the price levels that are consistent with efficiently decarbonising economies in line with the Paris Agreement.

8. Section 3 reflects on the role of carbon price stability for clean investment, the key theme of this paper. It shows that volatile carbon prices cause risk-averse investors to forego clean investment that they would have undertaken with more stable prices.[7] In other words, excessive carbon price volatility limits emission reductions and discourages clean investment. The section also reviews how investors form expectations about future carbon prices bringing together insights from economics, finance, psychology and sociology.

9. Section 4 evaluates the effectiveness and efficiency of policy instruments to stabilise carbon prices in emissions trading systems, which tend to produce volatile carbon prices in the absence of price stability

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[3] Note that not all of these damages are best tackled by fuel taxes. For example, time and location specific congestion charges are more effective in curbing congestion than fuel taxes reflecting average congestion levels.

[4] The sum of all tradeable permits equals the emission cap.

[5] The term "taxes" can also refer to non-tax market-based measures such as regulatory charges with the primary purpose of reducing emissions as it is the case in Canada under the federal carbon pollution pricing fuel charge.

[6] In the Paris Agreement signatories agreed to aim for limiting global average temperature increases to 1.5°C compared to pre-industrial levels and ensuring that global average temperature increases remain well below 2°C. Many model simulations predict that the 1.5°C goal requires net-zero emissions in the 2050s, while for a 2°C goal net-zero emissions by 2070 can be sufficient (IPCC, 2019[108]). In addition, the possible amount of emissions to be removed from the atmosphere affects the pathway to net-zero emissions. Any references in this paper to the Paris Agreement requiring decarbonisation by about mid century are made with a focus on the 1.5°C target.

[7] Carbon prices dropped significantly in recent economic crises in many ETSs.

support measures. The section also discusses how carbon prices can be designed to generate a price path that increases over time.

10. The broad and in-depth discussion of price stability and policy instruments to support carbon price stability in sections 3 and 4 is novel and the main contribution of this paper. The sections that follow consider additional design features in order to provide a more holistic picture on carbon price design choices. These topics have generally been discussed in other publications already, so the focus of sections 5 to 9 is on providing short overviews and pointing towards publications that discuss the topics in more depth.

11. Section 5 looks at implications of permit allocation rules and tax free allowances. It shows that taxes and emissions trading systems that apply to the entire emission base are much more effective than systems that grant some emission rights for free to emitters.

12. Section 6 looks at revenue from carbon pricing. It considers revenue potential, the existence of constraints on revenue use, and the case for integrating decisions on carbon pricing with general tax policy and budget considerations. Revenue can also be used to raise support for carbon pricing from households (Section 7) and firms (Section 8).

13. Before concluding, the paper discusses administrative considerations of carbon pricing (Section 9), focusing on the benefits of implementing carbon prices via a fuel-based approach or an emission-based approach. In a fuel-based approach, the government levies the carbon price on the carbon content of fuels; in an emission-based approach, the government levies the carbon price on measured emissions.

2 Carbon prices: What, why and how (much)?

14. This section briefly discusses what carbon prices are, how they can be measured, why they are an important policy tool for decarbonisation, and what level of carbon prices would be in line with the goals to decarbonise economies as spelled out in the Paris Agreement.

2.1. What are carbon prices and how to measure them?

15. Carbon prices increase the price of carbon-intensive energy, products and assets relative to low-carbon goods. Considering energy use, any policy instrument that results in a price that is proportional to a primary energy product's carbon content and is thus not levied on zero-carbon sources is effectively a carbon price. The proportionality condition implies that a carbon price can be expressed in EUR (or any other currency) per tonne of CO_2.[8] Carbon prices would be uniform and maximise the emission reductions from a given amount of money invested in emission abatement and foregoing low-value activities if the rate per unit of carbon emissions were the same for all primary energy products (a condition rarely satisfied in practice).

16. This paper puts for expositional purposes an emphasis on carbon emissions from energy use, noting that carbon prices can also be levied on non-energy relate process emissions as well as on greenhouse gases other than CO_2. Carbon emissions from energy use account for 85% of total greenhouse gas emissions including land use (change) and forestry in industrialised economies, i.e., the countries listed in Annex I of the United Nations Framework Convention on Climate Change (UNFCCC, 2019[7]). As long as emissions can be measured consistently, carbon prices can also be applied to non-energy emissions, as well to non-CO_2 greenhouse gases, by measuring these emissions and considering their CO_2-equivalent global warming potential. The general issues discussed in this paper on price stability, carbon price basses, revenue use and political support remain valid in the context of non-energy related carbon prices and prices on other greenhouse gases, but in terms of administration the latter often rely on an emission-based approach, which will be discussed in Section 7 – Administrative Considerations.[9]

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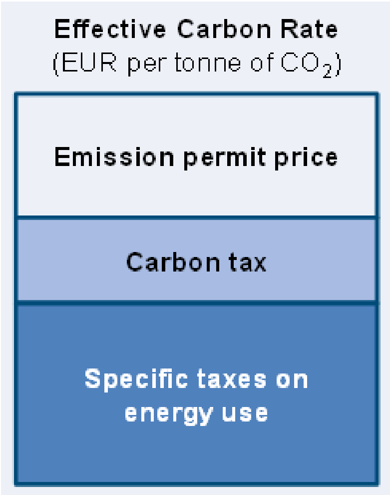
[8] Note, that taxes on electricity use are not a carbon price. While electricity taxes can be expressed in average EUR per tonne of CO_2 in the grid, they are not proportional to the carbon content of the primary energy products used to generate electricity. As such, they do not increase the price of carbon-intensive energy relative to low carbon energy.

[9] Canada calculates emissions from methane and nitrious oxide emssions from fuel use based on the technology that is most commonly used to combust a fuel (Environment and Climate Change Canada, 2017, p. 22[4]). This encourages emitters to reduce fuel use and thereby emissions, but provides no additional incentive to reduce methane and nitrous oxide emissions through cleaner technology.

17. OECD (2018[1]) measures carbon prices on energy use with the *Effective Carbon Rate (ECR)*, which is the sum of specific taxes on fuels (including fuel- and emission-based carbon taxes) and prices of tradeable emission permits expressed in EUR per tonne of CO_2 (see Figure 2.1). The *ECR* shows by how much taxes and permit prices increase the price of carbon-intensive energy relative to low- and zero-carbon energy for energy users.[10] Taxes on fuels have a long history and are the most important component of effective carbon prices on energy products today.[11] Sometimes taxes on fuels are labelled as carbon taxes, often they are not.[12] Emission trading systems also price carbon by requiring emitters to hold a tradeable permits for each tonne of CO_2 they release into the atmosphere.

Figure 2.1. The effective carbon rate



Note: The effective carbon rate measures the overall price on the carbon content of energy. Its level indicates to emitters whether it pays to reduce emissions: If the rate is higher than the investment needed to reduce one unit of CO_2, emission abatement is profitable. If the rate is lower than the needed investment, it pays to pay the price.
Source: OECD (2018[1]).

[10] Economic theory predicts that under perfect competition energy and carbon taxes as well as permit prices are fully paid by the energy user, even if another entity upstream is legally liable for the tax payment. Empirical evidence generally supports the prediction of full cost-pass-through of energy taxes into energy prices. For the case of gasoline taxes Alm et al. (2009[102]) find full cost-pass-through for the United States, Baker and Brechling (1992[103]) find similar effects for the United Kingdom and Stolper (2016[104]) also observes on average full pass-through for Spain. He observes some regional differences with larger pass-through rates where gasoline stations have more market power. Pass-through rates also increase in area-average house prices. Andersson (2019[11]) observes full pass-through of the Swedish carbon tax on gasoline prices. In the electricity market, cost pass-through rates of carbon emission permit prices into wholesale prices are found to lie between 60% and larger than 100% (Fabra and Reguant, 2014[106]; Sijm, Neuhoff and Chen, 2006[105]) Hence, independently of who is liable for paying the tax or the permit price, all three components of the ECR increase the price of carbon-intensive energy relative to low- and zero-carbon energy for energy users.

[11] About 90% of all carbon prices in OECD and G20 countries result from taxes.

[12] In fact, carbon taxes in several countries are integrated with the excise tax system for energy products (e.g., France, Mexico). In some cases the carbon component is entirely additional to pre-existing excise taxes, in other cases the carbon component partly or fully replaces excise taxes.

18. The *ECR* makes carbon pricing efforts comparable by expressing all of their three elements in the same unit. A higher carbon price implies a stronger incentive to reduce emissions (see also Section 2.2.). Sometimes the question arises whether explicitly naming a tax a carbon tax, or whether introducing a new tax instead of reforming existing taxes, affects the incentives to reduce emissions independently of its rate or not. While it cannot be ruled out that such things may have an effect, there is no evidence in the scientific literature that they do and even if they did, this effect would likely be small compared to their price effect.

19. The broad definition of a carbon price via the *ECR*, allows tracking progress over time, because the *ECR* includes all pricing elements that make carbon-intensive energy more expensive compared to low-carbon sources. A narrow definition, e.g. one which would only include new pricing instruments, or instruments labelled as carbon pricing instruments, risks measuring pseudo-effort. For example, when existing taxes are relabelled into carbon taxes without changing the effective rate on carbon emissions, a narrow definition would indicate higher carbon prices, while effective rates remain the same.[13]

2.1.1. Carbon price base or coverage

20. Depending on context, the emissions subject to a carbon price are referred to as emission "coverage" or "base". "Coverage" is common in the environmental domain, while the fiscal domain generally speaks about the emission "base" or the tax "base". This paper use both terms interchangeably.

21. A carbon price is generally more effective, the more emissions it covers.[14] Uncovered emissions make a carbon price less effective via two channels. First, there is no incentive to cut emissions in the sector that is not covered by the price, meaning that some profitable abatement opportunities are likely foregone. Second, there is an incentive to shift emissions from covered emission base to an uncovered emission base. For example, if a carbon price only applies to oil and gas products, but not to coal, there is an incentive for emitters to reduce oil and gas consumption, but to increase the use of coal.

22. The emission base of the three carbon price components – energy taxes, carbon taxes and emission permit prices – often varies. Energy taxes are typically set by fuel and use, which means that certain fuels and uses may be part of the carbon price base. Carbon taxes are often initially envisioned to apply the same rate across fuels and usage, but in practice, they often cover only some fuels and uses, at different rates.[15] The emission base of permit prices varies substantially across systems. The trading systems in California and Korea cover the vast majority of economy-wide emissions, while the EU ETS only covers emission from electricity generation, industry and intra EEA-flights (OECD, 2018[1]). Emissions from other sources outside the ETS are covered to a large extent by energy taxes of the individual EU member states, at rates that differ strongly by sector, by fuel, and sometimes by type of user.

23. The variation of emission coverage by the three different price components provides an additional argument for considering all three components together when evaluating the carbon price base. This allows assessing which emissions are covered by a price and which are not. OECD (2018[1]) shows that

[13] From a fiscal perspective it matters whether new taxes are additional to existing taxes, i.e., whether they generate additional revenue, or not. Relabelling existing taxes into carbon taxes does not raise new revenue. Revenue use is discussed in Section 6 – "Revenue from carbon pricing".

[14] Tax policy advise generally advocates broad- over narrow-based taxes.

[15] For example, the carbon tax in Mexico does not apply to natural gas. The Swedish carbon tax applies to emissions from fossil fuels in sectors outside the EU ETS. While rates between industry and households differed initially, since 2018 rates for industry outside the ETS and households are equal.

base-broadening, i.e. expanding carbon prices to yet unpriced emissions, often remains a fruitful area for reform.

2.2. Why price carbon emissions?

24. Carbon prices are a very effective decarbonisation policy. Carbon prices reduce emissions by increasing the price of carbon intensive products, reducing demand for them. At the same time demand for carbon-efficient products increases, because, relative to carbon-intensive products, they become cheaper.[16]

25. Using OECD (2013[8]; 2016[9]) data, Sen and Vollebergh (2018[10]) estimate that a one Euro increase in the *effective carbon rate* leads to 0.73% reduction in emissions over time. This means that, for a country that starts from no carbon price at all, the introduction of a carbon tax of EUR 10 EUR per tonne of CO_2 on its entire energy base would reduce emissions by 7.3%.[17]

26. A practical example concerns the carbon price support in the United Kingdom, which increased *effective carbon rates* in the electricity sector from EUR 7 per tonne CO_2 to more than EUR 30 between 2012 and 2016. Emissions in the electricity sector in the country fell by 58% in the same period. The higher carbon rates in the electricity sector made it profitable for utilities to replace coal with natural gas, which is about half as emission-intensive as coal per unit of energy, and zero-carbon renewables. Overall CO_2-emissions in the United Kingdom decreased by 25%, of which 19 percentage points were due to cleaner electricity generation (OECD, 2018[1]).

27. The literature on the overall effect of carbon prices on emissions is only emerging (Sen and Vollebergh, 2018[10]). Most evidence for the effectiveness of carbon prices results from carefully conducted case studies, which generally observe a significant causal effect of higher carbon prices on emission reductions (see, for example, Andersson (2019[11]), Dechezleprêtre et al. (2018[12]) and Murray and Rivers (2015[13])).

28. Additional insights can be drawn from the vast literature on energy demand. Economists use the concept of the price elasticity to describe by how much demand for a good or a bad (e.g. emissions) decreases when prices increase. Typically, price elasticities indicate the percentage change in demand that corresponds to a one percent increase in prices. As mentioned previously *effective carbon rates* make different carbon pricing policies comparable in terms of their incentives to reduce emission reductions. Estimates of price elasticities put a number on how large the emission reductions will be for a given level of carbon and fuel prices.

29. Labandeira et al. (2017[14]) report in a recent meta-analysis of the literature average short-run fuel price elasticities of -0.126 for electricity (i.e. if prices for electricity increase by 1%, demand for electricity falls by 0.126%), -0.180 for natural gas and -0.293 for gasoline. Over time, energy demand adjusts more

[16] Higher prices do not reduce demand, if demand is entirely fixed, but this is a rare circumstance. Fixed demand requires absence of substitution and income effects and can only occur as a short-run phenomenon for small subsets of energy users. It is worth noting that changes in demand should not be confused with changes in benefits from energy use.

[17] The new tax will increase the price of carbon-intensive fuel, but at a level of EUR 10 per tonne of CO_2 the overall price increase is moderate. For example, heating oil prices will increase by about four percent, assuming that the a country also levies a standard VAT rate of 15% on energy products and that pre-tax heating fuel prices correspond to average levels in the EU 28 as of 26 November 2018.

strongly, leading to long-run elasticities of -0.365 for electricity, -0.685 for natural gas and -0.773 for gasoline.[18]

30. Fuel price (or own-price) elasticities typically do not consider all possibilities to reduce emissions, especially the prospect of switching fuels. Different fuels have a different carbon content per unit of energy. For example, coal is approximately twice as emission-intensive as natural gas. A tax on coal and natural gas at the same rate per unit of energy will encourage energy users to reduce the demand for both fuels, but will not incentivise any user to use more carbon-efficient natural gas instead of coal.

31. A carbon price, however, that covers all fuels at equal rates will alter prices more strongly for high-carbon fuels than for low-carbon fuels. This means the price for coal will increase more than for natural gas, encouraging energy user to substitute coal with natural gas. Prices for zero-carbon fuels will not change at all, making them even more attractive. To evaluate the full impact of carbon prices on emissions, the interest is hence in a carbon price elasticity, that includes the effects of switching to cleaner fuels, such as Sen's and Vollebergh's (2018[10]) estimate.[19]

32. A remaining question is whether all three components of the *ECR* always provide exactly the same incentive to reduce emissions. Economic theory predicts they do as long as price levels and price stability are the same. When expectations on price stability vary across the components, incentives to reduce emissions can differ as will be discussed in Section 3 – "The role of price stability".

33. Investigating a related question, namely whether carbon prices (independent of their component) and market prices provide the same incentive to reduce emissions, Tiezzi and Verde (2016[15]) and Rivers and Schaufele (2015[16]) show that taxes provide significantly stronger incentives to reduce emissions than a similar change in market prices would. Andersson (2019[11]) finds that increases in the Swedish carbon tax reduced emissions significantly more than similar fuel price increases. A possible explanation is that a tax-induced change in prices is expected to be more persistent than a change in wholesale prices, which change constantly (Tiezzi and Verde, 2019[17]). Another explanation is tax-aversion, meaning energy users react more strongly if they know the price change is due to a tax.

2.3. How much? Price levels required for decarbonisation

34. The Paris Agreement requires full decarbonisation by about 2050.[20] To reach this goal , the High-Level Commission on Carbon Prices (2017), for example, estimates that carbon prices at a level of 40-80

[18] A given carbon price increases fuel prices more strongly for a fuel that is currently hardly taxed than for a fuel with the same carbon content that is already strongly taxed. For example, diesel and heating oil are chemically – and thus carbon-content wise – similar. Typically, diesel is taxed more strongly than heating oil. Considering that fuel-price elasticities have broadly the same order of magnitude across fuels as discussed in this paragraph, this implies that a EUR 10 per tonne of CO_2 increase in effective carbon rates will typically increase the price for heating oil more strongly than for diesel. As a result, emissions from heating oil will decrease more strongly than from diesel. More generally, one can expect stronger emission reductions from low-priced fuels for a given increase in effective carbon rates than from a high-priced fuel.

[19] In addition, a carbon price elasticity expressed in emission changes per unit of carbon price change provides an accessible and readily available number for the impact of carbon price increases. To estimate the effect of an equal carbon price increase across fuels based on fuel price elasticities requires price and carbon content information on the entire set of available fuels.

[20] Remember that any references in this paper to the Paris Agreement requiring decarbonisation by about mid century are made with a focus on the 1.5°C target (see also Rogelj et al. (2018[5])).

EUR per tonne CO_2 are needed in 2020 for countries to decarbonise in line with the Paris Agreement.[21] In 2030, prices should reach 50-100 EUR per tonne of CO_2.

35. There are many more estimates for the level of carbon prices needed to decarbonise economies fully by mid-century. Two approaches are common.

36. First, social cost approaches estimate the damage that results from one tonne of CO_2 released to the atmosphere. Under this approach, it is economic to cut emissions as long the investment needed to reduce emissions is lower than the costs of emissions to society. By mid-century the social costs of emissions are expected to be so high that pretty much any effort to bring them to zero would pay off. Estimates vary considerably due to different assumptions, for example, how much future consumption is valued compared to current consumption, and which set of damages is considered. An illustration of the social cost approach is the social damage estimate of 180 EUR per tonne of CO_2 released in 2016 by the German Environmental Protection Agency (Matthey and Bünger, 2018[18]).

37. Second, shadow-cost of carbon approaches estimate what level carbon prices will need to reach in order to reach a certain political goal, e.g. decarbonisation by mid-century. Estimates also vary, for example based on the technological options assumed to be available at different points in time. To provide an example, the Quinet Commission (2019[19]) recommends a carbon price of EUR 52 per tonne of CO_2 in 2018, increasing to EUR 250 in 2030 and EUR 775 in 2050,[22] to be added to a baseline scenario.[23] If technological progress turns out to be stronger than assumed in the models to calculate the shadow-costs of carbon, the carbon prices needed to decarbonise by mid-century will be lower. A technologically more optimistic estimate by the IMF, that assumes optimal support for clean technology development and investment, recommends an increase in carbon prices by EUR 75 per tonne of CO_2 from current levels through 2030 (IMF, 2019[20]).

38. An increase in carbon prices over time is common to both approaches. It results from an increasing likelihood of ever-stronger damages as more carbon emissions accumulate in the atmosphere. When the stock of emissions is low, an additional unit does not cause great harm, but when the stock of emissions is already elevated, any additional emissions risks causing large and irreversible damage. From a policy perspective, the question is thus not only about how to implement a carbon price and at what level, but how to ensure that carbon prices increase over time, reflecting the increasing damage with more carbon accumulated in the atmosphere and incentivising the phase-out of carbon-intensive assets over time.

39. Today, the vast majority of emissions is priced significantly below low-end estimates of carbon costs. OECD (2018[1]) shows that only 12% of energy related carbon emissions from 42 OECD are priced at or above EUR 30 per tonne of CO_2, and only 9% above EUR 60. About half of OECD and G20 emissions are not priced at all.

[21] This paper assumes USD-EUR parity.

[22] Keeping the decarbonisation objective by mid-century in mind, there will be few emissions for which the carbon price needs to be paid.

[23] The Quinet Commission baseline scenario corresponds to the French effective carbon rates in 2017, excluding the French carbon tax and the EU ETS permit price.

3 The role of price stability

40. Consider a firm or a household deciding on whether to carry out a clean investment project or not. The clean investment project can be an upgrade of existing technology (e.g. adding solar heat to an existing heating system powered by fossil fuels) or an investment in a new clean technology once an asset has reached its lifetime (e.g. investing in a renewable power plant to replace a fossil fuel powered plant). The investor will weigh the gains and costs from the respective choices and pursue the action that she expects to offer the highest net gains.

41. A carbon price strengthens investors' inclination to opt for the clean investment instead of sticking with the status quo or continued dirty investment. The investor will evaluate the overall costs savings from the clean project with its investment costs. Costs savings can include reduced fuel use, but the focus here is on the cost savings that result from not having to pay the carbon price for emissions that the clean project abates compared to the status quo or continued dirty investment. Investment costs are independent of the carbon price. A higher the carbon price thus strengthens the incentives for clean investment.

42. In addition to the level of the carbon price, the stability of the carbon price affects the investment decision. A risk-averse investor prefers projects with less variability in returns. This means, for the same return, that risk-averse investors prefer projects with more reliable returns. There is evidence that people are risk-averse (Bruhin, Fehr-Duda and Epper, 2010[21]; Kahneman and Tversky, 1979[22]). Moreover, firms manage risks, i.e. they incur costs to reduce risks, for various reasons such as for mitigating the costs of financial distress, reducing the risks of bankruptcy and for avoiding lower than expected managerial compensation (Rampini, Sufi and Viswanathan, 2014[23]; Froot, Scharfstein and Stein, 1993[24]).

43. To illustrate the decision of risk averse investor consider that an investment of EUR 49 is required to abate one tonne of CO_2. The expected carbon price is EUR 50. The investor pursues the project only if it offers her a strictly positive utility. Risk-aversion is modelled through a concave utility function, $U(x) = \sqrt{x}$, with a diminishing marginal utility of consumption.[24] With a stable carbon price the investor will invest in the clean project as the utility from the cost-savings from not having to pay the carbon price ($\sqrt{50}$) exceeds that of the investment cost ($\sqrt{49}$). Now, consider a fluctuating carbon price. There is a 50% chance that the carbon price turns out to be EUR 36 and another 50% chance that it will reach EUR 64. The investment cost remains at EUR 49, implying a negative utility of -$\sqrt{49}$ = -7. The costs saving from not paying the carbon price amount to $0.5 * \sqrt{36} + 0.5 * \sqrt{64} = 0.5 * 6 + 0.5 * 8 = 7$. The utility from the cost

[24] A diminishing marginal utility of consumption implies that any additional unit of consumption is valued less than the previous one. For example, hungry Tom receives a lot of utility from a slice of pizza. The second and third slices also feel good, but a little bit less than the first as his appetite slowly vanishes with more bites of pizza in his stomach. At the fourth slice of pizza Tom starts feeling full and does not receive any additional benefit from eating more pizza. This example illustrates how the utility of consumption diminishes the more one consumes. More generally, people value goods or money less the more goods or money they already have. A result of the diminishing marginal utility of consumption is that investors attach more weight to a potential loss of a certain amount of money in a risky project than to equally likely gain of the same amount of money, which is commonly referred to as risk-aversion. The chosen utility function $U(x) = \sqrt{x}$ is a common example for a utility function with diminishing marginal returns of consumption.

savings do no longer exceed the investment costs, and as a result, the investor will refrain from investing in the clean project. A related example demonstrates the effects of an even more volatile carbon price. With a 50-50 chance of the carbon price being either EUR 4 or EUR 100 the investment will result in a negative expected utility, while a stable carbon price of EUR 52 would still lead to a positive expected utility.

44. Summing up the above discussion, for a given expected level of the carbon price, a more stable carbon price increases the chances that investors invest in clean projects. A volatile price, in contrast, could induce investors to abandon clean projects, even though the expected monetary value is positive. This is because investors give more weight to the loss incurred from paying for abatement when carbon prices are low, than to the savings from having invested in abatement in case carbon prices turn out to be high. In other words, carbon price volatility reduces the incentives to invest in clean projects, as risk-averse investors value stable returns higher than volatile returns.[25]

3.1. Carbon price volatility can significantly increase capital costs for green investment

45. Carbon price volatility weakens clean investment. To approximate the magnitude of the effect, consider how carbon price volatility alters the costs of capital of a green investment project. Taking electricity generation as an example, Aurora Energy Research (2018[25]) reports 1.5 percentage points lower capital costs for investment in renewable energy in a scenario with a carbon price floor compared to a scenario without. Roques (2018[26]) estimates that an insurance against a low-carbon price reduces capital costs for investment in renewable energy projects by about 1 percentage points.

46. Overall capital costs for energy projects amount on average to about 7% based on a survey of seven major OECD countries (NEA/IEA/OECD, 2016[27]). Capital costs for investment in renewable energy were estimated to be around 5% in the United States, 6% in Germany, Korea and the Netherlands and around 8% or higher in New Zealand and the United Kingdom. Varying capital costs reflect differences in country-level risk, technology and project risk, as well as cost, price and revenue risks.

47. Bringing these findings together, limiting carbon price volatility can significantly reduce capital costs for renewable energy projects. Compared to total capital costs of 7%, a one percentage point reduction in capital costs equals nearly 15% of total capital costs; a 1.5 percentage point reduction would equal more than 20% of total capital costs.

48. Considering that capital costs are by far the most important component of total costs of renewable energy, carbon price stability can have a strong impact on choosing to invest in a clean project. According to Dressler et al. (2018[28]) capital costs amount on average to 76% of total costs for onshore wind projects and 83% of solar PV projects, assuming a discount rate (or overall capital cost) of 7%.[26] With capital costs equalling 75% of total project costs for a renewable energy project, a one-percentage point reduction in capital costs amounts to about 10% lower project costs in total.

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[25] Baldursson and von der Fehr (2004[100]) provide a comparable argument. They show that risk-averse investors invest efficiently with stable prices for an environmental externality, while with volatile prices, investment choices are no longer efficient, as abatement costs are no longer equalised. Overall abatement costs thus increase with volatile prices.

[26] In comparison, capital costs for fossil fuel plants are much lower, amounting to 27% for coal power plants and 18% for natural gas plants on average.

3.2. How carbon prices are set

49. Taxes fix the carbon price. Emitters profit from reducing emissions and investing in clean projects as long as the costs of reducing emissions is lower than paying the carbon price. Aggregate emission reductions increase with the carbon price, but the exact amount of emission reductions is uncertain.

50. An emissions trading system fixes the quantity of overall emissions. The permit price is determined by the cost of the marginal abatement needed to reach the cap. As abatement costs are not fully known before setting the emission cap, the permit price is uncertain.

51. Weitzman (1974[29]) shows that fixing the carbon price improves welfare compared to fixing quantities, when the marginal abatement cost curve is steeper than the marginal damage curve of carbon emissions, which is likely under the Paris Agreement.[27] The marginal damage of carbon emissions increases in the stock of emissions (or marginal damages are lower with fewer emission), while marginal abatements costs decrease in emissions (or costs are higher the more emissions are abated). The Paris Agreement requires decarbonisation by about mid-century, i.e. very strong abatement over the next 30 years. In this case, the abatement cost curve is likely steeper than the marginal damage curve of emissions, implying that fixing the price would be superior to fixing quantities.

52. When the costs of additional carbon emissions increased faster than the costs of additional emission reductions, fixing quantities through a cap on emissions would be superior to fixing the price. For example, climate risks increase sharply close to a "tipping point", i.e. an irreversible and costly change in the earth's climate.

53. Hybrid regimes, that consist, in case of an emissions trading system, of a fixed price floor, a cap and a price ceiling, can provide additional benefits (Newbery, Reiner and Ritz, 2019[30]; Roberts and Spence, 1976[31]). A tax hybrid specifies emission caps, that stipulate increases in the tax rate, if emissions exceed the caps. Hybrids avoid weaker than expected emission reductions through the cap, while providing more predictable price levels than a simple ETS without any price stability measure.

3.3. Time horizon of investment and price expectations

54. Investments in energy, industrial and residential infrastructure have typically long time horizons. Lifetimes for investment in fossil-fuel-powered plants (such as coal or gas) are often 40 years or more and also the horizon for investment in renewable power (such as wind and solar) often exceeds 20 years. Investors thus do not only care about current carbon prices, but also need to form expectations about carbon prices over the entire lifetime of the investment.

55. Investors form expectations by extrapolating historic data as well as by considering new information (Tversky and Kahneman, 1974[32]; Gennaioli, Ma and Shleifer, 2016[33]). They may overweight future outcomes that become more likely in light of new information (Bordalo, Gennaioli and Shleifer, 2018[34]). The historic component of carbon price expectations can in principle be retrieved from historic information on tax rates and permit prices, but predicting the arrival of new information is illusory.

56. In addition, it matters how investors interpret new information. Because the future is unknown, investors imagine futures that help them to make decisions as if the future was going to develop in the way anticipated (Beckert, 2019[35]). If new information makes an imagined future, which was considered

[27] Weitzman's model compares taxes and emissions trading under uncertainty of abatement costs (a reasonable assumption given that exact abatement costs are unknown in advance) and asymmetric information on abatement costs (emitters know better than regulators how much it costs to abate).

credible, less credible, investors may also alter their interpretation of existing information. New information can thus lead to sudden and strong changes in expectations.

3.3.1. Historic component of price expectations

57. The following parts of this section consider first recent developments of carbon prices from taxes and permit prices, providing information on the historic component. Next, it will be discussed how new information may alter carbon price expectations for taxes and emission permits. Even if the arrival and content of new information is uncertain, certain structural features of taxes and emission trading systems may provide guidance on how strongly carbon prices react to new information.

Stable tax rates

58. Taxes fix the carbon price, but legislative changes can modify tax rates over time. However, effective tax rates of well-established taxes on fuels tend to change relatively little over time (OECD, 2018[36]). Between 2012 and 2015, taxes on fuels increased in some large countries and first steps to align rates on diesel, typically lower than those for petrol, with petrol rates were taken. While there is little movement in tax rates, if there is change, rates rather increased then decreased in recent years (OECD, 2016[37]; OECD, 2017[38]; OECD, 2018[39]). When new taxes are introduced, anecdotal evidence illuminates challenges to keeping them in place when the government changes in some jurisdictions (e.g. carbon prices in Alberta and Australia have been repealed), but not in others (e.g. carbon taxes in Chile, Mexico, and European countries stayed in place).

59. Several countries index tax rates for inflation (Mahler et al., 2017[40]). Belgium recently introduced automatic indexation of energy taxes and Sweden indexes many of its environmentally related taxes (OECD, 2018[39]). Indexation for inflation guarantees that tax rates remain stable in real terms. Without indexation, nominally stable rates imply a decrease in tax rates in real terms over time.

60. While tax rates are generally well below the levels needed to implement the polluter pays principle (OECD, 2018[36]) and trigger decarbonisation in line with the Paris Agreement (OECD, 2018[1]), some countries have increased rates stepwise. For example, France introduced a carbon tax at a level of EUR 7 per tonne of CO_2 in 2014 and increased the rate to EUR 44.6 in 2018. Further increases are under discussion. Canada's carbon pricing backstop levy is set to increase from CAD 20 per tonne of $CO_{2\text{-equivalent}}$ in 2019 to CAD 50 by 2022. The United Kingdom introduced a carbon price support at a level of GBP 9 per tonne of CO_2 in 2013 and increased it to GBP 18 by 2015. Earlier, at the beginning of the millennium, Germany increased tax rates on motor and heating fuels stepwise over a four-year period as part of its ecological tax reform.

61. There are several reasons for the observed stability in tax rates, and while a full discussion is beyond the scope of this paper, two factors are worth considering. First, a change in rates generally requires a legislative process including parliamentary votes, requiring an active effort by governments if rates are to be changed. Without explicit government action, rates will generally remain at their current level. Second, even if a government wanted to reduce rates, the fact that energy tax revenues generally fund the general budget (Marten and van Dender, 2019[41]) would require the government to look for alternative funding sources or face higher debt. Increasing rates, by contrast, generates additional revenue. While this provides opportunities for reforms, including tax reform, setting out the details of a reform agenda takes time, implying that many governments increase rates only from time to time.

Volatile permit prices

62. Carbon prices from emission trading systems tend to be volatile, especially if they come without a carbon price support mechanism. Consider, for example, the prices for European Emission Allowances (EUAs) in the European Union's Emissions Trading System (EU ETS). In the first commitment period of

the EU ETS, from 2005 to 2007, EUAs started trading at about EUR 25 per tonne of CO_2, rising quickly to EUR 30. However, the price fell quickly to EUR 0 in 2007, when it became apparent that the supply of permits vastly exceeded permit demand.[28] In the second commitment period from 2008-2012, EUAs started trading again above EUR 20, reaching nearly EUR 30 in July 2008 (MacDonald, 2016[42]). With the start of the global economic crisis, the price fell to EUR 10-15, before falling further to below EUR 5 in 2012. In the third commitment period, that started in 2013, the price lingered for a long time around EUR 5. The price only increased significantly with the approval of the Market Stability Reserve (MSR, to be discussed in detail in Section 4.4), hovering around EUR 20 to EUR 25 from end of August 2018 to February 2020. In early March 2020 the price of an EUA dropped from EUR 24 to EUR 15 within a week (European Energy Exchange, 2020[43]).

63. The carbon price has also been volatile in the Regional Greenhouse Gas Initiative (RGGI), which establishes an ETS for 9 North-Eastern states in the United States. Starting at USD 3 per tonne of CO_2 in 2008, prices fell below USD 2 in 2009, climbed to USD 7.5 in 2015, fell gain to USD 3 in 2017, and trade at about USD 5 since the beginning of 2019 (RGGI, 2019[44]). Even at a low price level, volatility is significant. The Chinese regional emissions trading systems exhibited very high price volatility at their start, which decreased over time together with the price level (Zhang, Liu and Xuid, 2018[45]).

64. Given that emissions trading systems fix the quantity of emissions and not the carbon price, permit prices are more volatile than taxes, everything else being equal. Permit prices fluctuate reflecting changes in economic activity, weather conditions, fuel prices, fuel switching possibilities, carbon market conditions, speculation, and regulatory decisions (see, for example, Borenstein et al. (2018[46]) or Kettner et al. (2011[47])).

65. In the short-term, when options for abatement are limited without additional investment, economic activity influences permit prices. The economic crisis starting in 2008 significantly reduced the demand for permits in the EU ETS and thus depressed permit prices (Bel and Joseph, 2015[48]). Permit prices also dropped significantly in early March 2020.

66. Weather conditions affect the availability of renewable as well as of fossil-fuel-powered energy sources and thus the demand and supply of permits (Roig-Ramos, 2018[49]). Low water levels of the Rhine River, due to a drought in summer and fall of 2018, led to supply restrictions of coal and thus reduced availability of coal-powered plants (Freud, Clarke and Dart, 2018[50]).

67. Fluctuations in fuel prices affect the profitability of power plants, e.g. whether it is more profitable to run a coal-fired plant or a gas fired plant. A gas-powered plant is about half as emission-intensive as a coal-fired plant, so the choice which plant to runs affects the demand for emission permits. The extent to which such a fuel switch is possible depends on available capacity.

68. Market conditions include the liquidity of the market, e.g., whether there is sufficient demand and supply of permits to generate a predictable price. If there is very little demand or supply, permit prices are likely to fluctuate significantly. Speculation, e.g., by financial investors who expect future permit price increases or decreases, affects permit demand and thus contemporary permit prices. Last, but not least, regulatory decisions can have a strong impact on permit prices (Borenstein et al., 2018[46]; Roig-Ramos, 2018[49]). Policies that accompany emission trading systems, e.g. renewable support schemes or energy efficiency measures, lead to steeper demand curve for permits, and thus increased permit price volatility (Flues et al., 2014[51]).

[28] Emitters were not allowed to bank permits from the first commitment period for the second commitment period. Hence permits become worthless once supply exceeded demand.

3.3.2. New information and long-term price expectations

69. The historic component of price expectations suggests more stable carbon prices with tax rates than with permits, but it is an open question how investors interpret new information on carbon prices. When tax rates change suddenly after a long period of stability, it is unknown whether investors interpret such a change as a one-off legislative change or as a sign of more changes in the future. Similarly, investors may see changes to the rules of an ETS as a one-off action, or as a sign of increased future action.

70. Communication on future policy plans may help to funnel expectations in a certain direction, but the possibility that the government changes implies that investors may not put much weight on announcements of future policy changes. Wide-ranging agreement across the political spectrum on future carbon price targets may help to increase the credibility of price expectations. In addition, embedding carbon pricing in policy frameworks that have broader support than climate action alone, e.g. general tax reform, increased public investment or public debt reduction, can help to create credible carbon price expectations.

71. While the arrival of new information on carbon prices and their interpretation is unknown, certain structural features of taxes and emission trading systems can affect the formation of long-term expectations on carbon prices. These features include how carbon prices interact with accompanying climate policies, how carbon prices respond to technological change, the price formation mechanisms when emissions approach zero and when emission targets become negative. These are discussed next. The analysis also considers how accompanying policies, technological change and the price-formation mechanisms at low, zero and negative emission levels impact incentives to reduce emissions from an investor's perspective.

Accompanying climate change policies and their structural impact on carbon price stability and emission levels

72. When forming expectations about future carbon prices, investors may take the interaction of carbon prices with accompanying policies into account. Tax rates are generally not affected by accompanying policies, while permit prices may react strongly.

73. Climate change policies that accompany taxes do not change the carbon price and may thus be disregarded when forming carbon price expectations. Because they do not change carbon prices, accompanying policies can, however, prompt additional emission cuts. For example, a coal-phase out in addition to a carbon tax will generate additional emission cuts, if the carbon tax is not high enough to do so on its own. In addition, accompanying policies can reduce emissions, if they remove market frictions. For example, requiring heating be billed by use instead of living space will make households respond stronger to an increase in carbon prices. If the accompanying policy provides weaker incentives than the tax to cut emission, it will be ineffective. Accompanying policies increase compliance costs when marginal abatement costs are no longer equalised across all emitters.

74. In contrast, accompanying policies under an ETS generally trigger a decline in permit prices and will thus be important when forming price expectations. Accompanying policies fail to cause any additional emission reductions as long as the overall emission cap stays fixed. They merely shift emission reductions between sources. For example, a coal phase-out will free up emission permits in the electricity sector, depressing permit prices. Lower permit prices in turn provide an incentive to other sources to increase their emissions compared to emissions that would have resulted under the higher price. As long as the overall cap is fixed and binding, the total amount of emissions will not change. Accompanying policies that resolve

market frictions allow compliance at lower costs, but will not affect the overall amount of emissions under a fixed cap.[29]

75. Accompanying policies under a simple ETS do not only affect the permit price level, they also increase carbon price volatility (Borenstein et al., 2018[46]; Flues et al., 2014[51]), and may thus increase carbon price volatility expectations. To see this, remember that the intersection of the cap, i.e., the permit supply curve, and the marginal abatement cost curve determines the permit price. Any legislated emission reduction through an accompanying policy will happen independently of the permit price, meaning that the emission reductions for which permit prices matter become fewer. As a result, the abatement cost curve becomes steeper. The steeper the abatement cost curve, the more permit prices will fluctuate, if, for example, changes in economic activity cause the abatement cost curve to shift inward or outward. Thus, in addition to being environmentally ineffective, accompanying policies that fall under a simple emission cap also increase permit price volatility.

The cumulative abatement cost curve and carbon prices

76. It is not known whether abatement costs will increase or decrease with the cumulative amount of abated emissions. Without considerable technological progress, increasing abatement costs are a likely outcome as long as emitters choose to invest in the least-costly abatement options first. This means that the cumulative abatement cost curve slopes upward. Technological breakthroughs, however, can trigger a sudden substantial decrease in abatement costs. After such a breakthrough, new abatement options appear, that are cheaper than the emission reductions already carried out. The cumulative abatement cost curve starts sloping downward. This section explores how the shape of the abatement cost curve affects carbon price expectations under a tax and a simple ETS.

77. With a tax, the carbon price is not affected by the shape of the abatement cost curve. Emitters will abate as long as the abatement costs are lower than the tax. If abatement costs are strictly increasing in abatement, a fixed tax rate implies that once abatement costs exceed the tax rate no further emissions cuts will occur. Any additional emission cuts then require a higher rate. If a technological breakthrough leads to a decrease of abatement costs, a fixed rate will lead to increasing emission reductions over time. From the perspective of an emitter, decreasing cumulative abatement costs, imply increasingly strong incentives to cut emissions over time, as the difference between abatement costs and savings from not having to pay the tax increases.

78. With a simple ETS, the intersection of the abatement cost curve with the cap determines the permit price. Thus, the shape of the cumulative abatement cost curve has a strong influence on the permit price trajectory. With increasing abatement costs, permit prices will increase over time as cheap abatement options are increasingly exhausted. With decreasing abatements costs, however, permit prices fall once new, cheap abatement options become available. From the perspective of an emitter who considers a clean investment, decreasing permit prices increase uncertainty about the clean project’s profitability. With fixed or increasing carbon prices, emitters can be sure to receive a minimum return on clean investment (from not having to pay the permit price). However, if permit prices may fall over the lifetime of an investment, investments deemed profitable when implemented may become loss making when permit

[29] Some accompanying policies provide support to companies (beyond the reward provided by market prices) for undertaking activities that provide wider benefits to society. An example of such a positive externality is clean technology research and development, which can be expected to lower the overall costs of decarbonisation. If support for clean technology research and development is more successful than what had been expected when the emissions cap was set, there will be downward pressure on carbon prices. Some analysts argue that lower than expected permit prices may generate support for a stricter cap in the future.

prices decrease. The uncertainty on the development of permit prices over time may cause investors to postpone the decision to invest in clean technology.

Carbon prices when emissions approach zero

79. Consider now price expectations and the incentives for emitters to reduce emissions when total emissions approach zero. Under a tax, the carbon price remains fixed. Emitters continue to evaluate whether the costs reducing the remaining emissions are higher or lower than paying the tax. As long as their costs are below the rate, they have an incentive to reduce emissions further, as cutting emissions is cheaper than paying the tax. If the costs exceed the tax rate, they continue emitting, as paying the tax costs less than reducing emissions. Thus, the carbon tax provides a clear signal to emitters whether it pays to abate or to pay the tax. In the case that economy-wide emissions remain too far away from the goal of net-zero, governments face the choice of increasing rates or failing to decarbonise.

80. Under a simple emissions trading system, one might expect that the permit price would equal the marginal abatement cost to reach the cap, but with few permits in supply and ever fewer emitters demanding permits, it becomes increasingly questionable whether the market can generate a reliable carbon price signal. In the extreme case, zero emissions, there is no permit, and hence no price for a permit. Emitting without a permit would likely trigger a fine, and the carbon price would arguably be the fine for emitting without a permit. When there are still some permits available for acquisition and the fine is low, emitters may prefer to pay the fine instead of acquiring more expensive permits.[30]

81. More generally, when emissions approach zero, in the absence of price floors and ceilings, permit prices can be expected to become very volatile, deviating substantially from marginal abatement costs, and possibly alternating between zero and very high prices. In the short run emissions depend on factors which are not fully under control of emitters such as economic activity, weather conditions, fuel prices and switching possibilities, and the like (see Section 3.3.1). With a limited supply of permits, it becomes increasingly likely that emissions either exceed the amount of available permits or fall short of them. When the demand for permits exceeds supply, the permit price will approach the fine for emitting without holding a permit. When demand falls well short of supply, the permit price approaches zero, as the emission permits become useless without emissions. An oversupply of permits is a possible outcome when emissions approach zero, as emitters may decide well in advance of complete decarbonisation to invest in zero-carbon technologies in order to avoid falling prey to permit shortage and high fines when economies approach zero emissions.

82. From an emitter's perspective, carbon price expectations and incentives for clean investment and emission abatement can differ significantly between taxes and emissions trading, when emissions approach zero. With a tax and no legislative change, the rate continues to provide a clear signal to emitters whether it pays to cut emissions further or not. With an emission trading system, the permit price becomes increasingly unpredictable and may thus offer little guidance for investment decisions.

Carbon prices for negative emissions

83. Without substantial, immediate cuts in emissions, reaching the goal of the Paris Agreement requires removal of emissions from the atmosphere (Rogelj et al., 2018[5]). A tax in itself does not provide any incentives to remove emissions from the atmosphere, but it can be complemented with policies that incentivise emission removal, e.g. a subsidy for emission removal. An ETS, in theory, can incentivise

[30] Paying the fine instead of complying is not a mere theoretical possibility as experience with the Corporate Average Fuel Economy (CAFE) standards in the United States shows. Some luxury car manufacturers opt for paying a relatively low fine instead of more expensive compliance with the CAFE standards (Kiso, 2019[101]).

emission removal if governments issue and grant emission permits for the removal of emissions, but carbon price levels and incentives for emission removal will be hard to predict.

84. In terms of price expectations, a subsidy for emission removal set at a fixed level would provide certainty to investors on the rewards from investing in emission removal technologies. With an ETS, an important question is how stable the price signal for emission removal would be. With few buyers for permits and a yet unknown number of providers of emission certificates (those that receive permits for removing emissions), it is a question of how liquid the market would be and whether it would provide a predictable price signal.

85. A subsidy for emission removal from the atmosphere, or the issuance of permits for emission removal, faces similar challenges as any other subsidy. Key among the challenges is the question, whether the subsidy creates "additional" emission removal to what would have happened anyway. For example, is a newly planted forest the result of support for emission removal (through a subsidy or issuance of permits), or would it have been planted anyway? If support for emission removal is provided broadly, without much consideration of additionality, it creates windfall gains for those who would have undertaken emission removal (e.g. afforestation) anyway, and this can become costly for a government's budget. Thus, there is an interest in granting support only to additional emission removal, however, in practice it can become difficult to determine what amount of additional emission removal is due to the support provided.[31,32]

86. Summing up, in the discussion on carbon price expectations and incentives for negative emissions, an analogy to the case for emission reductions can be observed. The price for emission permits that provides the incentive for investment in emission removal, is expected to fluctuate substantially under an ETS. A subsidy, in contrast, would provide more certainty on the rewards for investment in emission removal, much like a tax provides more certainty for the reward of emission reductions absent legislative changes.

[31] For a more general discussion about windfall gains and "free-riding" inherent in the provision of subsidies see, e.g. Greene and Braathen (2014[107]).

[32] A related task is to ensure that emission removal projects remove emissions from the atmosphere and do not only claim to do so. If claims on emission removal are higher than true emission removal, support becomes ineffective.

4 Mechanisms to support price stability

87. The discussion in Section 3 argued that, in addition to the carbon price level, carbon price stability is an important factor for the decision to invest in clean projects. Capital costs for clean projects are significantly higher, when carbon prices are uncertain (Section 3.2). While taxes provide a stable price signal over time (absent major legislative changes), carbon prices in a simple ETS fluctuate considerably.

88. Given that clean projects are often capital intensive and that volatile permit prices reduce the incentive to invest in clean projects, there is a case for improving carbon price stability in emissions trading systems. Accordingly, many major emissions trading systems feature stability measures, either right from the implementation date of the system, or as a result of reforms aimed at improving the performance of the system.

89. The following paragraphs consider currently implemented stability measures in four major emissions trading systems. The discussion starts with measures that directly stabilise carbon prices, i.e., the Carbon Price Support in the UK and the auction reserve price in the California and the Quebec Cap and Trade Programs. Then it examines measures that indirectly aim to stabilise permit prices by altering permit supply, i.e., the Emission Containment Reserve in RGGI and the Market Stability Reserve of the EU ETS. The discussion focuses on how each of the four stability measures affects emissions (effectiveness), economic outcomes (efficiency), and revenue (which can affect feasibility). It also considers the interaction of support measures with accompanying climate policies.

4.1. Carbon price support

90. A carbon price support establishes a minimum price that emitters pay for emissions by complementing permit prices from an ETS with a fixed tax rate on emissions. Emitters have to pay the tax irrespective of the permit price. If the cap is sufficiently strict, emitters pay the permit price on top of the tax. However, if emissions are well below the cap, permit prices can fall to zero, implying that the only carbon price emitters pay is the tax. Taken together, if emissions are low, emitters only pay the tax; while if emissions are high, emitters pay the tax plus the permit price.

91. From an emitter's viewpoint, a carbon price support guarantees a minimum return on clean investment, as the overall carbon price can never fall below the rate fixed by the carbon price support. The overall carbon price still fluctuates depending on the stringency of the cap and emission levels, but the carbon price support eliminates the risk of very low carbon prices.

92. The overall effectiveness and efficiency of a carbon price support depends on whether the support applies to all emissions covered by the ETS or only to parts of them. An example for a latter is a carbon price support that applies in one or several, but not all jurisdictions of an ETS (e.g. carbon price support in the UK within the EU ETS). Another example is a support that covers one or multiple, but not all sectors of an ETS (e.g. a price support for emissions from electricity generation only). Fuel taxes that exist prior to the introduction of an ETS also support the carbon price for the emissions they apply to and are thus an

example of the second case. The following discussion considers first a carbon price support that applies to all emissions under the cap. Then it analyses a carbon price support that applies to parts of the cap.

93. When the carbon price support applies to the entire ETS, its immediate effect on emissions depends on whether the tax or the ETS provides stronger incentives to cut emissions (see Table 1). In the first case, permit prices will be zero (as the cap is non-binding), but the minimum carbon price guaranteed by the price support cuts additional emissions compared to a simple ETS without a price support. In the second case of a binding the cap, the carbon price support will have no immediate impact on emissions. The overall carbon price would have been the same than without the price support, so the overall emission level does not change. However, the eliminated risk of very low future carbon prices may induce additional clean investment, lowering emissions over time when the cap is adjusted downwards.

Table 4.1. Effect of carbon price support – Case I

Carbon price support covers all emissions of an ETS

	Effect of carbon price support	Interaction of carbon price support and accompanying policies
Effectiveness: Additional emission reductions	+ : if price support is binding o : if emission cap is binding in short-run, but stronger incentive for clean investment may lead to additional emission cuts over time and increase support for a stricter cap	+ : if price support is binding o: if emission cap is binding
Efficiency: Exhaust cheap abatement options	o : equal price for all emissions ensures exhaustion of cheap abatement options	- : accompanying policies increase aggregate abatement costs, except they resolve pre-existing market frictions

Note: +: additional effect; o: no additional effect supporting policy goal; - additional effect counteracting policy goal

94. A carbon price support applying to all emissions of an ETS is economic (or cost-effective), i.e. overall emissions are reduced with a minimum amount of investment (costs). In other words, there is no cheaper way to reduce emissions. The cost-effectiveness results from equal carbon prices across all emissions covered by the ETS. Any emitter with lower abatement cost than the price profits from reducing emissions, while emitters with a higher abatement costs than the carbon price will find it cheaper to pay the tax or buy permits. As a result, overall abatement costs (or the overall amount of investment needed to reduce a certain amount of emissions) are minimised.

95. Accompanying policies cut additional emissions when the carbon price support applies. This situation is similar to the interaction of carbon tax with accompanying polices. In many cases, accompanying policies reduce emissions, but increase the overall cost of abatement, because they reduce emissions at a higher cost than the carbon price. For example, an energy efficiency regulation for light bulbs on top of a carbon price support may reduce emissions, but increase overall abatement costs when the implied abatement cost of the light bulb exceeds the carbon price.[33] However, when accompanying policies resolve market frictions (e.g. information asymmetries on carbon emissions of goods traded between buyers and sellers), they can contribute to cost-effectiveness.

[33] Otherwise said, the total level of abatement could have been achieved with a carbon price that exceeds the carbon price support but that is lower than the weighted average of the support price and the cost of the additional abatement from the energy efficiency regulation.

96. Accompanying policies may alter emissions of individual emitters, but not the overall level of emissions when the emission cap is binding. In this case, additional policies reduce permit prices, mitigating additional emission cuts.

97. A carbon price support applying to all emissions increases revenue when it increases the overall carbon price. It can also increase revenue, when the overall carbon price remains the same, but not all emission permits are auctioned.

98. When the carbon price support applies only to some sectors of an ETS, or some countries of a multinational ETS, it increases the total carbon price, i.e. tax plus permit price, where the carbon support applies (*the taxed emissions*). Note that if an emissions trading system is expanded to emissions that already face a carbon price from taxes, the existing taxes act as a carbon price support for those emissions. At the same time, for the emissions where it does not apply (*the untaxed emissions*), the carbon price support decreases the overall carbon price, i.e. the permit price only. Emissions will decrease in the jurisdiction or sector where the carbon price support applies, but increase where it does not (See Table 2). The overall amount of emissions will remain the same as long as the overall cap is unchanged and binding. However, governments can make a partial price support effective by retiring an emission permit for every unit of emissions that the partial price support has cut.[34] Additional emission reduction can also occur over time, for example, when the increased incentive for clean investment for the taxed emissions triggers a more stringent cap, or low permit prices lead to an expansion of the price support to the previously untaxed emissions.

Table 4.2. Effect of carbon price support – Case II

Carbon price support covers only some emissions of an ETS

	Effect of carbon price support	Interaction of carbon price support and accompanying policies
Effectiveness: Additional emission reductions	*Effect on emissions with price support* + : additional emission reductions *Effect on emissions without price support* - : lower permit prices increase emissions *Aggregate effect* o : carbon price support lowers emissions with price support, but increases emissions without a support; over time the partial price support may trigger a tighter cap, as well as an expansion of the support to more emissions	*Aggregate effect* o : additional emission cuts for the emissions with price support, but may be offset by even lower permit prices for emissions without a price support
Efficiency: Exhaust cheap abatement options	- : unequal carbon prices across emissions with price support and without imply some cheap abatement options are foregone	-: accompanying policies may lead to even greater price dispersion between emissions with and without a price support

Note: +: additional effect supporting policy goal; o: no additional effect; - additional effect counteracting policy goal

99. With a partial carbon price support, different carbon prices for taxed and untaxed emissions imply additional costs for reducing emissions. Cheap abatement options are foregone in the sector where only

[34] A requirement to retire permits would need to be integrated into the law establishing the carbon price support, or an additional decision is required afterwards. Determining the exact amount of emissions that the carbon price support has cut in addition to the ETS can be hard, but in practise approximations could be made, for example, based on carbon price elasticities (see Section 2.2). Note, however, that permits could also be retired without a carbon price support in place.

the permit price applies, while higher-cost abatement options are carried out were the carbon price support applies. Accompanying policies can trigger additional emission cuts for the taxed emissions, but these may be offset by even lower permit prices for the untaxed emissions. In terms of revenue, a partial carbon price support shifts revenue-generation from the untaxed emissions to the taxed emissions.

100. The United Kingdom provides an example for a partial carbon price support, which applies to the United Kingdom's electricity sector in addition to the EU ETS. In 2013, the carbon price support was introduced at a level of GBP 9 (EUR 12.40) raising to GBP 18 (EUR 24.80) per tonne of CO_2 by 1 April 2015. The overall carbon price, i.e. carbon price support plus permit price, has exceeded EUR 30 since then. Emissions from the electricity sector decreased by 58% from 2012, before the CPS was implemented, to 2016 (OECD, 2018[1]). In how far the UK Carbon Price Support has reduced the overall amount of emissions covered by the EU ETS depends on its interaction with the EU ETS's Market Stability Reserve (Section 4.4).

4.2. Auction reserve price

101. Auction reserve prices stabilise emission permit prices by specifying a minimum price that bidders need to pay at permit auctions. If bids are below the auction reserve price, no permits are sold. In effect, a reserve price restricts permit supply and thus tightens the overall emission cap in case permit prices are below the reserve price. Governments can achieve a similar effect by committing to buy back emission permits from the market, if permit prices fall below a certain price.

102. From the viewpoint of emitters, auction reserve prices establish a minimum price for emissions permits. When deciding on whether or not to invest in a clean project, the auction reserve price thus guarantees a certain minimum return on emission reductions. Accompanying climate change policies can still reduce permits prices below the level that would prevail if they did not exist, but accompanying policies cannot reduce the permit prices below the reserve price.

103. When the auction reserve price applies to all emissions covered by an ETS, its environmental and economic effects an auction reserve price are similar to a carbon price support (see Table 3, as well as Section 4.1). It encourages additional emission reductions exhausting all low-cost abatement options.

Table 4.3. Effect of auction reserve price – Case I

Auction reserve price covers all emissions of an ETS, effects are similar to a carbon price support

	Effect of auction reserve price	Interaction of auction reserve price and accompanying policies
Effectiveness: Additional emission reductions	+ : if reserve price is binding o : if emission cap is binding in short-run, but stronger incentive for clean investment may lead to additional emission cuts over time and increase support for a stricter cap	+ : if reserve price is binding o: if emission cap is binding
Efficiency: Exhaust cheap abatement options	o : equal price for all emissions ensures exhaustion of cheap abatement options	- : accompanying policies increase aggregate abatement costs, except they resolve pre-existing market frictions

Note: +: additional effect supporting policy goal; o: no additional effect; - additional effect counteracting policy goal

104. When the auction reserve price applies only to some of the emissions covered by an ETS, its environmental and economic effects differ from a carbon price support (Table 4). When permit prices fall below the auction reserve price, the reserve price restricts permit supply and thus tightens the overall cap.

As a result, permit prices are higher than without the partial reserve price. The overall amount of emissions decreases. Emission reductions are also cost-effective because the same price applies to all emissions. Accompanying policies have an additional effect on emissions to the extent that the reserve price restricts permit supply, but may increase overall abatement costs. In terms of revenue, there are two countervailing effects. Fewer permits are sold which reduces revenue, but higher permit prices increase revenue.

Table 4.4. Effect of auction reserve price – Case II

Auction reserve price covers only some emissions of an ETS

	Effect of auction reserve price	Interaction of auction reserve price and accompanying policies
Effectiveness: Additional emission reductions	+ : auction reserve price lowers emissions by tightening the cap	+ : additional emission cuts to the extent that the reserve price restricts permit supply
Efficiency: Exhaust cheap abatement options	o : equal price for all emissions ensures exhaustion of cheap abatement options	-: accompanying policies increase aggregate abatement costs, except they resolve pre-existing market frictions

Note: +: additional effect supporting policy goal; o: no additional effect; - additional effect counteracting policy goal

105. California as well Quebec provide examples for auction reserve prices that apply to an entire ETS. The California Cap and Trade Program (CTP), for example, established a minimum auction reserve price of USD 10 per tonne of CO_2 at the program start in 2013. The program also scheduled annual increases of the auction reserve price by 5% plus inflation (California, 2019[52]). In 2019, the auction reserve price thus reached USD 15.62 per tonne of CO_2 (California Air Resources Board, 2019[53]).

106. In practise, permit prices in the California CTP have been very close to the reserve price since its establishment. Borenstein et al. (2018[46]) argue that this is largely the effect of accompanying climate change policies requiring in many sectors stricter emission cuts in sum than the overall emission cap requires. As a result, the overall cap becomes nonbinding, but the auction reserve price prevents permit prices from falling to zero by automatically tightening the cap.

107. Comparing an ETS with an auction reserve price to a tax, the former mirrors a tax that is progressive in emissions (Bushnell, 2019[54]). If emissions are low, the auction reserve price establishes a flat minimum tax rate, but if emissions are high, the (tax) rate increases with the marginal abatement costs necessary to reach the emission cap.

4.3. Emission Containment Reserve

108. An emission containment reserve withdraws permits from auction and cancels them, when permit prices fall below a threshold value. The containment reserve thus creates an upward step in the supply curve of permits. If permit prices are below the threshold value, permit supply is restricted.

109. In essence, an emission containment reserve resembles a soft version of an auction reserve price. Instead of withdrawing all permits from auction when permit prices fall below a certain price threshold, the emission containment reserve reduces the number of auctioned permits. Its effect on emissions is similar in direction, but weaker in size than an auction reserve price. The effect of an emission containment reserve on permit prices is also weaker and more difficult to predict than for an auction reserve price as only some, but not all, permits are withheld from auction when permits fall below the threshold value. The following paragraphs describe the effects of a reserve that applies to the entire ETS (Table 5). The effects of a partial

reserve that applies only to parts of an ETS would resemble those of a partial reserve price, but its effect on emissions reductions would be more limited.

110. While the containment reserve does not guarantee a minimum reward for clean projects, it makes low carbon prices less likely. If the containment reserve withdraws a significant amount of permits when prices fall below a certain threshold, emitters may expect that permit prices do not fall significantly below this threshold. Accompanying policies can reduce permit prices, but the withdrawal of permits below the threshold price limits any negative effects on prices.

111. The containment reserve automatically tightens a loose cap and thus improves environmental effectiveness when permit prices are low, but in a softer way than a reserve price would do. This means that accompanying policies that reduce prices below the threshold value lead to additional emission reductions, but only to the extent that the emission reductions triggered by the accompanying policy do not exceed the amount of permits withdrawn.

Table 4.5. Effect of an emission containment reserve

Emission containment reserve covers entire ETS

	Effect of emission containment reserve	Interaction of emission containment reserve and accompanying policies
Effectiveness: Additional emission reductions	+ / o : l withdrawal of permits reduces emissions, when permit prices fall below price threshold, o: when prices are above the price threshold, but reduced risk of low permit prices may incentivise more clean investment	+ / o: additional emission reductions to the extent that accompanying policies trigger a withdrawal of permits o: as long as permit prices remain above price threshold
Efficiency: Exhaust cheap abatement options	o : equal price for all emissions ensures exhaustion of cheap abatement options	- : accompanying policies increase aggregate abatement costs, except they resolve pre-existing market frictions

Note: +: additional effect supporting policy goal; o: no additional effect; - additional effect counteracting policy goal

112. RGGI has scheduled the implementation of its emission containment reserve for 2021. It stipulates that 10% of an annual cap's emissions are withdrawn from auction and immediately cancelled when permit prices fall below a threshold value of USD 6 per tonne of CO_2 (RGGI, 2017[55]). The threshold price rise by 7% per year. The performance of the containment reserve is yet unknown.

4.4. Market Stability Reserve

113. A Market Stability Reserve (MSR) withdraws permits from the market if the number of permits in circulation exceeds a certain threshold and puts them into the reserve. When the number of permits falls below another threshold, the reserve releases permits to the market. Permits in circulation are permits that are not used for compliance. The aim of the MSR is to stabilise permit prices by putting bounds on the amount of permits in free circulation.

114. The MSR implemented in the EU ETS includes an additional feature, which may stabilise permit prices. If the number of permits in the MSR exceeds the number of permits auctioned in the previous year, permits in excess of the previous year's auction volume are to be cancelled from 2023 onwards. The cancellation of allowances makes the cap stricter (Table 6).

115. The mechanics of the MSR are distinct from an auction price reserve, a carbon price support, and an emission containment reserve. Instead of stabilising prices based on a predefined price (the reserve

price, the carbon price support rate, the threshold value for removing permits), the MSR aims to limit price fluctuations by removing or releasing permits based on predefined quantities of free permits in circulation. Predefined prices are exogenous to the outcome of the emission market and thus provide a focal point for market participants' expectations on the carbon price level. In contrast, the quantity of free permits in circulation is an endogenous market outcome and does not provide any focal point about future price levels. In addition, Perino and Willner (2016[56]) show that the MSR increases carbon price volatility if abatement costs are increasing and an economic shock occurs during a period where emitters bank allowances for future use.

116. From an emitter's point of view, the quantity-based MSR thus provides significantly less certainty than price-based stabilisation measures. Emitters may, or may not, expect that the MSR reduces the chances of very low permit prices while remaining uncertain about what really low price levels will be. As such, any additional incentives from the MSR to invest in clean projects and reduce emissions are likely limited.

117. The effect of accompanying policies on the carbon price level and emissions in an ETS with an MSR is complex (Perino, Ritz and van Benthem, 2019[57]; Edenhofer, 2019[58]). It differs depending on whether accompanying policies lead to an immediate shift of emissions between emitters regulated under the ETS, or whether accompanying levels trigger an accumulation of permits in circulation over time. An example for the first case is the legislated closure of certain coal-fired plants (Edenhofer, 2019[58]). With enough overall generation capacity, the closure of some plants can increase the utilisation, and thus emissions, of other coal fired plants. If the emission shift occurs within the same year, the MSR will not put any permits into the reserve. As a result, overall emissions and permit prices will be the same with or without the coal phase-out.

118. Support for zero marginal cost renewable energy, like solar or wind, is likely an example for the second case, where the MSR can trigger real emission reductions (Perino, Ritz and van Benthem, 2019[57]; Silbye and Sorensen, 2019[59]). An increase of renewable capacity generally leads to a higher share of renewable energy in the grid, because renewable's marginal generation costs are below those of fossil-fuel-powered plants. The resulting lower utilisation rate of fossil-fuel-powered plants leads to an increase in the number of permits in free circulation. As long as these additional permits in circulation are not bought and used by other emitters in the same year, the overall number of permits in free circulation increases. As a result, the MSR takes up more permits, restricting permit supply and putting upward pressure on prices. Further, if the additional permits are finally cancelled (once permits in the MSR exceed the number of permits auctioned in the previous year), the support for renewable energy results in emission reductions that are additional to an ETS without a MSR.

119. The permit cancelation feature of the MSR may generate a multiplier effect for voluntary permit cancelations. If a person, firm or state wishes to voluntarily cancel permits in order to reduce aggregate emissions, it can pay to hold the permits for several years instead of cancelling them immediately (Carlén et al., 2019[60]). Permits that are not used for compliance or cancelled account to the amount of permits in free circulation. The more permits are in circulation, the higher are the chances that the reserve takes up permits. In addition, if permits in the reserve exceed the previous year's auction volume, the excess is cancelled. Holding permits in times when the MSR takes in permits thus triggers the cancellation of other permits. In other words, by holding, but not using permits, the cap becomes more stringent.

120. Strategic investors could also use the permit cancellation feature in attempts to reduce the cap permanently in order drive up permit prices. If a strategic investor holds the amount of permits needed to trigger intake into the MSR, she can ensure that no permits will be released from the MSR. Knowing that permits in the MSR in excess of the previous year's auction volume will be deleted, the investor can be sure that permit supply decreases, which puts upward pressure on prices. While the amount of money required to hold the amount of permits to constantly trigger an intake into the MSR may exceed the capital available of many private investors, a sovereign investor may be able to shoulder the required amount.

Table 4.6. Effect of a market stability reserve

Market stability reserve covers entire ETS

	Effect of market stability reserve	Interaction of market stability reserve and accompanying policies
Effectiveness: Additional emission reductions	+ / o : deletion of permits from reserve reduces emission, when amount of permits in reserve exceeds the amount of permits auctioned in the previous year o: as long as no permits are deleted the market stability reserve shifts emissions over time, but does not reduce them	+ / o: additional emission reductions to the extent that accompanying policies foster an accumulation of permits in the reserve and trigger a subsequent deletion of permits from the reserve; o: accompanying policies that contemporaneously shift emissions between entities will hardly trigger any deletion of permits and hence be ineffective
Efficiency: Exhaust cheap abatement options	o : equal price for all emissions ensures exhaustion of cheap abatement options	- : accompanying policies increase aggregate abatement costs, except they resolve pre-existing market frictions

Note: +: additional effect supporting policy goal; o: no additional effect; - additional effect counteracting policy goal

121. The EU established a MSR in 2019. Since March 2018, when the reform of the EU ETS including a strengthened MSR had been passed, permit prices have increased from well below EUR 10 per tonne of CO_2 to well above EUR 20 per tonne of CO_2. Permit prices fluctuate considerably, but at a significantly higher level than in previous years (European Energy Exchange, 2020[43]).

4.5. Tentative conclusions on mechanisms to support price stability

122. Once a policy is introduced, it often persists or is reformed, rather than entirely revoked (Coate and Morris, 1999[61]). To the extent that this applies to price stability measures, studying combinations of several policy instruments allows insights into how existing policy instruments, e.g. the MSR, can be improved by combining them with other instruments.

123. The following paragraphs will first provide an example of how combining instruments that aim to stabilise prices via different channels, i.e. via adjusting quantity in case of the MSR, and via directly ensuring against low permit prices, in case of an auction reserve price, can provide additional benefits. However, combining policies introduces additional complexities, not just in terms of administrative effort, and in the worst case, effects of different policies may cancel each other out. Thus, the second part of this section asks which of the four mechanisms to support carbon price stability offers the most benefits on its own. This question becomes important when designing carbon price instruments from scratch. A related question is how an ETS with a price stability measure compares to a tax.

124. The MSR generates a corridor for the number of permits in free circulation, shifts permit supply over time, and may delete some permits permanently. However, it does not protect against very low permit prices, and may, in some circumstance, increase rather than decrease price volatility (Perino and Willner, 2016[56]). On its own, the MSR may only encourage limited investment in clean technologies and emission reductions, because low permit prices remain a risk.

125. Combining the MSR with an auction reserve price would protect clean investment against low permit prices and support its profitability. An MSR in addition to a price floor may also foster additional emission reductions from accompanying policies. Without an MSR, permit prices likely stay close to the floor, because accompanying policies reduce the demand for permits (Borenstein et al., 2018[46]). The MSR accumulates unused permits and deletes them when the number of accumulated permits becomes very

large. In addition, the MSR helps to avoid an oversupply of permits in the short-term, potentially stabilising permit prices. The combination of an MSR with an auction reserve price may thus encourage more emission reductions than each separate instrument would.

126. When designing an emission trading system from scratch, an auction reserve price likely offers most benefits in terms of effectively reducing emissions and doing so efficiently. When it applies to an entire ETS it ensures against low permit prices. This leads to immediate emission reductions when permit prices would have been below the reserve price in its absence. In addition, a permit reserve price encourages clean investment by guaranteeing a minimum return in comparison to more dirty investment. In terms of efficiency, an auction reserve price implies the same permit price for all emissions, encouraging investors to exhaust all cheap abatement options. When the auction reserve price applies to only parts of an ETS, it also restricts permit supply when the demand for permit is low, while keeping permit prices equal across the entire ETS.

127. Price stability mechanisms other than the auction reserve price are either less effective, less efficient, more complex or a combination of the three. While a carbon price support is similar to an auction reserve price when it applies to an entire ETS, it is less effective and efficient when it applies only to parts of an ETS. However, the effectiveness of a partial carbon price support can be improved by committing to delete permits that are freed up by the partial price support. An emission containment reserve behaves similar to an auction reserve price in terms of the directions of its effects, but its effects are generally more limited in size. By design an emission containment reserve restricts permit supply less than an auction reserve price would when prices fall below a predetermined threshold. The MSR is considerably more complex than any of three instruments above, as it aims to stabilise prices by regulating quantities instead of specifying price thresholds for delivering support. In addition, the risk of low permit prices is not eliminated by the MSR.

128. A common question when developing a carbon pricing policy from scratch, is whether to go for a tax or an emissions trading system. While simple questions have appeal, when it comes to the effectiveness, efficiency and feasibility of carbon pricing, design features of taxes and emission systems can matter more, than the simple choice of one instrument to another. Price stability is important, so how do emissions trading system with a price stability measure compare to taxes?

129. Taxes fix the carbon price, while emissions trading systems fix quantities, meaning the carbon price can fluctuate. However, carbon prices can also change under taxes, when tax laws change. The expectations of carbon prices over the lifetime of the investment is what matters ultimately for an investor considering a clean investment.

130. Absent recent legislative changes and new information, investors may expect stable carbon prices with taxes. However, they may react strongly to new information on tax reform. Observing fluctuation in carbon prices with emission trading, investors may also expect strong variability in future carbon prices. In addition, structural components, such as how permit prices interact with accompanying policies and technological change, as well as the price formation mechanism when the amount of permits approaches zero, may lead investors to expect more long-term price variability with permits than with taxes.

131. Carbon price stability support mechanisms have the potential to significantly change price expectations in emissions trading system, especially a carbon price support or an auction reserve price. Both eliminate the risk of very low carbon prices. When the support or reserve price is increasing over time, investors may also expect increasing carbon prices in the future. With a tax that has not changed recently, investors may, however, expect no changes in the future and thus no increases in the carbon price over time.

132. If the goal is to generate expectations of a carbon price that increases over time in line with the goals of the Paris Agreement to decarbonise by mid-century, a mechanism that increases current carbon

prices in regular intervals is sought for.[35] In California and Quebec the auction reserve price increases by 5% plus inflation each year. While future policy developments cannot be known, a regularly increasing auction price reserves can anchor the historic component of carbon price expectations to a price path that increases over time. Similarly, tax rates could be automatically adjusted upward each year. Some countries do adjust excise taxes on fuels for inflation, but an automatic adjustment to increase carbon prices in line with the levels required by the Paris Agreement has not yet been implemented anywhere. Switzerland provides an alternative by increasing the rates of its carbon tax when emission reductions fall short of emission targets (Swiss Federal Office for the Environment, 2018[62]).

[35] The marginal damage of CO_2 emissions also increases with the level of CO_2 concentration in the atmosphere.

5 Carbon price base design: Broad carbon bases, permit auctions, tax allowances and permit allocation rules

133. Carbon prices vary in how their rate applies to the entire carbon emission base. For example, a carbon tax on heating fuels consumed by households normally applies the same rate without any exemptions or reductions for all household emissions from heating fuels. Households thus pay the full rate for all emissions. However, taxes can also include tax-free allowances, implying that emitters do not have to pay the tax for all emissions. For example, tax-free allowances in the South African carbon tax imply that emitters have to pay only for 5% of their emissions (Roelf, 2019[63]). Tax-free allowances drive a wedge between the marginal price emitters pay for an additional unit of emissions and the average price they pay for their entire emissions.

134. Emission trading systems allocate permits via permit auctions and other allocation rules. With full permit auctioning, investment incentives from an emission trading systems are equivalent to a carbon tax that applies the same rate to all covered emissions for a given carbon price and similar expectations about carbon price stability. Instead of auctioning, permits can be distributed for free according to benchmarks and historical emissions (grandfathering). Any free allocation of permits in an ETS drives a wedge between marginal and average carbon prices, much like tax allowances do for taxes.

135. Taxes with uniform carbon rates for all emissions and emission trading systems with full permit auctioning provide stronger incentives for investment in clean technologies than taxes with tax-free allowances and emission trading systems with benchmarking or grandfathering (Flues and Van Dender, 2017[64]). Tax-free allowances, benchmarking and grandfathering affect economic rents, and they tend to do so in ways that favour carbon-intensive technologies. Investors value carbon-intensive technologies higher than in the absence of tax-free allowances or freely allocated permits, to the extent that allowances and permits increase profits of carbon-intensive projects. This risks changing project rankings to the detriment of clean technologies.

136. The effective average carbon rate, i.e. the carbon rate adjusted for any tax-free allowances, captures the effect of tax-free allowances on total expected profits and thus on project rankings. The same holds for the average permit price, i.e. the permit price adjusted for the impact of any free allocation, in emissions trading systems. In other words, the strength of the incentives to invest in clean technologies

can be compared across different tax and emission trading systems by comparing their effective average carbon rates.[36]

137. Recent empirical findings are consistent with the theoretical argument that effective average carbon rates reflect the strength carbon pricing systems to invest in clean technology. In an analysis covering nearly all industrial installations within the EU ETS, Brouwer et al. (2017[65]) find that installations with allocations above historical emissions increase their emissions, while installations with allocations below historical emissions decrease their emissions in subsequent years. Interviewing managers of Belgian ceramic plants, Venmans (2016[66]) reports lower perceived abatement investment incentives for firms with allocations above actual emissions compared to firms with allocations below actual emissions. Looking at low-carbon innovation, Martin et al. (2012[67]) report lower innovation efforts in firms with a higher share of free allocation, based on interviews with managers in 770 manufacturing firms in the EU. Efforts to innovate drop significantly in firms that exceed the administrative thresholds that grant additional free permits to firms in both trade- and carbon-intensive industries.

138. Benchmarks that favour carbon-intensive technology and very low effective average carbon rates in the EU ETS and the California Cap-and-Trade program imply weak signals for favouring low- over high-carbon investment (Flues and Van Dender, 2017[64]). The result is more carbon-intensive investment compared to the case where all permits would be auctioned or a linear (i.e., same rate of all emissions) carbon tax would be set.

[36] The meaning of "average" can be ambiguous. Here, "average" refers to calculating effective "average" carbon rates for prospective investment projects. This calculation allows measuring the impact of carbon prices on the ranking of different investments projects. Another meaning of "average" would be if "average" effective carbon rates were calculated across sectors or years. Such average rates would not directly allow a comparison of investment incentives across sectors or years as they could be heavily influenced by a high carbon price applying to very few emitters only (see also OECD (2018, pp. 29-30[1])).

6 Revenue from carbon pricing

139. While the primary goal of carbon pricing is to reduce CO_2-emissions, carbon pricing also raises revenue. Decisions on revenue use are of key importance when considering the economic case, distributional and political economy aspects of carbon pricing.

140. The introduction of a price on carbon implies defining property rights. In the case of emissions trading systems, an emissions permit defines the right to increase the stock of greenhouse gases by one unit of emissions. The carbon price is the rent resulting from the tradability of the permit, and it accrues to the initial owner of the permit (unless governments decide to give permits away for free, see the previous section). In the case of a carbon tax, the government, representing voters, is the custodian of the atmosphere and charges polluters for their contribution to its degradation. The carbon rent then takes the form of tax revenue. When there is no tax or trading system, the carbon rent is implicit (there is no financial flow) and accrues to emitters – polluters do not pay for the damages they impose on society. The size and the distribution of carbon rents can strongly influence public support for carbon pricing.

141. Revenue from carbon pricing can be substantial. Marten and Van Dender (2019[68]) analyse the revenue from effective carbon rates, i.e. emissions trading systems, carbon taxes, and excise taxes on energy use, in 40 OECD and G20 countries. Tax and auction revenue are over one percent of GDP in many OECD and G20 countries and the revenue could more than double if carbon price levels were increased to EUR 30 per tonne CO_2. EUR 30 is a very low estimate of the climate damage from emissions. Decarbonisation requires rates higher than EUR 30, and thus revenue can be expected to exceed two percent of GDP in the short- to medium-term. Eventually, carbon tax revenue declines with decarbonisation, but in a matter of decades (Marron, Toder and Austin, 2015[69]).

142. Most available descriptive analyses of revenue use have focussed on carbon taxes and ETS auction proceeds. For example, Sumner et al. (2011[70]) examine revenue use from carbon taxes in seven countries and five subnational jurisdictions and find that revenues are often used to fund carbon mitigation programmes, especially in subnational jurisdictions, to reduce income taxes, or to supplement government budgets. Carl and Fedor (2016[71]) study revenue use from carbon taxes and ETS auctions in 40 countries and 16 subnational jurisdictions. They distinguish three main categories of revenue use: green spending, general revenue, and broader tax reform (i.e. rebates or tax shifts). Carbon tax revenues are more often used in the context of a tax reform (72%) and auction revenues are more often used for green spending (70%), suggesting that the tax reform potential of carbon taxes is as important for policy makers as their climate mitigation potential.

143. Considering revenue use from excise taxes on fuels in addition to that of carbon taxes and trading system, Marten and Van Dender (2019[68]) find constraints on the use of revenue from excise taxes on fuels and from carbon taxes, both as legal earmarking and political commitments, are in place in about three out of five countries analysed. In the case of emissions trading systems, constraints exist in close to all countries in which such systems exist.

144. Across 40 OECD and G20 countries, the share of revenue subject to constraints on its use well exceeds 80% of total revenue from trading systems, and close to two-thirds of carbon tax revenue. Less than two-thirds (38%) of revenue from excise taxes is subject to a constraint. Revenue from excise taxes accounts for more than 90% of total effective carbon rates (OECD, 2018[1]),

145. The type of spending required by constraints on carbon pricing instruments is diverse, including using revenues to support tax policy changes (e.g. tax cuts, rebates, tax-free threshold increases), transfers to other levels of government, infrastructure spending, and green and energy-related spending. In the case of excise taxes on fuels, most constrained revenue is earmarked for transport infrastructure spending, reflecting that these taxes are viewed as user charges in several jurisdictions. Carbon tax revenue is more generally committed to supporting tax policy changes, suggesting that carbon taxes are frequently elements of a broader tax reform package. Revenue from auctioned tradable emissions permits is almost exclusively earmarked to support energy efficiency, low-carbon mobility and other green spending measures, with the second highest share dedicated to supporting energy users.

146. Environmental taxes, if well designed, improve economic efficiency and therefore increase total economic benefits, by reducing or removing a market failure. However, if the social value of the deployment of revenue is low, then environmental taxes may fail to deliver net economic benefits.

147. Potential claims on the use of carbon pricing revenue are many, including fresh spending (e.g. for infrastructure or research and development), boosting existing spending (e.g. on education), cutting other taxes, reducing public debt, providing support for increased energy costs to domestic households or firms, funding transfers to developing economies, etc. These options, alone or in combination, may or may not increase net economic benefits, depending on the conditions in the jurisdiction applying the tax. They can also contribute to overall well-being and create public support for carbon pricing.

148. An abundant literature investigates whether environmental tax revenue can economise the overall costs of raising a given amount of tax revenue by changing the tax mix. Parry et al. (2014[72]) find considerable potential for a double dividend. More broadly, socially productive revenue use can take various forms (cutting other taxes, increasing spending, reducing debt, redistribution, etc.) and productive use is as much a prerequisite for economically justifiable use of carbon pricing as is environmental effectiveness (e.g. OECD (2017[2]) and OECD and World Bank (2015[73]))

149. Revenue use is not just about efficiency, it is also crucial from a political economy angle. Combining pricing with statements of intent or legal commitments to particular types of spending can increase social and political support for pricing (see, e.g., Chapter 6 in UNEP (2018[74])). Recycled revenue can diminish or entirely reverse any negative direct impacts of carbon pricing on households or businesses. Tools include uniform lump-sum transfers, targeted transfers and tax reform, which reduces corporate or personal income tax contributions for example.

150. The choice between revenue recycling mechanisms depends on jurisdictions' specific circumstances, and combinations are possible. For example, reducing pre-existing taxes is likely more appealing where income taxes are high. Lump-sum transfers may increase political support where concerns over "big government" loom large, being highly visible and benefiting households across the political spectrum. They can contribute to the robustness of carbon pricing as governments change over time, compared to situations where revenues cater to more narrow constituencies (Klenert et al., 2018[75]). In addition, lump-sum transfers are often designed to imply revenue-neutrality in aggregate. Visibility of revenue use and revenue-neutrality can also be accomplished in tax reform policy packages, e.g. through making explicit how revenues are used to cut other taxes as is the case in British Columbia (Murray and Rivers, 2015[13]).

151. Targeting of transfers can help customise revenue deployment choices to alleviate cost increases where they are felt the strongest, e.g. low-income households and households with fewer short-run substitution options (Flues and Van Dender, 2017[76]). This can increase support for carbon pricing. Balancing social needs with maintaining the environmental effectiveness of the price signal calls for targeting based on income and social indicators, not on overly narrow energy spending. With increasing carbon efficiency, transfers can also be limited in time.

152. Further suggestions on revenue use include using carbon tax revenues for R&D and other climate policy measures that would likely require "fresh spending" (Bowen, 2015[77]). This can strengthen support, not only with constituencies that strongly favour climate action, but also with voters that doubt the effectiveness of carbon pricing as a behavioural signal but that support climate spending (Klenert et al., 2018[75]).

153. Overall, recent literature on the use of revenue from carbon pricing finds that it is possible in most circumstances to strike a balance between using the revenues in ways that are socially useful and that contribute to support for carbon pricing. Revenue use is not a panacea for building support though. Klenert et al. (2018[75]) note that introducing carbon pricing is more difficult where trust in government is low, and that lower trust in government conditions the options for revenue use, e.g. reducing space for tax reform and increasing the appeal of lump-sum transfers. Marten and Van Dender (2019[68]) argue that, as carbon pricing revenues rise, the case for integrating revenue use decisions with broad tax policy design rather than separating it (as is the case with labelling transfers as carbon dividends) becomes stronger.

7 Support for carbon pricing by households, energy affordability and distributional impacts

154. Support by citizens for carbon pricing depends on how it affects them. Carbon pricing encourages the use of clean energy and investment in clean technologies, e.g. renewable electricity and heating. It also encourages households to refrain from carbon-intensive activities that are of low value to them. While carbon prices support the adoption of clean technologies over time, it is also important to consider their immediate effects when they are introduced or increased.

155. The overall immediate effects of carbon prices on households depends on the use of revenues from carbon prices (see also the discussion above in Section 6) and the direct effects of carbon prices on households. Two questions are generally considered important. First, how do carbon prices affect the affordability of energy, i.e. can every household afford to pay for necessary levels of energy use? Second, how do carbon prices affect disposable income across the entire income distribution, i.e. do poor, middle-income or rich households pay the most?[37] The following paragraphs discuss both questions in turn.

156. Energy affordability is a household's ability to pay for necessary levels of domestic energy use (i.e. heating and electricity) within normal spending patterns (Milne, 2004[78]). Thus, indicators of energy affordability typically refer to a combination of high energy spending and low income. For heating and electricity, a prominent indicator is the ten percent rule (TPR) that states that energy is unaffordable for a household if it spends more than 10% of its disposable income on heating and electricity (Boardman, 1991[79]). There is widespread agreement in developed economies that households should generally be able to live in comfortable warmth and be able to pay for electricity that is needed to run basic households appliances, such as a fridge or a freezer. The indicator generally requires that households facing affordability risks also belong to the lower three deciles of the income distribution to ensure that the indicator is not affected by rich households that spend a lot on energy, for example, for heating their pool.

157. An increase in carbon prices can improve overall domestic energy affordability, if about one-third of the additional revenues from the carbon price are recycled back to poor households (Flues and Van

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[37] While affordability and distributional impacts are important considerations in policy debates, the impact of carbon price reform on household welfare – understood in the microeconomic sense of the net benefits drawn from household expenditure – arguably is the key concern. Unfortunately, often a full analysis of the welfare impacts is not possible with available data and modelling tools, given a lack of a comprehensive and consistent specification of prices and of demand. However, rough approximations can be made by considering how carbon price reforms affect households' real budgets. For an example, see Flues and Van Dender (2017[76]).

Dender, 2017[76]).[38] Possibilities to recycle parts of the additional revenue back to poor households include the social benefits system as well as income-tested payable tax credits.[39] An alternative to targeted support for the poor are lump-sum payments to all households (see also the earlier discussion on revenue use). For a given amount of recycled revenue, lump-sum payments ensure that more households benefit from support, but the poor will receive less than what they would have received with targeted transfers.

158. Across countries, carbon and energy prices are unrelated with energy affordability risks (Flues and Van Dender, 2017[76]). There are several explanations for this finding. First, higher carbon rates and energy prices reduce energy demand and improve energy efficiency, which may mitigate the effects of higher costs per unit of energy. Second, higher energy prices may trigger wage increases, which would reduce affordability risks. Third, social benefit systems may act as an automatic stabiliser. When energy prices increase, higher payments to the needy are automatically triggered, if social benefits adjust to price levels. Fourth, countries that might expect that higher energy prices would particularly challenge the poor, may try to keep them low.

159. In transport, it is more challenging to reach agreement on what constitutes a travel need. While it may be agreed that the commute to work and trips to participate in public life should be affordable to all households, there are many choices involved in where people live and work. Considering current travel may overestimate needs as people could move closer to work.

160. Microdata on household expenditure and travel patterns helps to assess how an increase in carbon prices for transport fuels affects households immediately. For example, Mattioli et al. (2018[80]) find that among low-income households in the United Kingdom, those who work, own a detached or semi-detached house in a rural area, and have a man earning most of the household's income are more likely to spend a large share of their budget on transport fuels. Based on such microdata, governments can decide in how far they may want to use the revenues from carbon pricing to support households.

161. Looking more broadly across the entire income distribution two general findings emerge. First, transferring a third of the additional revenue from higher carbon prices on electricity and heating fuels to poor households can generally create a progressive impact of the overall reform (Flues and Van Dender, 2017[76]). Second, a lump-sum transfer to all households leads to largely proportional outcomes across households.

162. To answer the question of how much revenue to recycle in order to achieve the overall desired distributional outcome of a carbon price reform, it is informative to consider the direct distributional impact of carbon prices, i.e. their impact without considering revenue use. If the direct impact of a carbon price is regressive, comparatively more revenue needs to be redistributed to achieve an overall progressive outcome than if the direct impact is already proportional.

163. Flues and Thomas (2015[81]) find that the direct distributional impacts of carbon prices differs across fuels. Carbon prices on transport fuels tend to have a progressive direct distributional impact in developing and middle income countries (Sterner, 2012[82]; Flues and Thomas, 2015[81]; Ohlendorf et al., 2018[83]). In high-income European countries, middle-income households tend to pay most taxes on transport fuels as a share of their overall expenditure (Flues and Thomas, 2015[81]). Low-income households are less likely to own a car, and if they do, tend to drive less than affluent households. Carbon prices on heating fuels tend to have a proportional or slightly progressive direct distributional impact (Flues and Thomas, 2015[81]). Though poorer households may live in apartments that are less well insulated, they

[38] Flues and Van Dender (2017[76]) examine domestic energy use, i.e., heating fuel and electricity use. The affordability of transport is discussed in the next but one paragraph.

[39] Note that if a social benefit system mainly provides assistance to the unemployed, the working poor may not benefit from increased transfers. In such a case a payable tax credit can ensure that all poor households benefit from support.

tend to live in smaller dwellings and are more likely to live in an apartment than in a detached house. The latter has more outer walls and thus requires more heating per square metre of living space. The direct distributional impact of a carbon price on electricity production generally turns out to be regressive (Flues and Thomas, 2015[81]). Some “fixed” amount of electricity is needed for electrical appliances, especially a fridge and a freezer. The demand for such appliances does not strongly depend on household income.

164. Governments can choose if, how, and how much of the revenue to recycle back to households in order to achieve the desired distributional outcome, as well as other policy goals (see also the earlier discussion in the section on “revenue use” in Section 6). How much and in which way revenues are recycled back to households depends on many factors and countries differ in the priorities they set. In very rich economies, where affordability risks are already low, energy affordability is likely a less important policy consideration than in poorer countries where affordability risks are more prominent.

165. When deciding on how to recycle revenues, a key question to ask is whether the recycling mechanisms keeps the incentives to reduce emissions in place. The advantage of providing income support through the general social benefit system, or via other income-tested benefits, is that they keep the incentive to reduce emissions in place, because the price increase for carbon-intensive fuels remains untouched. In contrast, if support was provided through social tariffs, i.e. lower rates for poor households, part of the carbon price increase would be muted and the incentives to reduce emissions would be weakened. Also, if revenue was recycled based on commuting distance, this would provide an incentive to commute long distances, likely counteracting the goal to reduce emissions.

8 Support for carbon prices by firms and competitiveness

166. Political support for carbon prices depends on how carbon prices affect firms' rents. By increasing the costs of dirty production, carbon prices shift rents away from dirty technologies towards clean technologies. Firms producing with clean technologies become more competitive. Clean technologies gain from carbon pricing and firms using them are likely to support carbon pricing.

167. In a net-zero carbon economy, which the Paris Agreement requires by mid-century,, only firms producing and using (net) zero-carbon technologies will be able to compete.[40] Carbon prices induce firms to reduce emissions, improve resource efficiency, take advantage of clean energy, and encourage investments in the latest clean technology (OECD, 2018[1]). With these improvements, firms can develop and conquer new markets as well as build a reputation for clean production.

168. While carbon-intensive firms may not immediately support carbon pricing, resistance can become self-defeating. The longer jurisdictions delay carbon pricing, the greater is the exposure of firms to market and technological risks, reputational risks, policy and legal risks, and physical risks.[41] The four risks sets are discussed one by one below: First, in a low-carbon future, there will be reduced market demand for high-carbon products, increased demand for zero- and low-carbon products and services, and new, clean technologies may disrupt markets (TFCD, 2016[84]). Carbon intensive assets thus loose value. The longer firms hold on to high-carbon assets, the more they take on market and technological risks (TFCD, 2016[84]; OECD, 2018[1]). Second, consumers that increasingly demand more sustainable products mean that firms who do not adapt to a net-zero future expose themselves to greater reputational risks (TFCD, 2016[84]; OECD, 2018[1]). Third, polluting firms may face litigation in the future due to the evolving product and producer responsibility requirements at international, national and state level. Firms can hedge against litigation risk by adopting cleaner processes (TFCD, 2016[84]; OECD, 2018[1]) Last, more frequent and more severe extreme weather events increase the risk of raising input costs, declining revenues and asset values, and higher insurance costs (TFCD, 2016[84]).

169. While support for carbon pricing from firms producing with carbon-intensive technology is limited, claims that carbon prices would be anti-competitive in the short-run fail empirical tests by and large (Arlinghaus, 2015[85]; Martin, Muûls and Wagner, 2016[86]). Naegele and Zaklan (2019[87]) find that firms regulated under the EU ETS continue to produce in Europe and show that differences in carbon costs between Europe and other parts of the world are low, especially when compared to labour costs. For 95% of European manufacturing carbon costs induced by the EU ETS are below 0.65% of total material cost. Aus dem Moore et al. (2019[88]) observe that multinational firms with productions facilities regulated under

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[40] If technologies to remove CO_2 from the atmosphere exist and are employed, some firms may still be able to emit carbon.

[41] Jurisdictions may of course apply policy instruments other than carbon pricing to reduce emissions. However, to the extent that other policy instruments are more costly (OECD, 2013[3]), firms may find themselves in a less competitive position than if they faced a carbon price.

the EU ETS in Europe and unregulated facilities in other parts of the world have increased their asset base more strongly in countries regulated under the EU ETS.

170. Recent studies also find that the carbon prices either do not strongly affect immediate economic outcomes related to the competitiveness of firms, or improve them slightly. In Germany, the EU ETS increased productivity and efficiency for some firms, while most firms' productivity and efficiency is hardly affected by the EU ETS at all (Löschel, Lutz and Managi, 2018[89]; Lutz, 2016[90]). In France, the Netherlands, Norway and the United Kingdom the EU ETS increases revenue and assets for regulated firms (Dechezleprêtre, Nachtigall and Venmans, 2018[12]).

171. The short-term competitiveness neutrality of carbon prices has sometimes been linked to emission trading systems frequently allocating large amounts of permits to manufacturing firms for free; however, even if firms pay more for all of their emissions, as it is generally the case with taxes and the removal of subsidies, similar findings emerge. Increased fossil fuel prices improve productivity for firms located close to the productivity frontier in Indonesia (Rentschler and Bazilian, 2016[91]). Cali et al. (2018[92]) find that increases in fuel prices improve the productivity of manufacturing firms in Indonesia and Mexico. Studying electricity prices, Gerster (2017[93]) shows that manufacturing firms subject to the full surcharge for renewable electricity in Germany did not perform different in terms of output and employment than firms subject to the reduced surcharge only. However, firms subject to the full surcharge substantially reduced electricity use, while firms facing the reduced surcharge did not. Flues and Lutz (2015[94]) find similar performance in terms of turnover, exports, value added, investment, and employment for firms paying the full electricity tax rate compared to firms paying the reduced electricity tax rate only.

172. Aside from any impacts of carbon prices on firms' competitiveness, it is sometimes considered important that carbon prices do not increase overall tax contributions by business, in order to gain their support. There are various choices on how to recycle revenues from carbon pricing (see the earlier discussion on revenue use in Section 6). Some choices keep the incentives to reduce emissions in place. Parts of the revenues from the British Columbia Carbon Tax, for example, lower corporate income tax rates (Murray and Rivers, 2015[13]). This way emitters face the full incentive to reduce emissions because of the carbon tax, while overall tax contributions from business remain at a similar level. Other choices reduce the incentive to cut emissions, as already discussed in the earlier section on permit allocation rules (Section 5). Free allocation of permits, for example, generally lowers the effective average carbon rate that signals the incentives to invest in clean compared to dirty technologies.

9 Administrative considerations

173. Administrative considerations play an important role in designing carbon pricing instruments. The following paragraphs briefly discuss the choice between levying carbon prices via a fuel-based or an emission-based approach. Grau Ruiz (2020[95]) discusses administrative issues in carbon pricing more broadly.

174. Under a fuel-based approach, governments levy the carbon price based on the carbon content of fuels. This is standard for a carbon price resulting from taxes. For excise taxes, the tax rate is generally stated in national currency amounts per litre, cubic metre or another physical unit, which can be recalculated as national currency units per carbon content of the respective fuel (OECD, 2019, p. 76[96]). Carbon tax rates are generally stated in national currency units per unit of carbon, which in turn can be expressed in national currency units per physical unit of the fuel. Emissions trading systems sometimes also follow a fuel-based approach. In this case, emitters have to buy emission permits based on their fuel use, like emitters in the New Zealand ETS (OECD, 2018[1]) or fuel suppliers (for transport fuels and natural gas) in the California Cap and Trade System (California Environmental Protection Agency Air Resources Board, 2019[97]).

175. Under an emission-based approach, governments levy the carbon price on measured emissions. Typically, emissions trading systems rely on an emission based approach. All emitters covered by the system have to measure emissions when released and acquire permits for them. Similarly, with an emission-based tax emitters have to measure their emissions and pay the respective rate, like with the carbon tax in Chile. Given the equipment needed for measuring emissions, emission-based systems generally exclude small emitters below a certain threshold (OECD, 2019[96]).

176. Fuel-based approaches tend to have lower administrative and compliance costs than emission-based approaches. Administrative costs are the costs incurred by the public sector to administer the carbon price. Compliance costs are any expenditures incurred by taxpayers to comply with the carbon pricing regime in addition to tax payment or payment for emission permits. As more or less reporting may be required from either the administration or the taxpayer, it is important to consider administrative and compliance costs together when comparing overall transaction costs of carbon pricing regimes.

177. Pavel and Vítek (2012[98]) report total administrative and compliance costs for the fuel-based approach, that rarely exceed 1% of additional revenue. Administrative cost estimates range between 0.12%-0.34% of additional revenue for the United Kingdom, 0.13% for Germany, and 0.7%-2.7% for the Czech Republic. Compliance cost estimates for the fuel-based approach range between 0.21% of additional revenue in Croatia, 0.23% in the United Kingdom, 0.28%-0.39% in the Czech Republic, and 0.8% in Canada.

178. For the emission-based approach Green at al. (2016[99]) provide estimates for some administrative and compliance costs surveying firms participating in the EU ETS as well as national authorities. Regarding administrative costs, they consider costs related to monitoring plans, improvement reports and emission reports. On average, these administrative costs sum up to about EUR 90’000 per Member State, or about 0.06% of additional revenue. Costs for running permit auctions and the free permit allocation are not included.

179. Compliance costs considered by Green et al. (2016[99]) include costs for monitoring emissions, preparing improvement and emission reports as well as third party verification of the reported emissions. These costs amount on average to about EUR 59’000 per EU ETS facility for the 2014 compliance cycle. At an average permit price of EUR 6 per tonne of CO_2 in 2014 and an estimated share of auctioned permits in total permits of 40%, compliance costs amount on average to 6.7% of additional revenue. Green et al. do not include the costs of acquiring and trading emission permits in their estimates.

180. Green et al. (2016[99]) note important differences in compliance costs based on facilities’ emissions. For low emission facilities compliance costs amount to EUR 3.34 per tonne CO_2, or 140% of additional revenue. Large emitters’ compliance costs amount to EUR 0.07 per tonne CO_2, or 2.9% of additional revenue.

181. Several additional factors impact the administrative and compliance costs independent of whether a fuel-based or emission-based approach is pursued (Pavel and Vítek, 2012[98]). First, administrative and compliance costs are generally independent of the carbon price, which means that a higher carbon price generates lower administrative and compliance costs as a share of additional revenue. Second, costs tend to be lower if the carbon price is collected only from a small number of entities. A fuel-based approach with compliance obligations on fuel suppliers generally requires revenue collection only from a small number of entities. With an emission-based approach, the number of entities tends to be larger, except if it only covers very large emitters. Third, administrative and compliance costs tend to be lower if reporting is tied to an existing base (e.g. an existing fuel tax base) or a base that is already reported for other purposes.

182. In addition to running administrative and compliance costs, it is worth to consider the costs of setting up the monitoring system. A fuel-based approach can often be integrated into exiting excise or sales tax regimes, while an emission-based approach often requires establishing a new monitoring system.

10 Concluding Remarks

183. This paper has considered how to design carbon prices in ways that effectively reduce emissions, do so efficiently and are feasible to implement. The paper has considered the role of carbon price stability for clean investment, ways to support carbon price stability, the emission base to which carbon prices apply, revenue use and ways to generate support from households and companies, as well as administrative choices. The authors hope the paper supports decision makers in making informed choices on carbon price implementation and reform.

184. Carbon prices reduce emissions and encourage clean investment, and a more stable carbon price increases the chances that investors will invest in clean projects, for a given level of the carbon price. A volatile price, in contrast, may lead risk-averse investors to abandon clean projects, even though their expected monetary value is positive. Recent research finds a reduction of 1 to 1.5 percentage points in the capital costs for clean investment projects when the risk of very low carbon prices is eliminated, e.g. through a price floor (Aurora Energy Research, 2018[25]; Roques, 2018[26]).

185. Taxes fix the carbon price. Emitters profit from reducing emissions and investing in clean projects as long as the amount of investment required for reducing emissions is lower than paying the carbon price. Aggregate emission reductions increase with an increase in the carbon price, but the exact amount of emission reductions is uncertain. An ETS, in contrast, fixes the quantity of overall emissions. The permit price is determined by the cost of the marginal abatement needed to reach the cap. As abatement costs are not fully known before setting the emission cap, the permit price is uncertain. While these properties of taxes and emissions trading system affect historic and structural components of carbon price expectations, substantive reforms of any carbon pricing system are hard to predict. This means that long-term carbon price expectations always have to deal with considerable uncertainty, no matter whether they result from taxes or emissions trading systems.

186. With regard to emissions trading systems, an auction reserve price likely offers the most benefits in terms of effectively reducing emissions and doing so efficiently. When it applies to an entire ETS it insures against low permit prices. This leads to immediate emission reductions when permit prices would have been below the reserve price in its absence. In addition, a permit reserve price encourages clean investment by guaranteeing a minimum return in comparison to more dirty investment. In terms of efficiency, an auction reserve price implies the same permit price for all emissions, encouraging investors to exhaust all cheap abatement options. When the auction reserve price applies to only parts of an ETS, it also restricts permit supply when the demand for permits is low, while keeping permit prices equal across the entire ETS.

187. Other mechanisms to support price stability in an ETS include a carbon price support, an emission containment reserve and a market stability reserve. A carbon price support is similar to an auction reserve price when it applies to an entire ETS, but it is less effective and efficient when it applies only to parts of an ETS. By committing to delete permits that are freed up by the support, the effectiveness of a partial carbon price support can be improved. An emission containment reserve behaves in a similar way to an auction reserve price in terms of the directions of its effects, but its effects are more limited in size. A market stability reserve is considerably more complex than any of three instruments above, as it aims to stabilise prices by regulating quantities instead of specifying price thresholds for delivering support. Low permit prices remain a risk with a market stability reserve on its own, however, this risk can be eliminated by combining the reserve with an auction reserve price.

188. If the goal is to generate expectations of a carbon price that increases over time in line with the goals of the Paris Agreement to decarbonise by mid-century, a mechanism that increases current carbon prices at regular intervals is sought. In California and Quebec the auction reserve price increases by 5% plus inflation each year. Similarly, tax rates could be automatically adjusted upward each year. Some countries adjust excise taxes on fuels for inflation, but automatic adjustments to increase tax rates by a certain amount or percentage each year are rare. Alternatively, carbon tax rates can be increased when emission reductions fall short of targets, an approach followed by Switzerland (Swiss Federal Office for the Environment, 2018[62]).

189. Taxes with uniform carbon rates for the entire emission base, and emission trading systems with full permit auctioning, provide stronger incentives for investment in clean technology than taxes with tax-free allowances and emission trading systems with benchmarking, or grandfathering (Flues and Van Dender, 2017[64]). Tax-free allowances, benchmarking and grandfathering affect economic rents, and they tend to do so in ways that favour carbon-intensive technologies.

190. While revenue from carbon pricing can be substantial, its use is currently often constrained considerably. Marten and Van Dender (2019[68]) find that carbon price revenue could exceed two percent of GDP, if all energy-related carbon emissions were priced at least at EUR 30 per tonne of CO_2. Across 40 OECD and G20 countries, more than 80% of total revenue from trading systems faces constraints on its use, and so does close to two-thirds of carbon tax revenue. A bit more than a third (38%) of revenue from excise taxes is subject to a constraint. The case for integrating revenue use decisions with broad tax policy design, rather than separating it (as is the case with labelling transfers as carbon dividends), becomes stronger as carbon pricing revenue raises.

191. When evaluating the impact of carbon prices on households, two questions are generally considered important. First, how do carbon prices affect the affordability of energy, i.e. can every household afford to pay for necessary levels of energy use? Second, how do carbon prices affect disposable income across the entire income distribution, i.e. do poor, middle-income or rich households pay the most? In general, revenue use strongly influences both energy affordability and the distributional impacts of carbon prices. With respect to the first question, recycling one-third of the additional revenue from carbon prices back to poor households is generally sufficient to improve domestic energy affordability. To answer the second question, recycling revenue also helps to make the overall impact of a carbon pricing reform progressive, even if the direct impact of carbon prices on some energy uses, especially heating and electricity use, is often regressive. More generally, governments can choose how (e.g. targeted to poor via the social benefits system, or to all households via tax reform or a lump-sum transfer) and how much of the additional revenue is recycled back to households in order to achieve a desired distributional outcome as well as other policy goals.

192. When evaluating the impact of carbon prices on firms, it is important to remember that carbon prices reduce emissions and improve the competitiveness of clean production methods by shifting rents from dirty to clean technologies. Clean technologies gain from carbon pricing and firms using them are likely to support carbon pricing. Considering that the Paris Agreement requires a net-zero carbon economy by mid-century, the competitiveness of firms will depend upon their ability to produce and use clean technologies in the long-run. Recent studies find that carbon prices either do not strongly affect immediate economic outcomes related to the competitiveness of firms, or sometimes even improve them slightly.

193. Carbon prices can be levied via a fuel-based and an emission-based approach. The fuel based approach levies the carbon price based on the carbon content of fuels. The emission-based approach levies the carbon price based on measured emissions. Fuel-based approaches tend to have lower administrative and compliance costs than emission-based approaches. However, administrative and compliance costs under an emission-based approach are often reasonable for large emitters. Some emissions, such as certain process emissions, may also require measurement when released into the

atmosphere. Fuel-based approaches can often be integrated into existing excise or sales tax regimes, while an emission-based approach often requires establishing a new monitoring system.

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