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Chapter 4. Economic Considerations: Cost-Effective and Efficient Climate Policies

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In this chapter we discuss the economics of climate change. We begin with a discussion of economic considerations that are important to take into account when designing and evaluating climate policy, including cost effectiveness and efficiency. We then discuss specific policies at the state, national, and international level in light of these economic considerations.

We have several recommendations for the path forward for climate policy. First, the goal of climate policy should be to reduce the damages caused by greenhouse gases. In addition to mitigation policy to reduce greenhouse gas concentrations in the atmosphere, one can also reduce the damages caused by greenhouse gases by adaptation measures that reduce our vulnerability to climate change impacts.

Second, policy-makers should use incentive- (or market-) based instruments as opposed to command and control policies (including quantity-based mandates) whenever possible. Whenever unpriced emissions are the sole market failure, incentive-based instruments such as a carbon tax or cap and trade program are more likely to achieve the social optimum and maximize social net benefits [1, 2]. Lin and Prince [3] calculate that the optimal gasoline tax for the state of California is \$1.37 per gallon.

Our third recommendation is to address the risk of emissions leakage, which arises when only one jurisdiction (e.g., California) imposes climate policy, but not the entire world. One way to reduce emissions leakage is to use the strategic distribution of emissions allowances to local producers. This method, known as “output-based allocation” or benchmarking, effectively subsidizes local producers and at least partially offsets the increase in their costs caused by an emissions cap [4]. Importantly, only local production is eligible for an allocation of valuable allowances, providing a counterweight to the incentive for emission leakage.

Our fourth recommendation is that if they are used instead of incentive-based instruments, quantity-based mandates such as the federal Renewable Fuel Standard, California’s Low Carbon Fuel Standard, renewable portfolio standards, and the Clean Power Plan should be combined with a cost containment mechanism. The findings of Lade, Lin Lawell and Smith [5] suggest that pure quantity-based mechanisms leave policies susceptible to large increases in compliance costs, particularly in the presence of capacity or production constraints that are inherent in energy markets. Given the experiences with the federal RFS2 in 2013, anticipating and designing climate policies in a way that can contain compliance costs is imperative.

Our fifth recommendation is that for international leverage, we should develop a climate club backed by border tax adjustments to non-participants. University of California at Berkeley Professor Larry S. Karp has been proposing an agreement between the top 10 emitters as an alternative to the UN framework [6]. Without international leverage or cooperation, unilateral climate policies, such as California’s AB 32 or the American Clean Energy and Security Act, are not only unlikely to fully combat climate change, but can also have other detrimental effects such as the reduction of economic competitiveness and the possible displacement of jobs from the U.S. to countries without carbon pricing [7].

Our final, and main, recommendation is that, as University of California at Berkeley Professor Severin Borenstein points out, California should focus on solving the problem of *global* climate change. The primary goal of California climate policy should be to invent and develop the technologies that can replace fossil fuels, allowing the poorer nations of the world – where most of the world’s population lives – to achieve low-carbon economic growth [8].

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Introduction

In this chapter we discuss the economics of climate change. We begin with a discussion of economic considerations that are important to take into account when designing and evaluating climate policy. We then discuss specific policies at the state, national, and international level in light of these economic considerations. We conclude by suggesting a path forward for climate policy.

Economic considerations when designing and evaluating climate policies

All undergraduate economics students, whether in the University of California system or elsewhere, are taught that under certain conditions, perfectly competitive markets maximize social welfare and therefore do not require any government intervention. However, as many real-world markets do not satisfy the idealistic assumptions required, agents in many real-world markets make decisions which lead to suboptimal social outcomes. There are numerous and well-studied types of market failures, but in the context of global climate change, two types of market failures reign supreme: negative externalities and public goods.

Negative externalities arise when individual agents do not internalize the full cost of their activities. In the absence of climate policy, individual consumers and firms do not pay for the negative effects of their greenhouse gas emissions on the environment and economy. This results in a socially inefficient large amount of greenhouse gas emissions.

The second major market failure, public goods, arises when a good in question is non-excludable and non-rival. Non-excludability means that no one can be technically excluded from the consumption of the good (e.g. national defense). Non-rivalry means that one agent's consumption does not diminish the amount of the good left over for everyone else (e.g. radio waves). If a good is public, it is both non-excludable and non-rival, and markets underprovide the good and in some cases do not provide this good at all. The public goods problem arises in two important ways in the context of global climate change. The first good related to global climate change that has public characteristics is emissions abatement. If one country (or state) abates its emissions, all other countries (or states) also benefit from the reduction and cannot be excluded from these benefits. This results in an under provision of emissions reductions by individual countries, which is consistent with the outcome of the United Nations climate change conferences. The second good related to global climate change that has public characteristics is innovation. If one private firm obtains a technological breakthrough in a renewable energy technology, unless intellectual property rights are well defined and enforced, other firms can copy the technology and capture some or all of the innovating firm's profits. This leads to an underinvestment in innovation.

Owing to market failures related to global climate change, well-designed government policy is important for addressing global climate change. In their study of the wind industry in Denmark, which has the highest wind

share of total electricity consumption in the world, Cook and Lin Lawell [9] find that the growth and development of the Danish wind industry was primarily driven by government policies rather than technological improvements.

In order to determine the optimal level of policy intervention when market failures exist, basic economic theory mandates that one compare the benefits from a proposed policy to its costs. Regulators in many places are mandated to calculate a ratio of the benefits to the costs (often referred to as the "benefit-cost ratio") and only pass policies when this ratio is strictly greater than one. In the case of climate change, calculating this ratio is especially complex as damages occur globally and over a very long time horizon, while the costs of mitigation are incurred much earlier and in their majority by a small number of countries or regions. Hence localities often compare local benefits to local damages when deciding whether to pass climate policies, when fundamentally this is a global problem with a corresponding global benefit-cost ratio.

In addition, since the benefits and costs of climate change policy occur over a very long time horizon, the appropriate measure of benefits is not the current benefits but rather the present discounted value of the entire stream of benefits over many years. Similarly, the appropriate measure of costs is not the current costs, but rather the present discounted value of the entire stream of benefits over many years. Calculating the present discounted value of benefits and costs requires using an appropriate discount rate. Moreover, since both investments in abatement technology and the damage from climate change are irreversible, there is an option value to waiting that should be accounted for in a dynamic optimization framework when comparing benefits and costs.

Estimating the benefits of greenhouse gas reductions is a complex undertaking and it is worth outlining what is required to arrive at a number. What one wants to calculate at a given point in time is the global damage from one more ton of emitted carbon dioxide equivalent. This number is called the "social cost of carbon" and has recently been estimated by an interagency working group and is currently being reviewed by the National Academies of Sciences. In order to calculate this number, one uses so called "integrated assessment models" of climate change, which are coupled climate-economy models, one of the most significant of which is the Climate Framework for Uncertainty, Negotiation and Distribution (FUND) model by David Anthoff and Richard Tol. These models estimate the impact of an additional ton of CO₂ on global radiative forcing. Using simple regional or global sectoral damage functions, the models then translate increases in radiative forcing into economic damages over time, which for most models is until the year 2100 or 2300. The damages from this additional ton of greenhouse gases are then discounted into present value terms to arrive at the social cost of carbon. The models differ greatly in their representation of the climate, sectoral detail, damage functions, and discounting. Even when varying the discount rate alone, the range in the social cost of carbon is large, ranging from \$12 to \$117 per metric ton of CO₂ in 2015 [10]. The current "official" number used by US regulators is \$43, which

is more than three times the traded value of permits on the California market and more than five times that of the value of permits on the European exchange (ETS).

While the social cost of carbon measures the marginal damage of emitting a ton of CO₂ equivalent (or the marginal benefit of avoiding its emission), there are significant other benefits to greenhouse gas reductions, which stem from the fact that the combustion of fossil fuels results in the emissions of greenhouse gases as well as other local and regional pollutants. There is a large literature on quantifying these co-benefits at the sectoral level. For many policies these co-benefits are a significant or in some cases the main portion of the benefits from greenhouse gas regulation. Importantly, the type and value of co-benefits from greenhouse gas regulation varies drastically across countries. As work by Veerabhadran Ramanathan's group has shown, reducing the combustion of biofuels and fossil fuels not only has significant local impacts in terms of improved health, but also has large scale positive impacts on local climate as black carbon is a highly potent, yet not long lasting greenhouse gas [11]. The quantification of these local co-benefits through their direct pollution impacts on health and agriculture as well as their indirect climatic effect through black carbon and aerosols are an area of active research.

The direct and indirect benefits of climate policies in terms of their impact on human health are especially important as climate change is now considered the biggest global health threat of the 21st century [12]. Over 150,000 deaths annually are attributed to ongoing climatic changes, and this toll is expected to grow by 250,000 additional deaths per year between 2030 and 2050 [13].

Deschênes and Greenstone [14] find that for the United States, each day of extreme heat (days where the average temperature exceeds 90 °F) relative to a moderate day (where the average temperature lies between 50–59 °F) raises the annual age-adjusted mortality rate by about 0.1. These results, combined with predictions from the Hadley 3 A1FI climate model and scenario, suggest that climate change will lead to approximately 63,000 additional deaths annually in the United States at the end of the century, or a net 3% increase in the annual mortality rate, assuming no adaptation. Similar detrimental effects of temperature extremes on infant health (measured by birth weight) are reported in Deschenes, Greenstone and Guryan [15]. Thus, in absence of an effective policy to curb greenhouse gases, the U.S. faces significant health risks as the climate continues to warm.

One aspect in which the University of California is a global leader in research is the estimation of damages from climate change. Cramer et al [16] synthesize the scientific literature on the detection and attribution of observed changes in natural and human systems in response to observed recent climate change. For policy-makers and the public, the detection and attribution of observed impacts will be a key element to determine the necessity and degree of mitigation and adaptation efforts. Key problems for current assessments include the limited availability of long-term observations, limited knowledge on processes and mechanisms involved in changing environmental systems,

and widely different concepts applied in the scientific literature. In order to facilitate current and future assessments, Stone et al. [17] describe the current conceptual framework of the field and outline a number of conceptual challenges. Based on this, in Stone et al. [17] propose workable cross-disciplinary definitions, concepts, and standards in order to serve as a baseline for continued development of a consistent cross-disciplinary framework that will facilitate integrated assessment of the detection and attribution of climate change impacts. Huggel et al. [18] propose framing the attribution problem with a more integrated risk concept. Auffhammer et al. [19] provide a brief overview of climate models and discuss two common and significant errors often made by economists when climate model output is used to simulate the future impacts of climate change on an economic outcome of interest. Auffhammer and Vincent [20] show that unobserved time effects confound the identification of climate change impacts.

An accurate measure of the social cost of carbon should include all costs of carbon and all climate change damages, both direct and indirect, including economic impacts, agricultural impacts, health, property loss, deaths, changes in frequency of extreme weather events, infrastructure costs with rising sea level, climate refugees, intra- and international conflicts, accelerated extinctions, loss of biodiversity, and loss of ecosystem services.

Another challenge is to quantify the costs of greenhouse gas regulation, which in the economic literature is called the estimation of abatement cost curves. In theory, each firm which reduces its emissions of greenhouse gas incurs a cost to do so. It can choose to reduce its emissions by producing less output, using new technology, or switching to lower carbon content inputs. A firm will compare the costs of each strategy, and the least cost approach to reducing its emissions at each level of output is called the firm's abatement cost curve. Since much of this information is private to the firm, regulators can have a difficult time determining what the true costs of abatement for a firm is. Anticipating a new policy, firms have no incentive to reveal the true abatement cost, yet have every incentive to exaggerate the costs of abatement. Hence, as the regulator attempts to determine the benefit-cost ratio, there is significant uncertainty about the cost component and regulators often have to rely on simplistic engineering calculations or educated guessing.

In order to design an optimal global climate policy, two market failures have to be addressed simultaneously. First, from a global perspective, since there is no global enforcer of a possibly agreed to climate policy by all countries, individual countries will underprovide abatement or simply not agree to follow or join an international agreement of cutbacks. This will lead to an ineffective global agreement on emissions reductions, which will fall short on what is required to stay under a maximum of 2 degree Celsius warming. One example of a failure of this approach is the largely ineffective Kyoto protocol. At COP 21 in Paris later this year, instead of attempting to pass one globally binding agreement, individual countries will propose individual cutback plans up front which they agree to enforce. In order to work, this type of agreement

will need to rely on climate “clubs”, which are regimes with small trade penalties on non-participants, to coordinate emissions reductions that are enforced with border tariffs [21].

The second market failure that needs to be addressed is the general externality problem once countries have agreed to an emissions target. In order to reduce emissions to address the externality there are two types of approaches: (1) command and control and (2) incentive- or market- based approaches. Command and control approaches come in three flavors generally. The first type is an emissions standard, which simply prescribes quantity emissions targets for an emitter. The second is an input target, which prescribes which type of input to production an emitter has to use. An example of this is a low carbon fuel standard. The third type is a technology standard, which prescribes a specific technology (e.g. electric vehicles).

Incentive-based approaches come in three flavors. The first is an emissions fee/tax, which charges an emitter the marginal external cost and makes the emitter internalize this cost. Hence the emitter is paying for the full opportunity cost of its activity. The second is a cap and trade system, which caps the total amount of emissions and issues a right to pollute for each ton emitted, which can then be traded. This approach essentially places a price on carbon as the permits have a price. The final incentive-based approach is subsidizing certain low carbon technologies or fuels, which artificially lowers their price in the market and increases the incentive for adoption.

In order to determine which policy should be used, two criteria are usually applied by economists for evaluating policy: cost effectiveness and efficiency. For a given emission reduction, a policy is cost effective if it achieves this reduction at least cost. A policy is efficient if it maximizes net benefits, or total benefits minus total costs. From an economy wide perspective, cost effectiveness and efficiency make sense as one would not want to spend scarce resources on meeting policies in an unnecessarily costly manner. Carbon taxes and cap and trade both have been shown to achieve this goal of efficiency time and time again. In contrast, command and control policies have been shown to be very costly ways of meeting a given emissions target.

One argument often raised in support of standards is the fact that they are more fair or equitable than price based policies. Under a standard, sources usually are subject to similar reduction targets, which is perceived to be fair. However, price based policies can be made more equitable as they generate significant revenue, which can be redistributed to increase fairness, all while minimizing the cost of the emissions reductions. These revenues can also be used to address the innovation market failure, whereby tax revenue is used to enable research in promising future low carbon technologies. One such example is research on carbon sequestration and storage, which carries a hefty price tag in the billions of dollars for each experiment. Such large scale projects are almost impossible to fund by the private sector, and thus are likely to be a good place for the regulator to step in.

Below we discuss specific policies at the state, national, and international level and how they satisfy the desirable features of good policy outlined above. We conclude by suggesting a path forward for climate policy.

California’s climate policy

California has been a global leader in environmental policy since the early 1970s. Many states and countries have adopted versions of regulations designed and implemented in the state. California is the eighth-largest economy in the world [22], but only ranks 20th in terms of greenhouse gas emissions, accounting for less than 2% of global emissions [23]. In California, the transportation sector is responsible for a disproportionately large share of the state’s greenhouse gas emissions, close to 40% [24].

Climate change is likely to affect California’s energy consumption and hence carbon emissions. Auffhammer and Aroonruengsawat [25] simulate the impacts of higher temperatures resulting from anthropogenic climate change on residential electricity consumption for California, and find that, holding population constant, total consumption for the households considered may increase by up to 1 to 6% by the end of the century. An increase in electricity consumption will increase energy costs to California residents and will likely also increase greenhouse gas emissions and further exacerbate climate change.

Concerns in California regarding climate change have been reflected in law since 1988, when by Assembly Bill 4420 [26] the California Energy Commission (CEC) was directed to study the impacts of climate change on the state as well as to develop the state’s first greenhouse gas inventory and provide policy recommendations. After the establishment of a voluntary registry scheme which started operations in 2002, one of the most important milestones in California climate policy came in 2002 when the passage of Assembly Bill 1493 [27] triggered the opposition of automakers and the subsequent involvement of the US Environmental Protection Agency (EPA). This bill required the California Air Resources Board to develop and adopt regulations to reduce greenhouse emissions from passenger vehicles, light-duty trucks and other non-commercial vehicles sold in California [28].

In September 2006, Assembly Bill 32 (AB32), the California Global Warming Solutions Act of 2006,¹ required the California Air Resources Board (CARB) to define strategies to achieve statewide greenhouse gas emissions at or below the 1990 levels by 2020 and 80 percent below 1990 levels by 2050 [29]. By passing AB32 in 2006, California became the first sub-national US entity to establish a statewide enforceable target on total greenhouse gas emissions.

Greenhouse gas mitigation strategies from a scoping plan adopted by the California Air Resources Board include vehicle greenhouse gas standards, a low carbon fuel standard, regional transportation targets, energy efficiency for electricity and natural gas, a renewable portfolio standard, and increases in combined heat and power generation [28, 30].

In its implementation of AB 32, CARB and other agencies adopted a combination of regulations and subsidies,

as well as establishing a cap-and-trade system. The cap-and-trade program establishes an aggregate cap covering approximately 85% of California's greenhouse gas emissions, and a system of tradable emissions permits that regulated facilities may use to meet their compliance obligations. The program covers emissions for the years 2013–2020, and is partitioned into three compliance periods. Beginning in 2013, emissions obligations were assessed on industrial facilities and first deliverers of electricity to the California grid. Emissions associated with fossil transportation fuels and retail sales of natural gas were included in 2015, at the start of the second compliance period. The third compliance period runs from 2018 through 2020 [24].

Several attributes distinguish California's cap-and-trade program. First, the established cap co-exists with other complimentary/competing policies directed at capped sectors, such as transportation fuels and electricity generation. Second, the program allows for a limited amount of greenhouse gas "offsets," a mechanism that has potential for achieving reductions beyond capped sectors, but can also be prone to credibility concerns [31]. Third, the cap-and-trade market features relatively tight price-containment measures that can constrain prices within a relatively narrow range of \$12 to \$60 per ton of CO₂ equivalent. This last feature is particularly important given the experience with other carbon markets around the world, which have experienced both volatility and periods of very low prices [32]. Building on the emissions forecasting work in Auffhammer and Steinhauser [33] and Auffhammer and Carson [34], Borenstein et al. [24] find that the combination of multiple regulations, such as energy efficiency programs and renewable energy requirements with a market-based regulation such as cap-and-trade increases the likelihood of extreme price outcomes in the cap-and-trade market. One implication is the importance of a robust price-containment mechanism that can ensure a relatively stable carbon price in order to long-run investment in carbon reduction technologies.

One last distinguishing characteristic of California's climate policy is the risk of emissions "spill-overs" into neighboring jurisdictions. These concerns are not unique to California nor to cap-and-trade regulations specifically. A common problem is emissions "leakage" whereby economic activity is shifted from regulated jurisdictions to unregulated ones in order to avoid the costs of emissions caps or other regulations. Jurisdictional limits present a fundamental challenge in developing policies to address a global pollutant through local regulatory action. Bushnell, Peterman and Wolfram [35] surveyed the policy options in light of these concerns.²

Given its history of integration with neighboring states, the electricity industry is particularly vulnerable to emissions leakage. Such risks were quantified in studies by Fowle [36] and Bushnell [37]. In light of the fact that roughly half of the CO₂ emissions associated with electricity consumption originate at plants outside California's borders, and that regulating local plants could exacerbate that ratio, California has explored policies that apply the carbon cap either "downstream" to electricity retailers [38],

or to importers of power. Such approaches represent forms of "vertical targeting", where the application of the regulation is strategically applied to a part of a supply chain (e.g. oil imports vs. gasoline sales) over which a local regulator has the most influence [39]. Unfortunately, none of these policies completely eliminate the risk of emissions spillovers. Bushnell, Chen and Zaragoza-Watkins [40] examine alternative forms of cap-and-trade regulations on the California electricity market. Specific focus is given on the implementation of a downstream form of regulation known as the first-deliverer policy, which places a cap on importers of power. Importers are required to report the source of their emissions and acquire cap-and-trade allowances to offset those emissions. Such a mechanism is vulnerable to reshuffling, an analogous problem to emissions leakage when regulations are applied downstream [35], whereby regulated consumers (or importers) swap sources with unregulated ones in order to acquire cleaner sources of products. In Bushnell, Chen and Zaragoza-Watkins [40], the authors find that, absent strict non-economic barriers to changing import patterns, such policies are extremely vulnerable to reshuffling of import resources. The net impact implies that the first-deliverer policies will be only marginally more effective than a conventional source-based regulation. This work was cited by both the CARB and industry stakeholders as the regulation evolved to develop a series of ad-hoc reporting rules in an attempt to mitigate the reshuffling problem.

Reducing greenhouse gas emissions from the transportation sector is a key component of climate policy, as the transportation sector is estimated to be responsible for over a quarter of the greenhouse gas emissions in the United States [41] and almost 40% of the emissions from the sectors under California's cap-and-trade system [24].

California's Low Carbon Fuel Standard (LCFS) was created by Executive Order S-01-07 in 2007 by former Governor Arnold Schwarzenegger. The Standard is a key complimentary measure in achieving statewide reductions in greenhouse gas emissions required under AB 32. The Standard requires substantial reductions in the carbon intensity of transportation fuels sold in California by 2020. The program went into effect in 2011.

Under the LCFS, obligated parties in California must reduce the weighted average carbon intensity of fuel sold in the state by pre-specified amounts each year. Obligated parties are defined as upstream producers and importers of gasoline and diesel fuel sold in the state.³ The program is agnostic as to which fuels can be used to meet the Standard. As a result, the industry faces only technological and economic constraints in choosing the optimal fuel mix to comply with the program. For example, provisions are made such that electricity providers for plug-in vehicles as well as hydrogen fuel providers for hydrogen vehicles may generate credits under the LCFS which can be sold to regulated parties [42].⁴

In many respects, the LCFS is a first-of-its-kind regulation. As with similar policies whose success depends on the development of new technologies in order for the policy's goals to be met, there is significant uncertainty as to how compliance may be achieved in coming years, particularly

given the unprecedented nature of the program. Given the unpredictable nature of new technologies and the scale at which alternative fuels will need to be produced in order to maintain compliance across all obligated parties, there is significant concern regarding the potential for high and volatile costs of the program in coming years [42].

In particular, because of the large degree of uncertainty regarding future compliance paths, there is concern that LCFS credit prices may become both costly and volatile. Volatility in compliance credit markets can undermine the underlying policy and obfuscate price signals for investors in low carbon intensity fuels [42].

Lade and Lin [42] study multiple issues related to the costs of the LCFS in the near future, and discuss provisions designed to contain compliance costs at reasonable levels. In addition, they discuss a number of other important issues such as concerns over market power in the state's fuel and credit markets; the role of dynamics and uncertainty on market outcomes; and incentives to innovate and invest in renewable fuels and their potential interactions with cost containment mechanisms.

Lade and Lin [42] find that compliance costs may increase rapidly in the future if there are large differences in marginal costs between traditional fossil fuels and alternative, low carbon intensity fuels; or if there are capacity or technological constraints to deploying alternative fuels, particularly those with low carbon intensity. In the absence of readily available, low carbon intensity fuel alternatives, the fuel market will adjust along two dimensions to maintain compliance with the LCFS: (i) increase the use of cheaper fuels below the Standard such as ethanol derived from corn starch and sugarcane; or (ii) increase fuel prices and reduce fuel consumption to a level where the Standard is technologically feasible. Both options will be associated with high LCFS credit prices. Because firms are able to bank credits over time, anticipated high costs in the future may lead to higher costs in the present before any constraints bind on the industry.

The potential for compliance costs to increase rapidly in the near future motivates Lade and Lin's [42] recommendation to institute a hard cap on LCFS compliance credits through a mechanism such as an unlimited credit window or noncompliance penalty. Both mechanisms guarantee that compliance costs will never exceed either the credit window price or the non-compliance fee, and provide a clear and transparent alternative compliance strategy. Both proposals have the additional advantage of generating funds which may be used to increase investments in low carbon intensity fuel technologies. Importantly, neither mechanism will compromise the greenhouse gas reduction goals set by Assembly Bill 32 [42].

California is a clear leader in enacting greenhouse gas policies in the United States and around the world. Extreme compliance costs in programs such as the LCFS may compromise greenhouse gas policies currently in place, as well as discourage the adoption of similar programs in other jurisdictions. As a result, instituting a hard cap on LCFS credit prices using a transparent containment mechanism as suggested in Lade and Lin's [42] report is imperative.

Lade and Lin Lawell [43] discuss the design and economics of low carbon fuel standards, including important policy design elements of a low carbon fuel standard; the history of prominent low carbon fuel standards that have been enacted or proposed in the US and abroad; the market effects of a low carbon fuel standard; incomplete regulation, leakage, and market power; policymaking with multiple objectives; innovation and learning; and overlapping policies and policy interactions.

The California Air Resources Board has overcome a number of important legal challenges since the inception of the LCFS. In December 2011, a District Court judge granted a preliminary injunction against CARB, finding that California's LCFS violated the federal commerce clause due to its life-cycle accounting methods. The injunction was stayed by the Ninth Circuit court, and CARB has continued enforcement of the policy [44, 45]. In September, 2013, the Ninth Circuit Court of Appeals upheld the LCFS, and in June 2014 the US Supreme Court chose not to review the lower court's decision [43].

In 2013, California's Fifth Appellate District Court found that the LCFS adoption process violated the California Environmental Quality Act (CEQA). The court allowed CARB to continue enforcing the LCFS, but required the Board to freeze the standard until it readopted the program. The case has resulted in a lengthy re-adoption process, and CARB has used the opportunity to propose a number of amendments to the original regulation. The amendments currently under consideration include: (i) modifying the LCFS compliance schedules for 2015 to 2019; (ii) changing the process for determining fuel carbon intensities; (iii) updating indirect land-use change estimates; (iii) allowing refiners to generate credits for reducing emissions from producing gasoline and diesel; and (iv) including cost containment provisions in the regulation [43, 46, 47].

Researchers at the University of California at Davis Institute of Transportation Studies provide regular and timely updates on the progress of California's LCFS [48, 49, 50, 51, 52]. The updates review important developments in the regulation including the total credit and deficit generation, the composition of generated credits, and compliance credit prices. A recent update finds that the average carbon intensity of alternative fuels sold in the state fell 15% since the program's inception. While ethanol generates most credits, its share of generation has decreased since 2013 as larger shares of credits are generated by renewable diesel, biodiesel, and to smaller extent, electricity [43, 53].

California's fuel industry must comply with other carbon policies in addition to the LCFS. The most important carbon policy, which will affect California fuel markets in the near future is the phase-in of all emissions associated with the combustion of fossil fuels under the state's cap and trade program. The state's cap and trade program is composed of two phases. During the first compliance period from 2013 to 2015, refiners are responsible for all greenhouse emissions directly associated with their production.⁵ Beginning in 2015, in addition to emissions directly associated with production activity, California refiners are also responsible for CO₂, CH₄, and N₂O emissions, which result from the combustion of all fossil fuels produced in

and imported into the state. Emissions associated with qualifying biomass-derived fuels are not included in the compliance obligation of any refiner.⁶ Thus, any portion of fuel produced from fuel ethanol, bio-diesel or other renewable sources is not included under the cap [54].

As a result of the cap and trade program, beginning in 2015, for every gallon of conventional fossil fuel produced or imported, refiners have been required to purchase permits to cover the emissions associated with the fuel. So long as individual refiners cannot affect cap and trade permit prices, the cap and trade program can be modeled as a fee on conventional fuels, where the fee is equal to the cap and trade permit price times the emissions of each unit of fuel [54].

Accordingly to simulations results by Lade and Lin [54], the cap and trade policy shifts the conventional and total fuel supply curves upward, leading to higher fuel prices and decreasing fuel demand. Because all renewable fuel emissions are not included under the cap, the relative price difference between the inputs becomes smaller. As a result, LCFS credit prices will experience downward pressure as cap and trade permit prices increase [54].

US climate policy

Passed in December 2007, the Energy Independence and Security Act (EISA) laid a path to reduce greenhouse gas emissions from the transportation sector, increase farm income, and promote energy security. To achieve these goals, EISA sought to decrease US oil imports, increase domestic energy production, and increase the efficiency of the US vehicle fleet. EISA created and expanded several policies, including increasing Corporate Average Fuel Economy standards for new vehicles, creating requirements for federal alternative fueled vehicle acquisitions, establishing more stringent standards for large electric durables, and increasing mandates for biofuel consumption in the US [55].

The expansion of the Renewable Fuel Standard was the most ambitious provision of the law. EISA increased the original Renewable Fuel Standard, established under the Energy Policy Act of 2005, from requiring just over 7 billion gallons (bgals) of biofuel consumption per year by 2012 to 36 bgals per year by 2022. In addition to expanding the overall biofuel mandate, EISA created separate mandates for four biofuel categories: cellulosic biofuel, biodiesel, advanced biofuel, and renewable biofuel [55].

The Renewable Fuel Standard (RFS2) is implemented using a market for tradeable compliance credits. Lade, Lin Lawell and Smith [5], develop a dynamic model of compliance with the RFS2 in which firms face uncertainty about future fuel prices and the future stringency of the mandate to demonstrate the potential effects of changes in policy expectations on the price of compliance credits. They then estimate empirically the effect of three “policy shocks” that reduced the expected mandates in 2013. Estimates indicate that one shock, the release of the 2013 Final Rule in which the Environmental Protection Agency suggested it would likely reduce the 2014 mandate, decreased the value of the subsidy (tax) provided by the RFS2 to the biofuel (fossil fuel) industry in 2013 by nearly \$8 billion.

Similar shocks followed with two subsequent events that released preliminary versions of the 2014 mandate reductions. They provide evidence that the burden of the mandate reductions fell primarily on advanced biofuel firms and on commodity markets of the marginal compliance biofuel [5].

A number of policies currently in place and being proposed in the energy sector share many features with the RFS2. For example, several states have passed low carbon fuel standards and renewable portfolio standards that require large increases in the share of fuel and electricity that must be derived from renewable sources, respectively [56, 57]. In addition, the EPA’s proposed Clean Power Plan will require states to institute either a mass-based or rate-based carbon emissions standard for fossil-fuel fired electric generation plants [58]. All policies will face similar constraints to those placed on the deployment of renewables that were experienced by biofuel producers in 2013. Thus, the findings of Lade, Lin Lawell and Smith [5] regarding the detrimental effects of responding to high compliance credit prices by reducing statutory mandates have important implications for how to better design this new class of policies. The findings suggest that pure quantity-based mechanisms leave policies susceptible to large increases in compliance costs, particularly in the presence of capacity or production constraints that are inherent in energy markets. Given the experiences with the RFS2 in 2013, anticipating and designing these policies in a way that can account for these features is imperative.

The RFS2 is administrated by the U.S. Environmental Protection Agency (EPA). In February 2010, the EPA released an extensive Regulatory Impact Analysis (RIA) studying the benefits and costs of the policy ex ante. Lade, Lin and Smith [55] compare the EPA’s estimates to two useful ex post measures implied by the price of RFS2 compliance credits. First, they use the compliance credit prices to quantify the policy-induced transfers from gasoline and diesel producers to biofuel producers. These transfers reveal the incentives for industry participants to lobby for or against the policy and thereby show the potential for such lobbying to derail the policy. Second, they use the credit prices to estimate an upper bound on the increase in wholesale gasoline and diesel prices due to the policy. The second measure provides a direct estimate with which they compare the EPA’s ex ante cost estimates.

Overall, Lade, Lin and Smith [55] find that the EPA’s RIA overlooked three important factors, which led to an overly optimistic characterization of fuel market impacts of the RFS2. First, the EPA did not consider delays in the development of the advanced biofuel industry. Second, it did not account for delayed investments in alternative fuel vehicles and fueling infrastructure necessary to consume more than 10% ethanol-gasoline blends. Finally, the EPA did not properly characterize the uncertainty inherent in predicting future relative prices of oil and biofuels.

The shortcomings of the RIA contributed to the problems currently facing the EPA in implementing the RFS2. As of January 2015, the EPA has failed to finalize the mandate requirements for 2014, and will likely not finalize the 2014 or 2015 mandates until mid-2015. In addition, the

EPA has vastly scaled back requirements for cellulosic biofuel since 2010, and has proposed large cuts to the 2014 total biofuel mandate. The proposed cuts were the direct result of high compliance costs arising due to the issues highlighted above [55].

In light of their findings, Lade, Lin and Smith [55] recommend a simplification of future RIAs, particularly for transformative policies like the RFS2. Meeting the goals of policies such as the RFS2 requires relying on large investments in order for the policy objectives to be met, and therefore involves important transitional costs. As such, they also recommend that RIAs study short to medium term compliance scenarios, as well as explicitly consider “worst case” compliance scenarios in order to anticipate the effects of delays in technological progress or investments on compliance costs.

Yi, Lin Lawell and Thome [59] develop and estimate a dynamic structural econometric model to analyze the effects of government subsidies and the Renewable Fuel Standard (RFS) on the U.S. fuel ethanol industry. Preliminary results show that the RFS is a critically important policy for supporting the sustainability of corn-based fuel ethanol production, and that investment subsidies and entry subsidies are more effective than production subsidies.

On August 3, 2015, President Obama and the EPA announced the Clean Power Plan. Fowlie et al. [60] raise two concerns regarding the Clean Power Plan. The first is the perverse incentives for expanded electricity production in place of reduced emissions. The second is the potential overestimation of energy efficiency gains that will effectively weaken the standard.

China and India

California leads the nation in fighting climate change. However, the state's share of global energy-related CO₂ emissions, 1.07% in 2011 [61, 62] is very small. Over the next few decades, the majority of emissions will come from developing countries [8]. Emission reductions in California will have a small impact on global climate unless the state can leverage mitigation efforts of other major emitters.

China is the world's largest greenhouse gas emitter, responsible for over one-quarter of global carbon emissions. Four sectors – electric power, industrial, building, and transport – account for about three quarters of China's greenhouse gas emissions. Although China has taken increasingly aggressive measures for energy conservation and carbon mitigation, Wang, Yang and Zhang [63] argue these efforts are still below the requirement to keep global temperature below the dangerous level.

In order to provide insights for future mitigation needs, it is useful to forecast China's carbon emission trajectory under the business-as-usual scenario [64]. Using detailed energy consumption data and spatial econometrics, Yang, Zhang and Wang [64] show that China is unlikely to comply with its Copenhagen commitment to slash its carbon intensity by 40–45 percent from the 2005 level by 2020. Even worse, China's emission growth in the next decade is more than triple the emission reductions that the EU and the US have committed to in the same period.

An international carbon market, known as the Clean Development Mechanism (CDM) in the Kyoto Protocol, has been created to achieve cost-effective emission reductions. However, poor design of the baseline-and-credit scheme has plagued the integrity of this carbon market. Zhang and Wang [65] find that the CDM, a project-based carbon market between developed and developing countries, creates perverse incentive for market participants to inflate carbon credits. Their research suggests that the CDM does not have a statistically significant effect in lowering carbon emissions in China. It provides the first empirical evidence that the CDM activities might have generated many bogus carbon credits.

As the world's top two emitters, the collaboration between China and the US on climate change is essential to form a global treaty. Bi et al. [66] argue that since a treaty on CO₂ lacks the support at present, reducing short-lived climate pollutants has become an economically and politically viable option for climate mitigation. In a separate study, Zhang and Wang [67] propose that a phase-down of the climate-damaging hydrofluorocarbons (HFCs) is aligned with China's self interest. This finding is timely as the US and China regard HFCs are a promising area in the bilateral climate collaboration.

China's climate action is not only a result of diplomatic pressure but also due to its own incentive [68]. Zhang, Zhang and Chen [69] estimate the economic impact of climate change on the Chinese agriculture. They find that climate change will reduce the yields of rice, wheat, and corn in China by 9.31%, 4.52%, and 45.04%, respectively. Their study also makes a methodological contribution by demonstrating that the climatic variables other than temperature and precipitation – such as humidity, evaporation, daylight hours, and wind speed – are important confounders in evaluating the economic impacts of climate change on agriculture. Their research suggests that previous studies which ignored these climatic variables are subject to serious omitted variable bias.

On January 1, 2009, China initiated a modest reform of its fuel tax, which led to an increase in the gasoline consumption tax from 0.2 Yuan per liter to 1.0 Yuan per liter, and an increase in the kerosene consumption tax from 0.1 Yuan per liter to 0.8 Yuan per liter. Although this reform is considered a big breakthrough, the changes made are modest since most of the fuel tax simply replaces pre-existing road maintenance fees and some of the tax revenue is given back to fuel consumers who previously did not pay for the road maintenance fees, including airlines, utilities and the army. The existing fuel tax in China is not sufficient to substantially reduce vehicle emissions and congestion, thus raising the question of what the optimal gasoline tax for China should be [70]. Lin and Zeng [70] calculate that the optimal adjusted Pigovian gasoline tax for China is \$1.58 per gallon, which is more than 2.65 times the current level. In this optimal tax, the congestion costs would be taxed the most heavily, at \$0.82 per gallon, followed by local air pollution, accident externalities, and finally global climate change.

Lu, Lin Lawell, and Song [71] examine the effects of energy policies in China on energy consumption and find

that some energy policies in China may be ineffective or even have perverse consequences. One possible reason is there may be a rebound effect, which arises when some of the gains from improving the efficiency of energy use are lost because of behavioral responses [72].

A second reason some energy policies might be ineffective in China and California is that having multiple energy policies in place may diminish the effectiveness of individual policies, or even lead to perverse impacts [71]. In the context of overlapping policies for reducing pollution, Novan [73] finds that if one policy places a binding cap on a subset of pollutants, additional policies to reduce emissions through expansions in renewable electricity have the potential to increase instead of decrease pollution.

A third reason why some energy policies in China may be ineffective or even have perverse consequences is that the structure of energy regulatory agencies, where some areas of energy may be regulated by multiple agencies while other areas are not regulated by any, may cause energy policies to be ineffective [71]. A fourth reason why some energy policies in China may be ineffective is that these policies may be poorly enforced or have loopholes [71]. A fifth reason for the ineffectiveness of some energy policies is that energy prices in China are often partially controlled by the government [71].

While the predicted impacts of climate change on mortality in the United States are quantitatively important, most analysts expect them to be significantly larger in developing countries since their economies are still largely weather-dependent. Burgess et al. [74] find that the marginal effect of daily temperatures above 90°F on mortality is 5 to 10 times as large in India as it is in the United States. Under business-as-usual emission scenarios, and absent adaptation the results indicate that the annual mortality rate in India could increase by as much as 50% by the end of the current century due to climate change.

Barreca et al. [75] document that there are tremendous opportunities available to mitigate climate change's impacts on mortality through the use of existing technologies and find that it is likely that the diffusion of air conditioning in at-risk countries (e.g., China, India, etc.) can significantly reduce the health costs associated with climate change. At the same time, it is probable that the greater use of residential air conditioning will speed up the rate of climate change because fossil fuels (e.g., coal and natural gas), which can cause climate change, are the most inexpensive sources of energy. This paradox underscores the complicated nature of trying to mitigate the rate of climate change when any solution requires reductions in greenhouse gas emissions by countries with very different income levels.

A Path Forward

We have several recommendations for the path forward for climate policy.

First, the goal of climate policy should be to reduce the damages caused by greenhouse gases. Reducing gasoline use is one way to achieve this, but necessarily the only way. Similarly, reducing greenhouse gases is one way to reduce the damages caused by greenhouse gases, but not the only

way. In addition to mitigation policy to reduce greenhouse gas concentrations in the atmosphere, one can also reduce the damages caused by greenhouse gases by adaptation measures that reduce our vulnerability to climate change impacts. Such adaptation measures include policies to protect coastlines and deal with sea-level encroachment; policies to best manage land and forests; policies to deal with and plan for reduced water availability; policies to develop resilient crop varieties; and policies to protect energy and public infrastructure [76].

Second, policy-makers should use incentive- (or market-) based instruments as opposed to command and control policies (including quantity-based mandates) whenever possible. Whenever unpriced emissions are the sole market failure, incentive-based instruments such as a carbon tax or cap and trade program are more likely to achieve the social optimum and maximize social net benefits [1, 2].

Lin and Prince [3] calculate that the optimal gasoline tax for the state of California is \$1.37 per gallon. The Pigovian tax is the largest part of this tax, comprising \$0.85 per gallon. Of this, the congestion externality is taxed the most heavily, at \$0.27, followed by oil security, accident externalities, local air pollution, and finally global climate change. The other major component, a Ramsey tax, comprises a full \$0.52 of this tax, reflecting the efficiency in raising revenues from a tax on gasoline consumption due to the inelastic demand of this consumption good.

Our third recommendation is to address the risk of emissions leakage, which arises when only one jurisdiction (e.g., California) imposes climate policy, but not the entire world. It is possible that regulations in California alone can cause an increase in aggregate emissions around the world [36]. It is also possible that regulations in California alone can cause an increase in aggregate damages.

One way to reduce emissions leakage is to use the strategic distribution of emissions allowances to local producers. This method, known as "output-based allocation" or benchmarking, effectively subsidizes local producers and at least partially offsets the increase in their costs caused by an emissions cap [4]. Importantly, only local production is eligible for an allocation of valuable allowances, providing a counterweight to the incentive for emission leakage. Bushnell and Chen [77] study the proposal to apply output-based updating to the electricity industry under a multi-state or California only cap. They find that updating using a single benchmark rate can be effective at mitigating leakage in a multi-state context. They also propose "fuel-based" allocation, which would distribute allowances at differential rates to coal and natural gas power plants and would inflate the price of allowances and largely reverse the benefits of output-based allocation.

Output-based allocation is not limited to the power sector. It is most commonly considered as an option for protecting local energy-intensive and trade-exposed (EITE) industries [4]. Concerns over the migration not just of emissions, but of economic activity and jobs can be serious impediments to aggressive mitigation policies. One such trade-exposed industry is the Portland cement industry. With support from CARB, University of California

Berkeley Professor Meredith Fowlie has been studying options for preventing leakage from the cement industry. In Fowlie, Reguant, and Ryan [78], they find that output-based updating is the most attractive option for preventing leakage, even relative to taxing imported cement at an equivalent carbon price.

Our fourth recommendation is that if they are used instead of incentive-based instruments, quantity-based mandates such as the federal Renewable Fuel Standard, California's Low Carbon Fuel Standard, renewable portfolio standards, and the Clean Power Plan should be combined with a cost containment mechanism. The findings of Lade, Lin Lawell and Smith [5] suggest that pure quantity-based mechanisms leave policies susceptible to large increases in compliance costs, particularly in the presence of capacity or production constraints that are inherent in energy markets. Given the experiences with the federal RFS2 in 2013, anticipating and designing climate policies in a way that can contain compliance costs is imperative. Lade and Lin Lawell [42] show in the case of renewable fuel mandates that whenever the marginal cost of renewable fuels is high relative to fossil fuels, cost containment mechanisms such as a credit window have the benefit of both constraining compliance costs and reducing dead-weight loss. In addition, when both a fuel mandate and cost containment mechanism are set optimally, the efficiency of fuel mandates can increase substantially over optimally setting fuel mandates alone. Using a numerical model of the US gasoline market, Lade and Lin Lawell [42] show that the efficiency gains from strategically including a credit window offering with a fuel mandate are sizable. However, incentive-based instruments should be used instead of mandates whenever possible.

Our fifth recommendation is that for international leverage, we should develop a climate club backed by border tax adjustments to non-participants. University of California at Berkeley Professor Larry S. Karp has been proposing an agreement between the top 10 emitters as an alternative to the UN framework [6].

Without international leverage or cooperation, unilateral climate policies, such as California's AB 32 or the American Clean Energy and Security Act, are not only unlikely to fully combat climate change, but can also have other detrimental effects. A leading concern cited by opponents of such unilateral climate policies is the potential for such policies to reduce economic competitiveness and the possible displacement of jobs from the U.S. to countries without carbon pricing. Deschênes [7] finds that employment rates are negatively related to real electricity prices. Interpreted in the context of predicted increases in electricity prices that are consistent with H.R. 2454, the American Clean Energy and Security Act of 2009, the results suggests that in the short-run, an increase in electricity price of 4% (the upper bound of the scenarios implied by H.R. 2452) would lead to a reduction in aggregate FTE employment of 0.6%.

Our final, and main, recommendation is that, as University of California at Berkeley Professor Severin Borenstein points out, California should focus on solving the problem of *global* climate change. Instead of focusing on reaching emissions targets for California, the primary

goal of California climate policy should be to invent and develop the technologies that can replace fossil fuels, allowing the poorer nations of the world – where most of the world's population lives – to achieve low-carbon economic growth [8]. California should therefore include as a criterion for evaluating its climate policy whether it is exportable to the developing world [8]. This means, for example, that a new technology about which California (and the rest of the world) will learn a lot may get funded even if it is likely to be more expensive than replicating a mature technology [8]. Also, as Borenstein [8] recommends, California should consider creating a Climate Change Solutions Institute akin to the California Institute for Regenerative Medicine, whose goal would be to research and develop approaches that could be applied by a large share of the world's population.

Competing Interests

The authors have no competing interests to declare.

Notes

- ¹ University of California at Berkeley Chancellor's Professor Michael Hanemann [79] provides a compelling recount of the events leading to the passage of this legislation in California. He explores the political and legal circumstances reigning during the few years prior to the law enactment but the narration is also enriched by tracing back the seeds to the ahead-of-federal regulations on air pollution in the middle of the twentieth century and the creation of a unique state Energy Commission in 1974. The interested reader will find further interesting details about the different segments and characters along the road to the passage of AB32 in Hanemann [80].
- ² While no regulation is completely immune to negative spillovers such as emissions leakage, directed subsidies, while generally criticized by economists have the advantage of being less vulnerable to leakage.
- ³ Final Regulation Order, Section 95484.
- ⁴ The full list of fuels which substitute for gasoline under the program is available at http://www.arb.ca.gov/fuels/lcfs/121409lcfs_lutables.pdf.
- ⁵ Emissions covered under the cap in the first compliance period include emissions from stationary combustion, processing, catalyst regeneration and flare and destructive devices.
- ⁶ Also excluded from having a compliance obligation are emissions associated with geothermal facilities, natural gas, hydrogen fuel cells, emissions from the storage of petroleum and natural gas, emissions from asphalt blowing operations, equipment leaks, storage and loading operations, emissions from low bleed pneumatic devices, emission from high bleed pneumatic devices reported prior to January 2015, vented emissions from well-site centrifugal and reciprocating compressors with horsepower less than 250 hp; carbon dioxide that is imported or that is exported for purposes other than geological sequestration; and emissions from facilities covered under NAICS code 92811 – national security facilities through 2013.

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