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Lessons from the Literature for State Carbon Pricing Policy Design

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Executive Summary

In the US, many states have adopted ambitious decarbonization goals for the decades to come. For example, Hawaii, New York, and Maine have set targets to reduce statewide greenhouse gas emissions by 100 percent in the coming decades. In many cases, states have not yet implemented policies that will ultimately achieve these ambitious goals. As states look to do so, many may consider adopting some form of a carbon pricing policy, a tool typically recognized by economists as the most efficient for achieving emissions reductions, as part of a collection of policies to meet state goals.

This literature review offers a comprehensive overview of carbon pricing policy design. It draws on literature from existing carbon pricing programs, simulation modeling for proposed programs, theoretical concepts, and descriptive analyses. It is intended to guide policymakers in establishing carbon pricing programs as well as to identify gaps in the research and suggest next steps. The literature review offers the following key takeaways:

- **Mitigating Leakage**: Carbon pricing policies can create emissions and economic leakage, but policy design options (like a border carbon adjustment or output-based allocation) can be used to mitigate those.
- **Designing for Policy Interactions**: Carbon pricing policies should be designed to work well with other policies to overcome the waterbed effect. One option is price-responsive supply.
- **Addressing Distributional Concerns**: Using revenues in the form of tax breaks or dividends to households can reduce the regressivity of carbon pricing.
- **Garnering Political Support**: Policies that address other local concerns such as air quality or improve social inequities can improve political support.
- **Improving Policy Durability**: Policy sequencing can also be used to build policy support and accelerate technological development.
- **Viable Alternatives**: When carbon pricing is not possible, other pricing policies (such as tradable performance standards) can achieve nearly as efficient outcomes. Many of these other policies can also work well with carbon prices.

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1. Introduction

In the US, many states have adopted ambitious decarbonization goals for the decades to come. For example, Hawaii, New York, and Maine have set targets to reduce state-wide greenhouse gas emissions by 100 percent in the coming decades. In many cases, states have not yet implemented policies that will ultimately achieve these ambitious goals. As states look to do so, many may consider adopting some form of a carbon pricing policy, a tool typically recognized by economists as the most efficient for achieving emissions reductions, as part of a collection of policies to meet state goals.

Carbon pricing can take two main forms: a carbon tax, which places a tax on each ton of carbon dioxide (CO_2) equivalent emitted, or a cap on aggregate emissions (typically labeled cap-and-trade or cap-and-invest), in which emissions allowances are either auctioned or issued to compliance entities and can be traded at a market-determined price. In recent literature and practice, design features for both program types have emerged that aim to make these policies adaptable to changes in costs and emissions reduction opportunities, which, in turn, lead them increasingly to resemble each other. Other policies, particularly sector-specific policies like a clean electricity standard or a tradable emissions performance standard, can be designed to mimic carbon pricing and achieve similar outcomes.

Many countries and certain parts of the United States have some form of carbon pricing policy. The European Union has had a cap-and-trade program (EU Emissions Trading System, ETS) since 2005 covering electricity and industry sector emissions, and many European countries have additional carbon taxes that typically apply to sectors not covered by the cap (World Bank 2020). The European Union is also considering a proposal to make the ETS targets more stringent and to introduce a new, separate trading system to cover transportation and buildings. Other countries with some form of carbon pricing program in place or scheduled for implementation include Mexico, China, Australia, Chile, Argentina, and South Africa. In the United States, cap-and-trade programs are in place in California, Washington State, and the several northeastern states in the Regional Greenhouse Gas Initiative (RGGI).

This literature review offers a comprehensive overview of carbon pricing policy design. It draws on literature from existing carbon pricing programs, simulation modeling for proposed programs, theoretical concepts, and descriptive analyses. It is intended to guide policymakers in establishing carbon pricing programs as well as to identify gaps in the research and suggest next steps.

The review is organized as follows. Section 2 summarizes literature that explains why carbon pricing is considered more efficient under specific conditions than other policies for reducing economy-wide emissions. Section 3 looks at the literature that compares the benefits and drawbacks of the two types of carbon pricing (tax vs. cap-and-trade or cap-and-invest). Section 4 reviews literature related to policy design, such as how to set a tax or cap, options for using the revenue, and auction design under a cap program. Section 5 focuses on macroeconomic effects. Section 6 discusses the distributional effects of carbon pricing and ways to improve outcomes. Section

7 explores issues with “leakage” (shifts in economic activity that cause economic losses in the region affected by the policy and/or an increase in emissions in regions or sectors not covered by the policy) and how to mitigate it. Section 8 looks at the policy interactions between cap-and-trade programs and overlapping policies also designed to achieve emissions reductions or closely related goals. Section 9 considers the political feasibility of carbon pricing and what research shows about overcoming opposition to carbon pricing. Section 10 looks at other real-world challenges, such as how to leverage existing policies in a way that can be beneficial for carbon pricing. Section 11 summarizes alternatives to pricing carbon that could be adopted if opposition to carbon pricing is very strong. Finally, Section 12 identifies gaps in the literature, and Section 13 concludes.

2. Why Carbon Pricing?

Types of Policies

Carbon pricing: Pricing policies that directly target carbon emissions, like carbon taxes and emissions trading programs (in which a carbon price is determined through a market).

Other pricing policies: Pricing policies that typically do not directly target carbon emissions but instead target outcomes that will ultimately lead to emissions reductions, such as promoting low-emitting technologies, alternative fuels, and sometimes energy efficiency when averaged across a performance category. These other pricing policies include tradable performance standards (TPS) of various types, including tradable emissions rate policies, as well as clean energy standards, renewable portfolio standards, and tradable renewable fuel standards.

Nonpricing policies: All policies that do not include a direct price on emissions or closely related outcomes or any form of trading, such as uniformly applied emissions performance requirements, other types of performance requirements, and technology prescriptions and bans. Specific examples include building electrification or energy efficiency requirements, maximum emissions rate standards for new investments, and public investment in electric vehicle charging stations.

In the environmental economics literature, carbon pricing is often established in isolation and then compared with other pricing and nonpricing approaches, including regulatory mandates, to characterize a somewhat stylized situation where a policymaker is choosing one approach or the other. Under specific assumptions set forth in economic theory, including comprehensive coverage with no or limited leakage, carbon pricing is a more efficient approach to reducing emissions than regulatory mandates (Pomerleau and Dolan 2021). Carbon pricing is technology neutral and encourages the lowest-cost reductions across the covered sectors or the entire economy. It minimizes costs by offering entities subject to the policy a choice: either reduce emissions, or pay the price (pay the tax or purchase carbon allowances) to continue emitting. Therefore, in theory, polluting entities will reduce emissions up to the point that their marginal abatement costs equal the tax or allowance price, and thus the policy encourages firms to undertake all cost-effective emissions reductions. Consequently, a carbon pricing policy imposes the same marginal costs on all covered entities. Other regulations, in contrast, may require similar actions or similar performance from all regulated firms regardless of the cost of undertaking those actions or meeting those performance goals.

Carbon pricing policies also create an incentive to conserve energy because they affect the price of fossil energy, which may not be a feature of other regulations (unless they directly target energy efficiency). Additionally, because carbon pricing policies are technology neutral, they encourage innovation and deployment of any clean technologies that will benefit from the policy. Nonpricing policies, in contrast, typically push for a limited set of identified technology types.

When implemented as the sole policy, a well-designed carbon pricing policy prices carbon at the marginal social cost, thus encouraging emissions reductions up to the point that they are socially optimal. Pigou (1920) established that pricing an externality (such as carbon emissions) at the marginal cost of the damages it imposes on society would enable the market to reach the socially optimal outcome by exposing producers and consumers to the full costs of their actions.

In the real world, when carbon pricing is adopted, it always is part of and preceded by a portfolio of policies. One reason is that pricing carbon high enough to achieve the economically efficient level of emissions reductions is difficult to do, and implementing such a carbon price when acting unilaterally is politically and economically unsustainable because of the threat of leakage. Sections 8, 9, and 10 explore several real-world implications of pricing carbon as complicated by policy interactions, political feasibility, and other factors.

3. Carbon Fee versus Cap-and-Trade

Carbon pricing can take two forms: a carbon tax, or a cap-and-trade program—and cap-and-trade can be in the form of cap-and-invest, in which program revenues are invested to advance the goals of the policy. Most literature focuses on cap-and-trade without the investment component, but in practice, most programs have an explicit link to distribution or investment of the revenue raised. In theory, either policy type (tax or cap) could be designed to yield the same outcomes at the same level of efficiency, and in the literature and in practice they increasingly are designed to mimic each other.

In a context with full information and no uncertainty, these policies should achieve similar outcomes because of the way covered firms or individuals are expected to react (Goulder and Schein 2013). Under a cap, firms will reduce emissions up to the point where their marginal abatement costs equal the price of an allowance, and under a carbon tax, firms will reduce emissions up to the point where their marginal abatement cost equals the tax. Thus, both policies will reduce emissions efficiently, with the main difference being how the price is determined (either directly, through a tax, or indirectly, through prices for allowances). Specific emissions reduction outcomes depend on how the tax or cap is set.

Goulder and Schein (2013) also find that the two approaches are more or less similar in their effects on international competitiveness and the need for border adjustments, as well as in their distributional effects (assuming no revenue recycling, though that could create differences in outcomes, depending on the cap-and-trade design).

The two approaches do have important differences in practice, however. These include uncertainty about environmental outcomes and program costs, administrative complexities, and uncertainty about firms' abatement costs.

Goulder and Schein (2013) observe that a cap-and-trade program can be more administratively complex and thus could be more costly to implement than a tax. Yet taxes can also be administratively complex—for example, if they include exemptions or provisions for favorable treatment. The administrative costs of existing cap-and-trade programs have been very small compared with nonpricing policies, however, and are not likely to be much different from administering a carbon tax.

However, taxes can be more difficult to impose than cap-and-trade programs. In the US, imposing emissions taxes typically requires new legislation, whereas implementing a cap-and-trade program may be within the authority of the environmental regulator or another administrative agency. This difference is likely one reason why cap-and-trade approaches are more prevalent in the real world than are carbon taxes.

Goulder and Schein (2013) identify the volatility of allowance prices, as evidenced by the EU ETS experience, as a downside of a cap-and-trade program. Volatile emissions outcomes are likely an analogous disadvantage of a carbon tax. However, a cap-and-trade program can be designed to limit the volatility of prices that may drive emissions reductions either up or down, making it more like a carbon tax, and conversely, a carbon tax can have adjustment mechanisms that respond to changes in emissions. These design options are discussed in the next section.

Another difference in these policies involves the ease with which they can be linked with approaches in other states. The advantages to linking programs across jurisdictions include reductions in leakage and administrative costs, resilience to changes in energy demand and fuel supply disruptions, and cost savings overall. However, linking may also lead to a shift in the location where emissions reductions and new investments are achieved, which can be viewed critically by some parties (Mehling et al. 2018; Burtraw et al. 2013). A cap-and-trade program in one region can be easily linked to another regional program (Stavins 2020) because it requires only coordination in regulatory design and trading of allowances across regions. (One example: in recent years Virginia and New Jersey have joined the RGGI program, greatly expanding the RGGI market.) A carbon tax, in contrast, would by nature be specific to the jurisdiction. Interstate coordination on tax levels is politically challenging because it involves legislative outcomes.

The academic debate over which approach is better focuses largely on ability to deal with real-world uncertainties and a policy's robustness to those uncertainties. In "Quantities vs. Prices," Weitzman (1974) argued that a price-based instrument like a carbon tax would likely be a better tool for addressing pollution emissions than cap-and-trade if there is relatively greater uncertainty about firms' marginal abatement costs than about marginal benefits of emissions reductions. Karp and Traeger (2018) revisit this famous paper and suggest that its conclusions may not be accurate because Weitzman focused on flow pollutants rather than stock pollutants, like greenhouse gas emissions, that stay in the atmosphere for many years. To address that difference, they use a dynamic programming model and find that taxes are not necessarily superior to cap-and-trade because of the technological uncertainty across multiple periods that Weitzman (1974) failed to account for, and that in fact, cap-and-trade might better accommodate technological uncertainty.

4. Policy Design

This section relies on theoretical literature and lessons from existing programs to inform states of the best practices for designing a robust carbon policy. Most considerations depend on the policy type—carbon tax or cap-and-trade.

4.1. Carbon Tax

4.1.1. Setting the Tax

A critical decision a state would face in implementing a carbon tax[1] is how to set the initial tax, how it escalates over time, how far into the future to set the tax, and how the tax rate responds to changes in the economic or political spheres. In addition, policymakers would need to decide which sectors to cover, and the point of compliance (e.g., fuel suppliers or consumers). In theory, the tax should be set equal to the marginal damages of carbon pollution to correct the externality and achieve the socially optimal market outcome (Pigou 1920). In practice, estimating marginal damages is challenging and depends on the approach taken. Using another method to set the tax may be more practical.

The social cost of carbon is an estimate of the marginal damages of carbon pollution. The estimate heavily depends on two crucial assumptions: what discount rate to apply to future damages, and which damages to include. At the federal level, the Interagency Working Group, a collaborative effort among the Department of Energy, the Environmental Protection Agency, and other executive branch agencies, periodically publishes updated estimates of the global social cost of carbon with various discount rates. The current federal central estimate of the social cost of carbon is $51 per ton in 2020, assuming a 3 percent discount rate is applied to future damages (IWG 2021). The federal estimate is under review currently, and most observers expect it to be increased, perhaps substantially, because of a more comprehensive assessment of climate impacts as well as potentially a different discount rate.

Estimates of the social cost of carbon have evolved considerably and are expected to continue to do so. Economic theory continues to evolve as well. A literature rooted in public finance suggests that the efficient carbon price may be below the marginal social cost because of interactions of the carbon price with preexisting distortions that make the economy less efficient, such as preexisting taxes (Goulder 2013). Subsequent literature has invoked other efficiency-reducing distortions in the tax code, such as the home mortgage interest deduction, to conclude that the tax price should be greater than the measure of social cost (Parry and Bento 2000). Conversely, the literature on directed technological change suggests that the optimal price may be above marginal

1 A carbon tax could cover other greenhouse gas pollutants if their emissions are calculated in CO_2-equivalent terms.

social cost, to create incentives for innovation and investment to overcome the barriers embodied in legacy infrastructure. (Acemoglu et al. 2012).

Another way to set a carbon tax is to estimate a carbon price level that targets a certain level of emissions reductions by basing the prices on marginal abatement costs instead of the marginal damages reflected in the social cost of carbon. Kaufman et al. (2020) estimate CO_2 prices for the year 2030 for the United States using a targeted emissions approach: they select a net-zero emissions date of 2050 and an emissions trajectory to that date, and then use these targets as inputs in energy-economic models to estimate a series of CO_2 prices that would achieve these reductions. They find that to reach a net-zero target by 2050, the US should price carbon at between $34 to $64 per ton in 2025 and ramp up to $77 to $124 per ton in 2030.

4.1.2. Addressing Uncertainty

A carbon tax provides a higher level of cost certainty at the expense of a lower level of certainty about emissions reductions. A carbon price is typically anticipated to increase in nominal terms over time. To address uncertainty about the emissions reductions, a recent literature has suggested that the tax change over time to reflect changes in emissions targets, abatement costs, or effects of the tax on the economy, among other things. Kaufman et al. (2020) suggest regularly updating the estimates. Aldy (2020) also proposes a framework in which a carbon price is updated every five years to keep up with changing environmental and economic conditions.

Hafstead and Williams (2020) explore the option of incorporating a tax adjustment mechanism in a carbon tax program to provide more certainty about emissions reductions. This mechanism would automatically adjust the tax in response to emissions. For example, if emissions reductions are lower than expected, then the tax would adjust upward according to a predetermined formula. Using simulation modeling, Hafstead and Williams (2020) find that the use of a tax adjustment mechanism can greatly reduce emissions uncertainty and increase the chance that the carbon tax policy hits its target. The Swiss carbon tax, for example, has a tax-adjustment mechanism in place, and the mechanism has been triggered several times since the tax’s inception in 2008. The tax rose in 2014, 2016, and 2018 in response to high emissions, and will rise again in 2022 because 2020 emissions triggered the mechanism.

4.1.3. Evidence from Real-World Experience

Many European counties have carbon taxes that generally apply to fossil fuel uses not covered by the EU ETS. Of these, Sweden has the highest carbon tax (about $137 per metric ton in 2021), followed by Switzerland and Lichtenstein ($101.47 per metric ton) (World Bank 2021). Other European countries, Ukraine among them, have very low carbon prices, at only a few cents per metric ton.

Sweden's carbon tax, which mainly covers emissions from fossil fuel use for transportation and buildings, is a case study for estimating the effects of implementing a carbon price that is close to the DEC estimate of the social cost of carbon. Studies have found that Sweden's carbon tax has reduced emissions across both sectors. Andersson (2019) uses transportation emissions data from 1960 to 2005 and compares Sweden's average emissions per capita after the introduction of the carbon tax with the average emissions per capita of a synthetic control group of 14 developed nations with a similar emissions trajectory but no carbon price. The results show that transportation emissions in Sweden fell by 11 percent annually after the adoption of a carbon price relative to the control group; 6 percentage points were attributed to the carbon price.

Historically, a carbon tax on the transportation sector has caused a switch from gasoline cars not to electric cars but to slightly more fuel-efficient diesel cars—an unintended effect for which Nadirov et al. (2020) found evidence in 17 European countries from 2013 to 2017. Andersson (2019), too, found that Sweden's emissions reductions from the carbon tax came primarily from fuel switching from gasoline to diesel, and the proportion of diesel cars grew substantially after the tax's introduction in 1991 through the end of the sample in 2005. A carbon tax that encourages a switch to diesel may not reduce CO_2 emissions by much and could also result in more air pollution at the local level.

Such an outcome is less likely to occur in the United States, however, for several reasons. First, diesel fuel is more heavily taxed here than gasoline. As of July 2021, federal taxes and fees for diesel fuel were 6 cents per gallon higher than for gasoline (EIA 2021). Additionally, the United States imposes stricter regulations on local air pollutants, particularly nitrogen oxides (NO_x), than Europe, which has less stringent standards for diesel vehicles (Nesbeit et al. 2016). Lastly, the European carbon taxes have, in some countries, been in place for several decades, and implementing a carbon policy today would likely have different effects because consumers have more alternatives to gasoline vehicles, like hybrids and electric vehicles.

Runst and Thonipara (2020) look at the effects of the Swedish carbon tax on the residential sector and estimate that the tax has reduced emissions from home energy use by about 800 kg per capita relative to countries without a carbon tax, and by about 200 kg per capita relative to countries with a carbon tax larger than 20 euros. The study also finds that the carbon tax is more effective than other policies in encouraging consumers move away from electric resistance heat. For instance, based on policy evaluations the authors cite from the Odyssee-Mure Database, the carbon tax is estimated to have encouraged conversion to heat pumps more effectively than subsidies for heat pumps (and also better than subsidies for renewable fuels, district heating, or solar heating); the researchers note that heat pump sales skyrocketed in the early 2000s, when the carbon tax was increasing sharply. They suggest that a carbon tax can be effective at reducing emissions from the residential sector if it exceeds 120 Euros,[2] and that the level of the tax ultimately determines its effect.

2 As of October 2021, 120 euros is approximately $140.

4.2. Cap-and-Trade

A cap-and-trade program typically has more design features than a carbon tax and may therefore be more administratively complex. As with a carbon tax, cap-and-trade program design must identify which sectors to cover and the point of compliance. Other important elements of design—some of which likewise have analogues in carbon tax policy—are the level of the cap, its trajectory, rules on banking and borrowing, and the allocation of emissions allowances . This section describes findings from the literature on each of these features.

4.2.1. Cap Level and Trajectory

Setting the cap and the trajectory of that cap will depend on the area, sectors covered, current emissions levels, and political considerations and preferences.

The International Climate Action Partnership (2021) provides a comprehensive overview of how best to design a cap-and-trade program. The two main options are top-down and bottom-up. The top-down approach bases the cap on policy objectives, and the bottom-up approach bases a cap on feasibility based on each covered sector's potential to reduce emissions.

Caps can also be absolute (measured in tons) or intensity-based (measured in tons per unit of output, such as per megawatt-hour of electricity). Over time, the cap typically becomes more stringent, so policymakers must determine the trajectory and decide how far into the future to go.

One important consideration when choosing a cap level is balancing ambition with costs of the program. The International Climate Action Partnership (2021) advises that the cap, which will impose higher costs on covered sectors the stricter it is, should be both environmentally stringent and economically fair, and may affect competitiveness in the region.

The report also highlights the information needed to set a cap, which is similar to the information needed to set a carbon tax if fairness and competitiveness are taken into account: historical emissions and economic data, projections for a business-as-usual case, estimates for the technical feasibility of reductions in both covered and uncovered sectors, and, to avoid extremely high compliance costs, estimates of the marginal abatement cost curves of covered sectors.

4.2.2. Banking and Borrowing

A cap-and-trade program can be designed to allow for intertemporal banking (allowances can be banked for use in future compliance periods) and borrowing (allowances can be borrowed from future compliance periods for use in the current compliance period).

The International Climate Action Partnership (2021) describes the benefits of including banking and borrowing provisions in a cap-and-trade program. Banking can reduce price volatility by enabling entities to hold allowances rather than sell them in a market with low prices, and it can also better ensure that short-term climate targets are met because emissions allowances are banked for future use rather than used in the current period. Banking also creates support for continuation of the program: entities that bank allowances will support continuation of the program so that the banked allowances remain valuable, thus creating a coalition and making the policy more durable.

Borrowing similarly increases the flexibility of the policy, particularly if entities can reasonably achieve reductions in the future but, because they need to invest in technological upgrades, not in the present. However, the International Climate Action Partnership (2021) notes that borrowing can be risky: it can increase emissions in the current period and could make it more difficult to achieve short-term targets. Unlike banking, borrowing could create support for ending the program because, having borrowed against future allowances, entities will have to comply with stricter requirements in subsequent periods. However, programs that set a declining cap over time achieve some of the benefits of borrowing for the program as a whole: they allow more emissions in the near term and thereby limit near-term costs and postpone greater reductions to the future. One way to implement borrowing with tight constraints is through multiyear compliance periods, as one observes in the RGGI and California emissions trading programs.

Kuusela and Lintunen (2020) simulate economic welfare under an emissions trading scheme and show that a policy that includes banking, but not borrowing, can be welfare improving relative to both a carbon tax and a policy without banking.

Banking has been used in the EU ETS, RGGI, and California cap-and-trade programs. Looking at decades of experience with cap-and-trade, Schmalensee and Stavins (2017) assert that the EU experience demonstrates the importance of allowance banking. In the first period, the EU ETS did not allow banking, and the allowance price dropped significantly—to near zero at the end of the first compliance period—when the number of allowances that had to be used was very high relative to total emissions. The second and third periods, which did allow banking, saw more price stability.

4.2.3. Allowance Allocation

Allowances in a cap-and-trade program can be auctioned or distributed for free to specific polluters (with the assumption that firms will trade among themselves). Although allowance allocation shouldn't affect the emissions outcomes, it can affect the cost-effectiveness of the program, among other things. For example, distributing allowances for free can be enticing for political reasons, but free allocation can limit transparency about costs and limit market trading, and inefficient pricing may result (Burtraw and McCormack 2017).

Burtraw and McCormack (2017) explore how consignment auctions can be used to better allocate free allowances to prevent inefficient outcomes and improve program transparency. They propose that firms that receive free allowances be required to participate in a revenue-neutral consignment auction in which they either auction off their allowances to others or buy back their own. With a consignment auction, the revenues are returned to the entities that received the allowances for free in proportion to their share of all allowances sold in the auction. By enhancing price transparency, the use of a consignment auction can improve efficiency more than a program in which allowances are distributed for free with no price-revealing auction. By nesting free allocation within a consignment auction, the regulator can enforce a price floor in the auction—as in the current California carbon market for allowances allocated to utilities. This feature was also an element of the US sulfur dioxide trading program.

A drawback of free allowance allocation (or a consignment auction) is that it does not provide revenue. A regular allowance auction, on the other hand, provides revenues that, like a carbon tax, can be used for various purposes (Section 6).

In RGGI, the primary method for initially distributing allowances has been through auctions, which have generated several billion dollars since 2009. Hibbard et al. (2018) estimate that from its inception through 2017, RGGI auction proceeds (totaling $2.7 billion) led to $4.7 billion in economic benefits in RGGI states. The revenues supported strategic energy investments, including energy efficiency upgrades.

Auction design for the RGGI market is detailed in Holt et al. (2007) as recommendations prior to the program's inception that were later adopted. RGGI's uniform price auctions, in which winners all pay the same price for allowances, are held quarterly, and some allowances of later vintages are auctioned in prior periods to help inform the market about future price expectations. A crucial feature is the reserve price, which helps limit price manipulation by large buyers. This reserve price, which represents a price floor, also provides a mechanism to support the allowance price when technology improves and marginal costs fall, ensuring that this improvement maps into additional emissions reductions.

4.2.4. Addressing Uncertainty

With cap-and-trade programs, compliance costs are uncertain and may fluctuate. For example, both the RGGI market and the EU ETS have seen low prices, often influenced by outside market conditions, such as the 2008 financial crisis, and other policies. In every market for atmosphere resources, prices have been lower than initially expected through most of the programs' duration and have often fallen in real terms (Burtraw and Keyes 2018).

Options for controlling prices in a cap-and-trade program include a price ceiling, which sets an upper bound for allowance prices if they rise too high, and a price floor, which sets a lower bound if allowance prices dip too low. Ensuring that allowance prices do not drop to zero helps support a minimum level of emissions reductions. In allowance markets, price floors and ceilings are practically implemented through reserve prices that serve as a minimum acceptable price for all or some tranche of allowances.

Economists have explored other options for controlling costs under cap-and-trade. Roberts and Spence (1976) described a hybrid of a carbon tax and emissions trading approach to address uncertainty. In "Quantities with Prices," Burtraw et al. (2020) build on this idea to introduce a price-responsive supply curve for allowances, in which the number of available allowances is adjusted up or down to counteract extreme prices. In this framework, a price-responsive supply curve contains costs and emissions in two ways. First, an emissions containment reserve, in which allowances are withheld from the market, is triggered if prices fall too low and is intended to ensure that emissions reductions are achieved. Second, a cost containment reserve keeps costs from rising too high by releasing more allowances to the market if prices rise above a certain threshold. Burtraw et al. (2020) show through proofs, laboratory simulations, and electricity system modeling that this price-responsive supply approach improves market efficiency when costs of abatement are uncertain.

Burtraw et al. (2017) explore the application of an emissions containment reserve that was being proposed for the RGGI market. They model an allowance supply curve as a step-wise, price-responsive supply curve with one step, three steps, and a ramp to account for unexpected changes in demand. In these cases, if demand falls and the price dips to the level of the reserve trigger price, allowances would be removed from the market, much the way that allowances remain unsold when the price falls to the price floor. They find that such a reserve, if implemented in the RGGI market, would mitigate some of the "waterbed effect," whereby reduced demand for allowances in one area lowers the price of the allowances, which then increases demand for allowances elsewhere in the covered region—with no positive effect on emissions.

5. Macroeconomic Effects

An economy-wide carbon policy will raise the costs of carbon-intensive goods and services and thus will affect the economy broadly. The extent to which economic activity is affected depends on many factors, including the stringency of the policy, which sectors are covered, and how revenues are used. Some studies that have looked at the macroeconomic effects of carbon pricing rely on empirical evidence from existing programs; others are based on simulation modeling.

McFarland et al. (2018) look at the effects of US economy-wide carbon pricing on GDP growth. They use several models and project the effects under four carbon price scenarios, starting at $25 or $50 per ton in 2020 and escalating at either 1 percent or 5 percent annually, and a reference case. In some scenarios, the carbon prices rise quite high, with one reaching $216 per ton by 2050.

In all scenarios, the addition of a carbon price does not significantly affect economic growth relative to the reference case, with only a very slight estimated reduction in economic growth in all cases; this slight reduction grows with the carbon price. Although economic growth was slightly lower than the reference case across the board (and not by very much), the models notably do not include the economic effects of climate change, which are expected to be more costly in the reference case than in the policy scenarios; their inclusion would affect the growth trajectories.

In all cases, McFarland et al. (2018) find that the average annual growth rate from 2015 to 2050 is positive with carbon pricing in place for all scenarios (above 1.9 percent annually, even in the most aggressive policy scenario) and is mostly similar to its reference baseline trajectory, deviating only about 0.1 percentage point. They also find that the use of revenue does not significantly affect the growth rates in most models. For the few exceptions, they observed that using the revenue to reduce capital taxes showed slightly higher economic growth relative to a household rebate or labor income tax credit. In some cases, the models showed that use of a capital tax swap led to higher economic growth relative to the reference case.

Metcalf and Stock (2020) use empirical evidence from 30 years of experience with carbon pricing programs in Europe to estimate the effects on the economy. They look at 31 European countries that are part of the EU ETS, of which 15 countries have additional carbon taxes for emissions not covered by the ETS. They estimate the effect of the carbon pricing policies (separate from the ETS) on GDP growth and on employment and find no evidence that the policies have had a negative effect on either GDP growth or employment.

British Columbia's experience with a carbon tax since 2008 similarly provides useful lessons for evaluating the effects of a carbon pricing policy on emissions and the economy. The tax, which started at $10 per ton in 2008 and rose to $30 per ton in 2012, covers all fossil fuels consumed in the province (roughly 70 to 75 percent of all greenhouse gas emissions). It is estimated to have reduced emissions in the province by 5 to 15 percent with little effect on the economy (Murray and Rivers 2015). Yamazaki

(2017) finds that the provincial program also increased employment by a statistically significant amount of 0.74 percent annually from 2007 to 2013, relative to a baseline growth rate without the tax.

Hafstead and Williams (2018) look at employment effects of a carbon price in both covered and uncovered sectors. This study uses a two-sector general equilibrium model and assumes a $20 per ton carbon tax under alternative scenarios for revenue use: lump-sum rebates to households (equal payments, typically total revenue divided by number of eligible households), and a reduction in payroll taxes (to balance the government budget). The study finds that a carbon price reduces employment in covered sectors, but that employment increases in the uncovered (nonpolluting) sectors, and therefore the net effect on overall unemployment is negligible.

In a study focused on a statewide carbon pricing policy, Hafstead et al. (2019) look at policy options (carbon pricing options and nonpricing options that target specific sectors, and both in combination) for helping Vermont reach its decarbonization goals of 26 to 28 percent below 2005 levels by 2025. They find that under all carbon pricing policy scenarios and combinations, the effects on employment, economic growth, and economic welfare are minimal.

A carbon price will also affect energy prices. Cronin et al. (2019) find that a price of $25 per metric ton of carbon would increase commodity fuel prices by 27 percent, 44 percent, and 133 percent for petroleum, natural gas, and coal, respectively, relative to 2017 prices, assuming the tax is 100 percent passed through to fuel prices.[3] Metcalf (2007) sees a lesser effect on fuel prices but assumes a lower tax ($15 per metric ton); this study was conducted when natural gas prices were higher. He finds that a $15 carbon tax would increase fuel prices by 13 percent, 6 percent, and 91 percent for petroleum, natural gas, and coal, respectively, relative to 2005 average prices.

Durable carbon pricing policies can also have positive effects on private investment, which is beneficial for economic growth. Prest et al. (2021) use simulation modeling to understand how option value—the value of waiting to make an investment decision—plays a role in investment decisions. They find that a carbon price, even at a modest level, provides a strong signal of policy durability, which encourages firms to make clean investments. The investments, in turn, could lead to short-term economic growth and further reduce emissions. This effect is typically ignored in most economic modeling analyses of carbon tax effects, which assume certainty in both a baseline scenario with no carbon tax and a policy scenario that includes a tax.

3 These percentages would likely be different today due to changes in fuel prices. In the US in 2021, for example, assuming the dollar value per unit increases resulting from the $25 carbon tax do not change, the resulting increases in fuel costs would be 18 percent, 10 percent, and 86 percent for oil, natural gas and coal, respectively. Average 2021 fuel prices are from the US Energy Information Administration, Short-Term Energy Outlook (Jan 11, 2022). **https://www.eia.gov/outlooks/steo/report/prices.php**

6. Distributional Consequences of Carbon Pricing

Carbon pricing policies raise the costs of carbon-emitting energy. Because lower-income households spend a higher proportion of their incomes on energy than wealthier households, the burden of the policy can be regressive: lower-income households are disproportionally affected by the increases in energy costs. However, carbon pricing also affects industries, which characteristically are owned by households in the highest income groups. Consequently, a carbon price that adversely affects industry profits could also have progressive effects, where the burden of the policy would fall disproportionally on upper-income households.

Studies offer various perspectives on when carbon pricing policies are regressive or progressive, but an overall lesson from the literature is that the decision about what to do with carbon revenues has a greater influence on the regressivity or progressivity of a carbon price than the direct influence of the price.

Studies have found mixed results on whether carbon prices are regressive or progressive, depending on which effects they focus on and, importantly, on the use of revenues. Williams et al. (2015) and Wang et al. (2016) both find evidence for regressive effects on households when revenue is not recycled. Wang et al. (2016) also find disproportionate effects on energy-intensive industries, relative to other industries.

Other studies have found the opposite—that carbon pricing can be progressive (Beck et al. 2015; Metcalf 2019; Cronin et al. 2019). What differentiates these studies from those above is the effects they focus on. Looking at British Columbia, Beck et al. (2015), for example, say that even without revenue redistribution to households, a carbon price can be progressive because the effect of the policy depends more on the household's source of income than its expenditures, and higher-income households that own stock in more carbon-intensive industries would be harmed more than lower-income households. Goulder et al. (2019) show evidence of both effects and look at the distributional consequences through what they call "source-side" impacts, which include effects of the policy on capital and wages, and "use-side" impacts, which include effects of the policy on goods and services. They find, consistent with other studies above, that the policy has progressive effects on the source side and regressive effects on the use side.

To the extent that a policy is found to be regressive, studies have shown that the revenue raised by the policy can be used to offset its adverse effects. Notably, however, a cap-and-trade program with free allowance distribution would not raise revenue, so these options are available only for a carbon tax or for a cap-and-trade (or cap-and-invest) program that auctions allowances.

Options for reusing revenue include reducing capital taxes, making lump-sum rebates to households, and reducing taxes on labor income. Williams et al. (2015) find that both lump-sum rebates and reductions in income tax make the policy more progressive, but that reducing the labor income tax by the same percentage across income groups is more efficient than making lump-sum rebates. Burtraw et al. (2009) explore other options, like expanding the earned income tax credit (increasing the credit for eligible households with earned income below a certain level) and cap-and-dividend approaches (returning a lump-sum payment to households). They find that these options make the policy more progressive.

Another distributional consequence to consider in connection with cap-and-trade policies is equity: what are the implications of trading for vulnerable communities? If allowances can be traded, and if emissions increase in vulnerable areas, those communities could be disproportionally harmed by higher emissions of local air pollutants highly correlated with CO_2 emissions.

To date, studies based on existing cap-and-trade programs have not found evidence that they increase co-pollutants in disadvantaged communities. Studies focused on the RECLAIM program in Los Angeles (Fowlie et al, 2012) and California's cap-and-trade program (Walch 2018, Hernandez-Cortes and Meng 2020) find no significant evidence that those programs have negatively affected disadvantaged communities. In fact, Hernandez-Cortes and Meng (2020) find evidence that the program reduced inequities of air pollution between disadvantaged and other communities. Walch (2018) also suggests that the California program may have caused co-pollutants to decrease in disadvantaged communities. In Europe, while Stuhlmacher et al. (2019) find that phase 2 of the EU ETS program did lead to more clustering of emissions from industries, these eventually fell with stricter emissions caps.

While empirical evidence suggests that cap-and-trade programs may not negatively affect disadvantaged communities, ensuring that emissions are reduced equitably is an important consideration for policymakers. Notably, as evidenced by the EU ETS experience, the extent of any adverse distributional environmental outcomes likely depends on how stringent the cap is. If the cap is not very stringent and allowance prices are low, then presumably emissions from some plants could increase because they can comply by buying allowances from other entities that reduce emissions elsewhere, and the cap could still be met. If the cap is stringent, however, allowance prices will be higher and incentives to reduce emissions will be stronger at all plants, increasing the likelihood that emissions fall in more locations and presumably reducing the occurrence of higher emissions of local air pollutants in certain locations. It is also possible, however, that emissions fall in disadvantaged communities, but that they fall by less than they do in other less-polluted communities, which represents another form of inequity.

Some studies have proposed solutions for addressing these equity concerns. Boyce and Pastor (2013) suggest incorporating cobenefits into analyses of climate policies, particularly in the treatment of locational emissions. In climate programs, one ton of CO_2 is treated equally in all locations, but that ton of CO_2 is usually associated with other copollutants that have different locational effects, depending on local air quality. Boyce and Pastor (2013) therefore suggest that climate policies aim to reduce emissions in areas where the cobenefits are greatest. They believe this can be done in numerous ways, such as differentiating by sectors (certain industries, like manufacturing, have the highest copollutants), incorporating copollutants into CO_2 permits and enforcing a “trading ratio” (where some permits are worth more than others), or using program revenues to mitigate copollutants in certain high-risk communities.

7. Leakage

Carbon reduction policies can cause a shift in economic activity to areas outside the regulated jurisdiction, leading to an increase in emissions in regions or sectors not covered by the cap. Because of such leakage, reduced emissions are partially displaced by increases in emissions elsewhere. Leakage is a serious problem that diminishes the effectiveness of a policy and undermines efforts to reduce emissions.

Several studies see leakage from existing programs. Fell and Maniloff (2018) find evidence of leakage in the RGGI program because increased coal generation in surrounding states offsets roughly 25 percent of the RGGI emissions reductions. Similarly, Caron et al. (2015) find that without any restrictions on imported electricity into California, the California cap-and-trade program would have increased out-of-state emissions in neighboring states by an amount about equal to 45 percent of the in-state reductions. However, as Caron et al. note, this amount falls to 9 percent because California makes electricity imports subject to the cap and prohibits resource shuffling. Leakage could also be an issue in RGGI as states add regulations to reduce emissions from electricity producers. Shawhan et al. (2019) find that the emissions containment reserve feature of RGGI coupled with a policy to address emissions from imported power would help reduce emissions leakage to other states if New York implemented carbon price set at the social cost of carbon in its wholesale market, as proposed by New York Independent System Operator.

Leakage can also describe a shift economic activity. Casey et al. (2020) studied the effects of a hypothetical carbon price of $10 on manufacturing output, employment, and profits in the Northeast and Mid-Atlantic states using data from 1982 to 2011. They found that the hypothetical policy reduced manufacturing employment in the regulated region, to the benefit of neighboring regions.

As evidenced by experiences of both California and RGGI, emissions leakage can reduce the effectiveness of a regional policy. Two of the design options to mitigate potential leakage from a cap-and-trade policy are a border carbon adjustment and output-based allocation.

A border carbon adjustment (BCA) addresses leakage resulting from trade with regions not covered by the policy. A BCA can be designed to address just imports, just exports, or both. Droege and Fischer (2020) explore options for designing a BCA through either taxing imports or relieving exports of their obligation to pay the carbon fee, or both—something that is under consideration in the European Union.

The International Carbon Action Partnership (2020) also offers recommendations for designing a BCA to avoid leakage from carbon pricing: keeping a BCA administratively simple, which makes it more feasible from a legal perspective as well, and setting standard emissions benchmarks for products rather than using separate emissions intensities for different countries.

Although a BCA is considered a potential solution to leakage, little empirical work has been done to explore whether it would be successful, and some modeling studies suggest otherwise. Fischer and Fox (2012), for example, model a $50 per ton tax in the United States with various combinations of border carbon adjustment policies for trade with Canada: a border tax on imports, a border rebate for exports, both together, and a home rebate, which would apply to all domestic production, not just exports. They find little evidence that any of the proposed methods would reduce leakage and as a result are unable to rank the options. Moreover, they find that the policies would be controversial and legally challenging to implement. Importantly, policy in Canada has evolved significantly since the date of the Fischer and Fox study, with the country committing to a nationwide carbon price as a backstop to provincial policies that would have to be at least as stringent as the backstop to escape coverage under the national price..

A concern for any type of border adjustment for a state is the Dormant Commerce Clause of the US Constitution, which precludes state regulation of interstate commerce. States have been able to navigate this constraint by implementing policies in a neutral way and treating in-state and out-of-state commerce in a like manner. California's accounting of emissions associated with imported electricity is intended to conform with this constraint by treating imported power the same way as in-state generation. This can be complicated by the challenge of assigning emissions intensity or a specific generator with electricity imports. The state has cleverly managed to assign most imported power to specific emissions sources, and the residual that cannot be specifically assigned is given a default emissions intensity value that does not disadvantage the power relative to in-state generation sources.

Compliance with the Commerce Clause domestically, or with the World Trade Organization internationally, has similar implications. An alternative to BCA at the international level, proposed by Neuhoff et al. (2016), could be relevant for states considering carbon pricing policies: an excise fee ("climate contribution") would be applied to materials and basic industrial goods independent of their origin, whether inside or outside the state. This uniform treatment would avoid Commerce Clause concerns. The fee, calibrated to the emissions intensity of the materials, would increase the cost of using these materials and encourage recycling, reuse, reduction in use, and the introduction of alternatives. It would also generate revenue that might, for example, be invested in promoting low-carbon materials.

Another option for reducing leakage is an output-based allocation method, in which allowances under a cap-and-trade program are initially distributed to polluting resources covered by the cap based on their level of production in the state. This approach can be applied either directly to allowances or to the allocation of revenue from auctioned allowances. By making allocations of valuable allowances contingent on how much a firm produces, the output-based allocation approach creates an incentive to produce in the state and therefore reduces the effect of the cap-and-trade program on product prices, helping the regulated industries stay competitive. In addition to covering electricity imports under the cap to prevent leakage, California's program has also updated output-based allocation of emissions allowances in the industrial sector to provide a production incentive to forestall shifts in economic activity that can result in emissions leakage. Burtraw et al. (2017) explore output-based allocation and find that it can be effective at reducing leakage.

The empirical literature addressing leakage due to carbon pricing has primarily been focused on the European Union, which, like California, freely allocates emissions allowances to the industrial sector based on output. Several studies abroad find little or no evidence of leakage under this regulatory approach (e.g., Naegele and Zaklan 2019). The disadvantage of output-based allocation is that carbon revenue is not available for investment or other uses.

8. Policy Interactions

States looking to implement carbon pricing often already have many existing and proposed environmental policies that target emissions and will remain in place. Examples include clean electricity standards and incentives for clean transportation and building decarbonization, such as rebates for electric vehicles and charging stations and for energy-efficient equipment in buildings. These policies can achieve goals beyond carbon reductions. For example, they can address other market failures, such as insufficient incentives for innovation, and could pair well with a carbon price.

The effect of interactions between other policies and a new carbon pricing policy depends on the design of the carbon pricing policy. First consider cap-and-trade with a fixed cap. If the allowance supply does not respond to changes in prices and is not subject to regular updating, the cap will dictate the level of emissions reductions. If other policies—say, a renewable portfolio standard (RPS) for electricity or a clean fuel standard for transportation—reduce emissions from a sector or region covered by the cap, those reductions free up allowances for use by other sources, thus leaving overall emissions unchanged (Goulder and Schein 2013). This is the waterbed effect (Section 4.2.4). In such a case, the other policies—pricing or nonpricing—reduce the carbon price, not overall emissions. In practice, cap-and-trade programs are subject to review, and allowance supplies are typically adjusted in response to changes in prices. Consequently, low allowance prices resulting from lower demand for emissions allowances could lead to a change in the cap over the long run as the cap evolves with program reviews and updates. However, the other policies to reduce emissions would likely not change the short-term emissions outcomes.

Now suppose a carbon tax. The other policies can lead to additional emissions reductions because aggregate emissions are not capped (Goulder and Schein 2013).

Given that most jurisdictions use a cap-and-trade approach instead of a direct price on carbon, and that most jurisdictions with carbon pricing policies also have other policies to promote clean energy, the issue of overlapping policies is important. Overlapping policies can affect how emissions reductions are achieved, and they will likely increase costs relative to pricing carbon alone (Palmer and Burtraw 2005). For example, an RPS drives investment in renewables and may tilt emissions reductions toward a strategy of substituting renewables for fossil fuels, bypassing potential lower-cost emissions reductions from substituting more efficient gas generators for less efficient ones. With no RPS, compliance with the cap could come from less expensive alternatives.

Burtraw et al. (2018) look at policy interactions in RGGI, California, and the EU ETS. In RGGI, they observe that companion policies, including energy efficiency and renewable energy requirements, have reduced emissions and thus the demand for allowances, which has reduced allowance prices. Costs per ton of avoided CO_2 of these other programs have been high compared with RGGI prices as well. To help counteract the waterbed effect, RGGI has implemented an emissions containment reserve (Section 4.2.4) that reduces allowance supply when prices fall below a certain threshold. RGGI also has a price floor, which enables additional emissions reductions when other policies significantly reduce demand for allowances.

California has similarly seen low allowance prices relative to the costs of compliance with its many other regulations (Burtraw et al. 2018), which include an ambitious RPS of 60 percent renewable electricity by 2030, a low-carbon fuel standard, and vehicle fuel efficiency standards. These complementary policies have similarly led to allowance prices that are lower than they would be otherwise.

Borenstein et al. (2019) analyze California's cap-and-trade program in the context of the companion policies that require emissions reductions at sources also covered by the trading program. The authors describe historical variation in economic activity and associated emissions. Because regulated sources under a cap may already be reducing emissions by complying with other regulations, the authors suggest that predictable variation in economic activity will likely lead prices in the trading program to gravitate to either the ceiling or the floor. Empirically, the allowance price has remained modestly above the price floor through most of the program, with brief exceptions during periods of regulatory uncertainty.

Fischer et al. (2017) look at the interactions among climate policies using an electricity sector model. They find that complementary policies targeting other market failures, such as innovation failures and insufficient R&D, can be welfare-improving when coupled with a carbon price. However, in the absence of additional market failures or other policy goals that the carbon price cannot address (e.g., technological diversity, equity across different groups), the study finds that additional policies can reduce societal welfare.

In summary, complementary polices can have advantages if they address market failures other than the environmental externality, such as suboptimal levels of innovation. Further, as we describe in Section 10, complementary policies may be fundamental in enabling the ultimate introduction of carbon pricing. However, complementary policies that also target emissions reductions will reduce the demand for allowances under a cap, thereby reducing the allowance price and possibly increasing demand for allowances elsewhere, resulting in no environmental benefit in the short term. RGGI, California, and the EU ETS provide evidence that this has occurred to various degrees. Consequently, design features for cap-and-trade programs that help mitigate these effects are important to the success of carbon markets; one such feature, an emissions containment reserve, is now being implemented in the RGGI market and will remove 10 percent of participating states' allowance budgets if the price falls below $6 in 2021 (the price threshold increases at 7 percent annually), or a price floor of roughly $2 that prevents allowance prices from falling too low.

Notably, the challenges mentioned here would not arise for a carbon tax policy. A tax would likely better allow for companion polices because emissions reductions are not fixed. For example,if there is a statewide tax on fossil fuels and municipalities require buildings to reduce their energy intensity, both policies will drive emissions reductions, not a reshuffling of emissions from one sector to another. The challenges might also not apply if the cap-and-trade program is so stringent that industries cannot meet the requirements and have to pay the fine for noncompliance. Then the program essentially becomes a tax, and the other policies would spur additional emissions reductions.

9. Political Feasibility

Any climate policy, even the best-designed carbon pricing policy, cannot be adopted without political support. Carbon pricing can be unpopular; a proposed policy in Washington State, for example, failed multiple times before finally being adopted in 2021. Several studies have sought to better understand why the public is resistant to carbon pricing and how to improve its political feasibility.

Results from a national survey of US adults show that 62 percent of Americans responded in favor of a carbon tax when asked if companies should be charged for their greenhouse gas emissions (Krosnick and MacInnis 2020). This percentage is much lower than support for other policies, like giving tax breaks to clean energy (83 percent) or to power plants that lower greenhouse gas emissions (81 percent).

Carbon pricing increases energy costs, and those increases trickle through the economy, so presumably people would be more receptive to a policy that provided a dividend payment from the revenue collected to help offset those higher costs. Surprisingly, Krosnick and MacInnis (2020) found no evidence of greater support for a carbon tax (applied to companies) with a dividend. Asked whether they would support a carbon tax with dividend amounts of $200, $600, or $800, roughly 60 percent of respondents favored a carbon tax regardless of the amount of the dividend—or even the presence of one.

Although a higher dividend may not make a policy more popular, several studies have found that the perceived fairness of a policy is vital for popular support. Maestre-Andres et al. (2019) review literature on the perception of carbon pricing policies (both cap-and-trade and carbon taxes) around the globe and find that people are concerned about potential inequities (particularly the effects on lower-income groups) and that support for a policy is correlated with the perception that the policy is more progressive in terms of costs. Counterintuitively, though, the study showed that people tend to favor the government's use of the revenues for green investments, such as renewables, over dividends that would make the policy more progressive and ease concerns about fairness. The authors suggest that the best way to make a policy more popular is to combine reinvestment in environmental projects with redistribution of the portion of the revenue.

Ewald et al. (2021) provide a survey case study of Sweden, which has had a carbon tax for years. Even though Swedes are generally very concerned about climate change and typically trust their government, some people are resistant to carbon pricing and have participated in protest movements, similar to the Yellow Vest movement in France. Researchers surveyed protestors who opposed petrol taxes and found that the biggest factors correlated with resistance to carbon pricing were educational background, rural residence, and most importantly, a distrust in government. Like Maestre-Andres et al. (2019), Ewald et al. (2021) also found that respondents were more supportive of the government's using carbon pricing revenue for climate projects rather than for redistribution to households.

Klenert et al. (2017), which reviewed extensive literature on the political feasibility and distributional effects of carbon pricing, found that for gaining political support, context matters. For instance, they find, if distributional concerns are the greatest barrier, then revenue should be used for dividends. If the main opposition comes from concerns about economic competitiveness, however, then the policy is more likely to gain support if the revenue is directed toward firms.

Aldy (2017) provides recommendations for increasing support for carbon pricing and strengthening its durability. He recommends starting with a modest policy that ramps up in stringency over time, gradually easing the public toward a more robust policy. He also recommends updating the policy in response to changing economic or environmental conditions. He observes that linking with programs in other states or regions can improve price stability and reduce potential leakage. He also suggests that overlapping polices can depress the costs of a carbon pricing policy and might make it more palatable to the public.

Goulder (2020) reviews various approaches to making carbon taxes more politically acceptable, including different ways to use the revenue. He suggests that if these approaches accelerate implementation of such policies, that those effects should be factored into assessments of policy cost-effectiveness—that is, to reflect this political reality and make explicit the value to society of acting sooner rather than later.

10. Other Real-World Challenges

In an economist's ideal world, a carbon pricing policy—in principle, the most efficient option for reducing carbon emissions—would be the primary lever to reduce greenhouse gas emissions. In the real world, however, carbon pricing policies stringent enough to align with state or national emissions reduction goals are difficult to implement. To the extent that competitiveness issues result in leakage, it is possible that economic activity could move to jurisdictions with greater emissions intensity. Moreover, carbon pricing rarely is introduced in a market that does not already have existing environmental policies for reducing emissions.

Some research suggests that given the variety of obstacles to ambitious and comprehensive carbon pricing, introducing other policies could help create the preconditions for more stringent, more comprehensive carbon pricing. Indeed, in every case where carbon pricing now exists, it was preceded by various regulatory policies, which typically remain in place and are often strengthened even after carbon pricing is adopted.

One reason companion regulatory policy may enable carbon pricing is the positive feedback loop associated with introducing environmental regulations, including support for new technology. Kelsey (2014) calls this a "green spiral"—the idea that climate policies will benefit certain groups (e.g., clean energy suppliers) and harm others (e.g., fossil fuel interests), thereby encouraging growth in the industries that benefit from the policies, which, in turn, will enhance support for those policies over time. Similarly, changes in technology costs make possible greater policy ambition.

Policy sequencing—the introduction of other policies and gradual ratcheting up of their stringency to pave the way for carbon pricing—is one method for increasing the role of carbon pricing over time. Meckling et al. (2017) describe the policy sequencing process undertaken in California, the European Union, and the RGGI states as a three-step process: first, a green industrial policy stage, where low-carbon technologies are supported; second, the addition of carbon pricing policies; and third, the reform of pricing policies to increase their stringency. They note, however, that these jurisdictions mainly experienced these stages only in their electricity sectors.

In California, sector-based policies like fleet emissions technology standards and the RPS paved the way for the state to adopt the more stringent cap-and-trade program (Pahle et al. 2018). Meckling et al. (2017), pointing to California's experience with policy sequencing and early support for renewables like solar, argue that such policies reduced technology costs by enabling learning-by-doing and economies of scale. Over time, the cap has been tightened and the program has been expanded from just electricity and some industrial sources to transportation and home heating as well. California has also designated at least 35 percent of auction proceeds to be spent on programs to benefit disadvantaged communities, and at least 25 percent to be invested in those communities. In practice, more than 50 percent of revenues has been dedicated to these purposes, creating support for the cap-and-trade program that otherwise would be visible in low-income communities primarily through higher energy prices. Another form of companion policy in California is air quality regulation, which delivers near-term benefits while coincidentally encouraging energy efficiency and a shift away from fossil fuels.

Pahle et al. (2018) describe Germany's experience with breaking down economic barriers to carbon pricing through investments in technology. Germany promoted renewable energy early in the 2000s through feed-in tariffs, and this policy enabled learning-by-doing and cost reductions for renewable technologies, especially solar. When the feed-in tariffs became too expensive, Germany switched to an auction-based program for distributing technology subsidies, which reduced the costs of subsidies and enabled the program to grow.

Policy sequencing can also help overcome political resistance barriers to carbon pricing (Section 9). Meckling et al. and Pahle et al. suggest that implementing policies with different tools and stringency levels in different sectors (Section 11) may ease opposition to policies that reduce emissions while providing broad signals that influence investment throughout the economy. For example, in sectors where current options to reduce emissions are limited by the high cost of low-emitting technologies, a modest carbon price, coupled with complementary policies to invest in technology development and deployment, might grow emerging industries that become advocates over time for greater stringency, improving the durability of the policy as well. Policy durability is important because it provides a market signal for the private sector to make long-term investments in technologies that will benefit from the policy.

11. Flexible Policy Alternatives to Carbon Pricing

In some instances, resistance to carbon pricing may be so strong that the state is unable to implement such a policy. In that case, other types of flexible pricing policies focused on sectors can still be beneficial and, in some cases, nearly as efficient as carbon pricing. Although they imply a smaller change in product prices than carbon pricing (because of their relative inefficiency in affecting channels for achieving emissions reductions in a nonuniform way), this can be an advantage for addressing both distributional and leakage concerns.

Research suggests that a clean electricity standard, which requires that a certain percentage of electricity sales come from zero or low-carbon resources, can mimic the efficiency of a carbon price, especially if crediting is based on emissions rates rather than on technology type: the former enables the policy to encourage marginal reductions within technology types as well (Paul et al. 2014). In general, partial crediting of natural gas, based on emissions intensity, could improve efficiency of the policy by encouraging fuel switching from coal to gas (to the extent that coal plants are still in operation) and from less efficient gas plants to more efficient gas plants. Picciano et al. (2020) show through electricity sector simulation modeling that a higher emissions intensity benchmark, or one that partially credits higher-emitting technologies, can raise the potential for emissions reductions, and those reductions can also be achieved at a lower cost.

Outside the electricity sector, tradable performance standards (TPS), which target either average performance of covered entities or emissions intensity, have been used in the transportation and building sectors in a variety of ways and can be an effective alternative or, in some cases, complement to carbon pricing.

Four prominent approaches used for transportation in North America are the corporate fuel economy (CAFE) standards and renewable fuels standards at the federal level, and zero-emissions vehicle standards and low-carbon fuel standards at the state level. Yeh et al. (2021) find that although TPS policies are less efficient than a carbon price overall, they provide targeted outcomes promoting technological change. For instance, in California, which has simultaneous carbon pricing on transportation fuels and a low-carbon fuel standard, a change in consumer prices for gasoline caused by the low-carbon fuel standard yields 10 times greater incentive for innovation than the same change caused by a carbon tax. A disadvantage of the low-carbon fuel standard, however, is that it raises no revenue. The researchers find that TPS policies also pair well with a carbon tax to encourage innovation.

Building performance standards (BPS), which can be structured as a type of TPS to reduce emissions mainly from commercial and large residential buildings, are being implemented in cities in many countries but are still relatively recent, so studies on their experiences are limited. Among the studies of best practices for designing a BPS, Bugnion and Palmer (2020) explore options for implementing a BPS for buildings above a certain square-footage threshold. To make the policy more efficient, they suggest including flexibility mechanisms, such as opportunity to trade across buildings, multiyear compliance periods that allow for banking, and the option to use offsets to achieve compliance. Bugnion et al. (2021) also look at options for implementing a BPS for federal buildings across the country. The authors suggest using a building-specific target (a building reduces emissions against its own baseline) rather than a common target, which could make implementation easier for a program encompassing buildings in different climate zones with different energy use patterns.

TPSs can also be designed to target industrial emissions. A standard could set carbon intensity requirements for industrial facilities, rewarding those that outperform with credits and penalizing those that underperform by requiring them to purchase credits (Fischer 2019). Gonzales et al. (2020) find substantial potential for policy-driven emissions reductions in iron and steel, cement, and petrochemicals—good candidates for a clean energy standard taking the form of an efficiency standard, a feebate, or a tradable performance standard.

In most sectors, direct pricing of emissions at politically feasible levels would likely go only partway toward achieving decarbonization goals. Other flexible policy options, such as a TPS, could be nearly as efficient and also pave the way for a greater reliance on carbon pricing in the future.

12. Gaps in the Literature

We see gaps in the literature that may be important to the policy design decisions that decisionmakers face in considering a carbon pricing policy to help achieve decarbonization goals. These include studies on cap-and-invest programs, the extent to which complementary technology policies lead to lower costs, and the sequence of technological changes that will result from pricing policies that drive decarbonization.

One reason for carbon pricing programs' appeal to governments is that they generate revenue, which can be invested in programs that contribute to achieving the policy goals. Indeed, both California and several RGGI states invest allowance revenues in carbon-reducing projects—high-speed rail in California, and energy efficiency upgrades to reduce electricity demand and emissions leakage in RGGI states (Burtraw and Sekar 2014). In the European Union, guidelines direct member states to invest at least 50 percent of auction proceeds in climate-related programs (Löfgren et al. 2018).

Cap-and-invest—a cap-and-trade policy implemented with an auction that raises revenue for climate-friendly investment—is not well studied in the economics literature. However, a separate and extensive economics literature has analyzed public sector investments: when they make sense, and how to think about their costs, given the economic costs of raising public funds. An important aspect of this literature concerns when such public investment helps spur learning or cost reductions that enable ("crowd in") future private sector investment and when it "crowds out" private investment, typically a situation to be avoided.

Another gap in the existing literature is how technology policies, and especially investments in infrastructure, contribute to technology development and forms of learning that lower costs or accelerate private investment. For example, the decline in renewable costs over the past few decades coincides with a surge in policies to promote renewables in the United States and parts of Europe, but the extent to which cost declines are directly attributable to which policy is still in debate (Gerarden 2018).

The most salient aspect of this literature gap is the lack of guidance on where and how to cost-effectively direct investments to accelerate an energy transformation. Without systematic overview, policymakers must rely on sector-specific strategies to advance industrial transformations.

A related gap involves the practical implementation of pricing policies that will drive deep decarbonization of the US economy in the face of the various constraints we have identified. Although some studies have evaluated strategies to reduce emissions, including specific technology changes and assumptions about human behavior, the tools used to develop these pathways do not incorporate markets or market equilibrium considerations and thus are not useful for understanding macroeconomic implications, anticipating the effects on specific product and fuel markets, or optimizing the technology pathway (Ribera et al. 2015). Studies that do incorporate markets typically do not have enough technological specificity to identify pathways for infrastructure investment (e.g., Hafstead et al. 2019).

13. Conclusion

Carbon pricing is an efficient approach to reducing emissions, but stringent, comprehensive carbon pricing faces several obstacles, especially at the state level. Nonetheless, a modest carbon price that by itself would be insufficient to achieve ambitious climate goals could be coupled with sector-specific regulatory policies to drive technology and social changes that may enable a greater role for carbon pricing over time. A crucial limitation to regulatory policies is the information asymmetry between private actors (firms) and the regulator, making it difficult to design perfect regulations; a modest carbon price gives the private sector incentives to look for emissions reductions and ensures that the state leaves no low-cost emissions reductions behind, even as it aims for more ambitious goals. This report provides a comprehensive overview of literature on carbon pricing design and related considerations to help decisionmakers in designing state climate policy.

Our main findings are as follows:

- In theory, a carbon tax and a cap-and-trade policy produce similar outcomes, but they differ in important ways. Carbon taxes provide certainty about compliance costs and are less likely to interact negatively with other polices, but the emissions outcomes are uncertain. Cap-and-trade programs provide more certainty over emissions reductions and can be more easily linked to other regional programs, but they are more likely to interact with other policies and, if not well designed, could mitigate the effectiveness of those other policies.
- Carbon pricing policies can create emissions leakage and economic leakage, but policy design could substantially mitigate the problem.
- If part of a portfolio, carbon pricing should be designed to complement other policies and avoid the potential waterbed effects of a cap-and-trade policy. Price-responsive supply of emissions allowances is emerging as an approach to accomplish this goal.
- The effects of carbon policy on low- and moderate-income households can be mitigated with revenues from the carbon pricing policy. Additional uses of the revenue include investing in clean technologies and offsetting impacts on industries, which can play an important role in achieving program goals.
- Garnering political support for carbon pricing in the United States is challenging, but developing a policy that benefits a range of constituencies and helps address other social concerns, like local air quality and social inequities, could help.
- Policy sequencing can be used to accelerate technological development as well as to build support to ratchet up the stringency of the carbon policy.
- Implementing a carbon price that is sufficient to achieve the climate policy goals is not possible in many jurisdictions today. However, policymakers can achieve nearly as efficient outcomes by beginning with other pricing policies that provide incentives for technology change and investment, such as tradable performance standards. As the policy landscape evolves, these policies tend to build technology, infrastructure, and political support for carbon pricing. Generally, other pricing policies and carbon pricing can be designed to work well together.

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