The Design and Implementation of U.S. Climate Policy: An Introduction

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Climate change is one of the most challenging issues facing policymakers today. Greenhouse gas emissions create externalities across the globe, which means that climate change mitigation requires globally coordinated policy intervention. At the same time, every sector of the economy creates greenhouse gas emissions, some in large quantities. Therefore, climate change action, whenever it occurs, will be an expansive undertaking for any government.

The prospects for U.S. federal climate change legislation have waxed and waned over the past several years. In 2007, the Senate Environment and Public Works Committee approved the Lieberman-Warner Climate Security Act. At the time, this was the farthest climate legislation had progressed in the U.S. Congress. In 2009, the full House of Representatives passed the Waxman-Markey American Clean Energy Solutions Act (HR2454). Since the eventual failure of that Act, Congress has not considered any new climate change legislation.

We launched this book with the aim of engaging economic researchers to answer specific questions on climate-policy implementation. In early 2009, some of our colleagues cautioned us against undertaking this effort, as they thought comprehensive climate legislation would be enacted before our authors had submitted their first drafts. As we write this introduction, the opposite concern appears more relevant, as legislation on climate change now seems unlikely for at least several years. Nevertheless, we believed in 2009 and believe even more firmly today that economists have tremendous expertise and insight to offer policymakers as they work through legislative and other approaches to mitigating climate change. Addressing climate change will be a massive undertaking, but we can draw on useful economic models as well as analogous experiences that economists have studied to help guide the policy process.

Early economic research on climate change contributed to our understanding of the scope of the damages associated with global warming as well as the costs and benefits of alternative policies to reduce the emissions of carbon dioxide and other greenhouse gases. The early work focused on high-level issues such as the costs of global warming to various sectors of the economy, the costs of climate policy, the potential savings from market-based incentives, and the major factors policymakers should consider when deciding whether to use a price instrument like emissions taxes or a quantity instrument like tradable permits.

While economic models are very useful to analyze the big picture issues, the next steps of the policy process require answers to a long list of more specific questions that bear on the actual design and implementation of U.S. climate policy. If a cap-and-trade program is chosen, how will permits be allocated initially? Can permits be banked for use in a later period? If so, under what rules? Who will be allowed to sell offsets for the reduction of GHG emissions or the sequestration of CO_2? How will those offsets be verified? What are the many distributional effects of these policies? How can any adverse distributional effects be ameliorated? What other environmental or non-environmental goals ought to be incorporated into the design of climate policy?

To get answers to these and other questions, we took a more prescriptive approach to developing this book than is conventional in economics. In particular, for most edited volumes in economics, editors select authors and give them some general guidance about the topic or topics they would like to see addressed. In contrast, we began by developing a detailed set of design and implementation questions that we thought needed to be answered. We next identified an academic economist whose expertise was relevant to each question. In almost all cases, we approached authors who had worked on related topics, but to write the chapter for our book would have to address topics that were new to them and new to the literature. For example, Hilary Sigman has worked on enforcement and monitoring issues before, but not in the context of climate change.

To help induce our authors to take on new research topics, we asked for chapters that were shorter than the usual research paper. We advised authors to think hard about their assigned question, start an economic model to analyze it, collect whatever initial data could be used in that model, and suggest initial answers. We hoped that starting to work on the topic for our book would lead these authors into further research on each topic, which we have been delighted to see transpire in several cases (Bushnell and Mansur, 2011; Chang and Sigman, 2011).

This introduction is intended to summarize the chapters of this book and relate them to each other. Unfortunately, however, we are unable to review all of the other important literature in this field. For a flavor of other recent work on this topic, we just mention the book edited by Guesnerie and Tulkens (2008) called *The Design of Climate Policy*, and a review article by Aldy *et al*. (2010) in the *Journal of Economic Literature* called "Designing Climate Mitigation Policy." These recent works provide more comprehensive reviews than is possible here.

A. CLIMATE POLICY IN THE BROADER CONTEXT

The first six chapters consider the possible effects of U.S. climate policy on a range of economic outcomes, including household income, employment, innovation, greenhouse gas emissions outside the U.S., emissions of non-greenhouse gas pollutants, and natural emissions plus absorption of carbon dioxide. All six authors use economic theory to identify different pathways by which these effects might operate. With simple, intuitive models, the points they raise will hopefully be absorbed by policymakers and applied in a number of contexts. Several of the authors also use simulations or empirical estimates to bring data-driven evidence to bear on the questions they examine.

The first chapter is arguably broadest in scope, as it quantifies the effects of climate policy on several different factors that impact household disposable income. Specifically, Gilbert Metcalf, Aparna Mathur and Kevin Hassett simulate the impact of a CO_2 price of $15 per ton and analyze the burden absorbed by households at different deciles of the income distribution. By way of comparison, several of their scenarios also examine households at different points of the consumption distribution. Consumption is a more reliable indicator of lifetime income, as some households, such as students, have income that is temporarily very low. They disaggregate household income into capital and labor sources and model the impact of carbon pricing on both of these components. They also analyze changes in the prices of consumption bundles.

Estimates like these are central to political debates about carbon pricing, which is often seen as regressive, given the rough logic that low-income consumers spend a higher share of their income on electricity, natural gas, and gasoline. As Metcalf, Mathur and Hassett point out, however, this rough logic is contradicted by the fact that higher income households are more likely to be hurt by reductions in employment or lower returns to capital caused by a CO_2 price. Their paper certainly suggests that we need to develop more thorough analyses of the extent to which carbon pricing is likely to be forward shifted (i.e., lead to higher consumer prices) or backwards shifted (i.e., reduce returns to capital and labor). Another possibility, which goes beyond the scope of the model in this chapter, is that the burden will be shifted abroad, for instance, to the Saudi government if climate policy causes oil prices to fall. While the authors use assumptions designed to cover a range of possibilities, it is important to continue to get concrete data that could inform which of their scenarios is most relevant.

In this spirit, Chapter 2 by Olivier Deschênes takes an important step in quantifying one of the backwards shifting mechanisms identified by Metcalf, Mathur and Hassett – the effects of climate policy on labor markets. The conventional wisdom is that putting a price on carbon will reduce employment, but, again, the economic model points out that this rough logic does not capture the full story. Deschênes begins by writing down a simple economic relationship that elucidates how a change in energy prices, such as one induced by a positive price on CO_2 emissions, might impact labor. Any cost-minimizing, profit-maximizing firm confronted with a price increase for one of their inputs faces two options, which are not necessarily mutually exclusive. They can use less of the more expensive input and substitute to other inputs, or they can make less of the good. If manufacturers reduce their output, employment will unambiguously fall. As Deschênes points out, this is commonly called the scale effect. But, for a given level of output, it is not clear whether energy and labor are substitutes or complements in the production process. Ultimately, the answer is empirical, and it may vary by skill-level of the job, industry, or region of the country.

To begin to get some insight into these questions, Deschênes estimates the empirical relationship between state-by-year variation in electricity prices and employment. He finds that a 4 percent increase in electricity prices, consistent with estimates of the impact of the Waxman-Markey legislation that passed the House in 2009, leads to approximately a 0.5% reduction in U.S. employment. Whether one interprets these effects as big or small depends on one's perspective. A 0.5% reduction means a loss of several hundred thousand jobs, which is a large number, but, as Deschênes points out, the 2008 recession caused employment losses that were almost ten times larger. We hope that in future work, Deschênes and others will also separate the effects along different dimensions, such as industry sector, region of the country, or skill-level of the jobs (which would speak to the assumptions in the Metcalf, Mathur and Hassett chapter on distributional implications). This will help inform policy discussions, not just about who will be the winners and losers, but also about how policies might be designed to mitigate the harm to those bearing the largest burden.

Chapter 3 addresses a related topic, as conventional wisdom often highlights the concern that jobs will be exported abroad if the U.S. unilaterally imposes a price on carbon. If jobs are exported abroad, emissions may go with them, which can undo the benefits of U.S.-based efforts to limit carbon emissions. Kala Krishna begins by describing some of the specific findings from work that relies on computable general equilibrium (CGE) models, highlighting findings on the effectiveness of border tax adjustments on mitigating leakage. Noting that a CGE model can be a “black box,” she writes down a simple, highly transparent model designed to elucidate some of the mechanisms by which the effects would work.

Krishna’s model draws from the trade literature, and posits two countries, both of which produce two goods, one clean and one dirty. She follows previous models in making several strong assumptions, such as constant returns to scale and non-tradable factors, though Meredith Fowlie’s extremely coherent comments point out that some of the assumptions behind Krishna’s paper may not apply in the CGE models she aims to unpack. Krishna’s model does point out how different conditions in product and factor markets will lead to different effects of policies. She makes an interesting point, for example, in the case where the U.S restricts emissions in a way that would normally lead to leakage elsewhere. If the rest of the world has a generous, perhaps even non-binding cap, then that emissions leakage will be mitigated, as the cap for the rest of the world may become binding. Any further pressure to increase emissions in the rest of the world will not result in more emissions, as it will only drive up the price of carbon abroad.

In Chapter 4, Charles Kolstad takes on another important consideration for any climate policy – how will it affect innovation designed to reduce greenhouse gas emissions? Specifically, the consensus is that achieving the types of greenhouse gas reductions required to thwart dangerous climate change will involve fundamental changes to the way society produces and consumes energy. It is critical to understand, therefore, how polices that the U.S. is likely to enact in the next several years will affect investments in activities that could bring about these types of transformative changes.

Kolstad’s model focuses on the incentives of the innovator. Specifically, he models a single innovating firm that licenses its technology to multiple identical atomistic polluting firms. He shows that a social planner can set either a tax or an emissions cap to achieve the first-best levels of abatement and investment in innovations that reduce the marginal cost of abatement. He shows that under a permit system, the innovator captures the entire surplus through a license to the polluting firms. Under a tax system, however, the innovator shares the gains with the polluters in the form of lower abatement costs. The intuition for this result is that under the cap-and-trade system the polluting firms are required to abate a certain amount, so their objective is to find the cheapest way to do it (strictly speaking, Kolstad is modeling a pure “cap” system, since his model has no trading between the identical firms). As long as the licensing fee plus the lower cost technology is epsilon cheaper than the pre-innovation abatement technology, the polluting firms will choose it. In the case of a tax, however, the cost of abatement factors into the polluting firms’ decisions about how much to abate, so the optimal licensing fee leaves some rents to the abating firm.

Kolstad’s result suggests that cap-and-trade systems may provide better incentives for innovation. Going forward, it will be important to evaluate this result under different assumption, for instance, to allow the innovating firm to use a multi-part price structure for the innovative technology or to otherwise enrich the depiction of the relationship between the innovating and polluting firms.

In Chapter 5, Stephen Holland describes, both theoretically and empirically, spillovers from CO_2 emissions regulations to other pollutants. This is an important point, and one that has received attention from an environmental justice community that fears GHG mitigation policies could lead to increased criteria pollutant concentrations in disadvantaged areas. The academic literature, at least to date, has largely overlooked the topic. It is important to consider, since reducing GHG emissions may lead to significant increases or reductions in other pollutants. Efficient climate policy design would consider spillovers, though the specific way to account for any costs or benefits depends critically on the nature (or lack) of regulatory treatment of the other pollutants. Spillovers may also factor into political and distributional considerations about climate policy.

Since the U.S. currently does not have a comprehensive climate-change policy, obtaining empirical estimates of the extent of spillovers is not straightforward. Holland takes a clever approach to solving that problem and looks for evidence of spillovers to CO_2 emissions from NOx regulations. Under relatively strong assumptions (i.e. unconstrained, profit-maximizing firms and only marginal changes in the prices of both CO_2 emissions and NOx emissions), the response of CO_2 emissions to a change in the price of NOx emissions is equal to the response of NOx emissions to a change in the price of CO_2. Holland finds that CO_2 and NOx emissions both fall when the price of NOx emissions increases, and this is primarily driven by the output effect, as higher NOx prices cause older plants to reduce operation. While Holland takes an electricity generating plant as his unit of analysis, it will be important to extend this type of analysis to more aggregate units of analysis, such as the western electricity grid.

The final chapter in this section addresses spillovers from regulations of anthropogenic carbon emissions to the larger carbon cycle. Some of the basic facts Severin Borenstein lays out are quite sobering and provocative: annual anthropogenic carbon emissions are about nine gigatons, while the natural carbon flux emits and absorbs 210 gigatons of carbon per year! Importantly, human activities can alter the natural carbon flux in many ways. So, if global governments succeed in enacting policies that reduce anthropogenic carbon emissions by half, which is a much larger reduction than contemplated by *any* near-term policies, all that work could be undone if the adjustments to achieve the reductions in anthropogenic emissions led to a mere two percent change in the natural carbon absorption. Borenstein goes on to discuss the implications of this fact for market-based climate policies.

B. INTERACTIONS WITH OTHER POLICIES

The effect of a U.S. federal climate policy is not independent of the policies enacted by other state or national governments. Chapter 7 by Lawrence Goulder and Robert Stavins considers the problem of interactions between state and federal policies, focusing on cap-and-trade programs or a carbon tax. Take as an example the effects of a sub-national cap-and-trade system such as enacted already in ten northeastern states (the Regional Greenhouse Gas Initiative, called RGGI). With no other climate policy anywhere, then RGGI might succeed in reducing emissions in those states. Other jurisdictions, however, might increase production, which could drive up their emissions (i.e., leading to “leakage”). As a result, the overall cost of emission reduction is not minimized because marginal abatement costs are not equalized.

Suppose instead that the Federal government has a carbon tax (or a permit system with a binding safety valve). Then the sub-national policy has very similar effects to those just described: any binding sub-national restriction may result in some leakage if other states increase production at their unchanged emissions price. On the other hand, consider a stringent sub-national policy in the context of a Federal permit system with a lower price (not at any safety valve ceiling price). In that case, Goulder and Stavins show that leakage will be complete -- with no net emissions reductions whatever. The reason is that firms in that sub-national regime must reduce emissions by some quantity, which makes exactly that quantity of national permits available to any firms outside that sub-national regime. It effectively increases the supply of permits to others, and so reduces the nationwide price of Federal permits.

Interestingly, it also implies a difference between a carbon tax and a cap-and-trade program, even with perfect certainty. With a U.S. carbon tax, RGGI could reduce emissions further. With a Federal cap-and-trade system, however, RGGI would have no effect on the environment, but would only reduce overall cost-effectiveness by introducing a difference between permit prices and therefore marginal costs of abatement. Goulder and Stavins consider other interesting cases and a variety of complications, some of which change the simple result we have described.

While Goulder and Stavins look at climate policy interactions between different jurisdictions, Chapter 8 by Arik Levinson looks at interactions between different policies. To reduce carbon emissions, even the same jurisdiction may choose to enact both a market policy (such as carbon tax or cap-and trade) and traditional standards (such as a low-carbon fuel requirement or an energy-efficiency requirement). Levinson points out that having both kinds of policies can lead to one of three outcomes: the policies may be mutually reinforcing (like “belts and suspenders”), the binding policy may render the non-binding policy irrelevant, or, if both policies are binding, then they may merely raise costs relative to one efficient policy to achieve the same abatement.

The cost-raising outcome occurs, for example, if a binding standard such as a low-carbon fuel standard means that more abatement takes place by that expensive means rather than by some other means – at the lower marginal abatement cost given by the common permit price elsewhere. In contrast, the irrelevant outcome occurs if the standard is not binding. Even if the standard alone would bind, a stringent carbon pricing policy may induce firms to reduce the carbon content of fuel below the standard’s requirement. Finally, the “mutually reinforcing” outcome may occur either because of some other market failure, or because of administrative complexity. For an example of the former, consider that if landlords’ energy-efficiency investments cannot be observed adequately, then renters may not be willing to pay for them. (Lucas Davis’ chapter, described below, considers this possibility directly.) A carbon pricing mechanism alone might then raise the cost of heating fuel paid by renters but still not be enough to induce landlords to pay for low-cost abatement via energy-efficiency investments. It may require additional regulations such as building codes. For an example of administrative complexity, consider the difficulty of applying carbon pricing to all forms of carbon, especially *ad hoc* fuels used in developing countries. A simple ban on the most carbon-intensive fuels may be more enforceable than collecting a price on the carbon content of it.

In addition to interacting with each other, both mandatory carbon pricing and other traditional type of energy regulations may interact with purely voluntary programs. A study of one particular voluntary program is provided in Chapter 9 by Matthew Kotchen. In 2005, the State of Connecticut started a “Clean Energy Options” program that allows individual households to pay extra for electricity that is “green” (produced by a mix of wind and small-scale hydro sources). In return, any municipality that achieves a certain threshold for their household participation rate can qualify for the “Connecticut Clean Energy Communities” (CCEC) program that provides free solar panels to display prominently in public locations. Kotchen regards the free solar panels as a “nudge”, a low-cost way to encourage voluntary household participation (not a true *quid pro quo* of any substantial value). He finds that the merely symbolic CCEC reward induced a 39 percent increase in household participation in the “Options” program to pay for green electricity. That increase represents 7,000 households, 31 percent of all participating households statewide, and prevents an estimated 23,000 metric tons of carbon dioxide emissions.

Kotchen thus demonstrates that a voluntary program can have significant impact. The next question is how that voluntary program might interact with other mandatory programs. If the state or federal government introduced a mandatory carbon abatement policy or carbon pricing policy, would households see their extra mandated costs as reasons *not* to incur any other costs voluntarily? In the language of other chapters just described, a binding cap-and-trade policy might make a non-binding voluntary program irrelevant. If so, it reduces the net abatement achieved by the cap-and-trade program by the loss of abatement that otherwise would have been achieved with just the voluntary program.

These studies explain just a few of the examples of climate policy interactions. More generally, climate policy can interact with any tax or regulation at the federal, state, or local level. Clearly a federal climate policy interacts with state or regional climate policy, but it also might interact with federal or state tax policy or even non-environmental regulations. For example, a federal tax or price on carbon may compound the effects of a federal or state tax on energy, such as the gasoline excise tax. Therefore a careful analyst must simultaneously consider the relevant taxes or regulations at all levels.

A climate policy may also interact with international policies, such as those intended to address the competitiveness of U.S. industry in trade with other countries. Certainly a simple U.S. tax or price paid on each ton of carbon dioxide emissions would raise the price of U.S. goods, and so it might best be paired with other policies that restore U.S. competitiveness in some manner. One of the proposed methods to address such problems is to give some CO_2 permits to firms in proportion to their output. Chapter 10 by Meredith Fowlie studies this kind of “output-based permit allocation” (OBPA).

As she notes, a standard carbon tax or price minimizes the total cost abatement, because it works via two effects. First, the “substitution effect” induces firms to shift from carbon-intensive inputs toward other inputs, which reduces the carbon per unit of output. Second, the “output effect” raises the cost of production and thus reduces the number of units of output demanded. In an open economy, however, the latter effect may harm U.S. competitiveness, move production overseas, and cause “leakage” (defined as the increase in emissions elsewhere).

Some U.S. proposals would combat this competitiveness problem by an OBPA, which essentially rewards firms for producing more output. Fowlie points out that this implicit output subsidy has both pros and cons. The advantage is that it can offset some of the climate policy's effect on U.S. output prices, which helps the U.S. compete and reduces leakage. The disadvantage is that it raises the overall cost of carbon abatement, by moving away from the cost-minimizing combination of abatement methods. A cap-and-trade program with OBPA still induces firms to shift towards less carbon-intensive production (the substitution effect), but it no longer induces consumers to reduce purchases (the output effect). With a fixed total number of permits and therefore a fixed requirement for total abatement, any attempt to protect one industry by OBPA means that more of the abatement must be undertaken by other industries. Those other industries must move up their rising marginal cost of abatement schedule.

Moreover, the House Bill (HR2454) specified that eligibility for this output subsidy would be based on some combination of the industry's energy intensity and trade intensity (that is, import penetration, or trade vulnerability). Industries with energy or emissions intensities above 20% are eligible regardless of trade intensity. But Fowlie shows that these are exactly the industries for which OBPA is most costly. Giving this output subsidy to energy-intensive industries means not reducing the output of energy-intensive industries. Instead, emissions must be reduced in industries that are not emission intensive, which can be very costly.

C. DESIGN FEATURES OF CLIMATE POLICY

Many economists like to characterize a carbon tax in simple models as a rate, t, on all carbon emissions, implicitly assuming perfect administration, measurement, and enforcement. This section describes issues in the detailed design of a climate policy, which includes decisions about how to administer it, how to monitor actual emissions, and how to enforce rules. Actual law must apply to particular firms and not others, and it may include various exemptions, varied rates, and offsets.

One issue in the design of climate policy is whether to apply it "upstream" on the producers of fossil fuel (mines, oil wells, and importers) or "downstream" on the users of fossil fuel (drivers, electricity generators, and manufacturing plants with smokestacks). Chapter 11 by Erin Mansur points out that most pollutants are best regulated downstream, because the actual emitters may have means of reducing the emissions per unit of fuel. If those abatement methods are omitted, then overall cost of abatement is not minimized. In the case of carbon dioxide emissions, however, some have argued that those "end of pipe" methods are negligible or too expensive (such as carbon capture and sequestration, CCS). The actual emissions may be based entirely on the carbon content of the fuel. Moreover, the tax or permit price could be collected from 150 refineries in the U.S. instead of from 105,000 gasoline service stations – or even worse, from drivers of 244 million motor vehicles. Measurement devices on all such vehicles would be prohibitively expensive.

Mansur develops a theory of cost-minimizing decisions about where to apply the tax on the vertical chain of production ("vertical targeting"). He models the tradeoffs explicitly, with choices both about fuel inputs and end-of-pipe abatement technology. He then adds transactions costs that depend on the number of firms who must be administered, and shows how the additional costs of administering more firms downstream might offset any cost advantages from capturing end-of-pipe abatement technology downstream. He discusses how the choice might also be affected by leakage, which might be minimized by aiming at whatever part of the vertical chain has the least elastic foreign supply. He also notes problems with "offsets", which are essentially payments for end-of-pipe or post-emission sequestration. Finally, he discusses how the analysis is changed by consideration of imperfect competition, price regulation by Public Utility Commissions that may or may not allow cost pass-through, and tax "salience" (where a more explicit payment of tax might affect actual behavioral reactions).

Chapter 12 by James Bushnell focuses on "offsets". He starts with the premise that a carbon tax or cap could readily be administered by measuring the carbon content of each fossil fuel. For a variety of reasons, however, actual climate policy is virtually bound to exclude certain firms from the taxed or capped sector. First, monitoring and enforcement may be particularly difficult for some other greenhouse gases, or for small businesses, residences, and agriculture. Second, political pressures from certain sectors seeking an advantage may expand the definition of "small business" and other exemptions. Third, some jurisdictions might not participate in the carbon policy agreement. Fourth, the lowest cost mitigation might include activities that take carbon out of the atmosphere in the form of "sequestration." In those cases, economic efficiency suggests that the policy not only place a positive price on emissions, but also provide a subsidy to sequestration activities that are *outside* the capping jurisdiction or capped sectors.

One way to achieve very low cost mitigation is to pay for sequestration though offsets, but the chapter by Bushnell points out a number of problems with those programs. First of all, any payments from firms in the capped jurisdiction to those in the uncapped jurisdiction inherently test the limits of inter-jurisdictional regulatory cooperation. Officials in the "host" nations must provide verification data or at least allow access to such data. Second, those host nations are often developing countries with weak regulatory or governance structures. Third, the system must set an "emissions baseline" against which to measure reductions. This step is literally impossible to do accurately, as it requires knowing what would have been the emissions in the absence of the program. Firms may have better information about those private plans than do the authorities, which gives rise to problems of moral hazard and adverse selection.

If authorities correctly gauge each firm's true baseline (emissions without any offset policy), then no such problems arise. With imperfect information, the moral hazard problem suggests that firms will have the incentive to invest in high-carbon projects or to delay investments in abatement, so that regulators set a high baseline. That way, they can receive offset payments for undertaking more abatement than they would have done absent the program. The adverse selection problem arises not from changes in firm behavior, but because authorities do not know which firms have high or low actual baselines. The effects of offsets will then depend on whether the authorities are right *on average* about firms' baselines. If so, only firms with low actual baselines will opt into the offset program. Those with high actual baselines opt out, undertake no abatement, and the result is more emissions and less overall abatement than anticipated. If authorities are wrong on average, then all baselines may be over-estimated, and payments may be high. In this case the offset program does not inefficiently allocate abatement, but it may result in less total abatement than anticipated – and thus may require tighter controls in the capped sector.

This study has implications for actual carbon policy design and implementation, particularly suggestions that the problems with offsets be addressed by placing a ceiling on the total number of offsets or a devaluation of all offsets. The former does nothing to fix the problem of adverse selection when only some firms opt into the program, and the latter may inappropriately treat all offsets as equally non-additional. More efficient responses might include overall program reviews, or randomized trials to collect better information.

Hilary Sigman provides a formal treatment of the monitoring and enforcement problem in Chapter 13. She assumes that the firm's chosen extent of compliance depends on the cost of reducing emissions, the price of a carbon dioxide permit, the probability of detection for noncompliance, and the fine for noncompliance. She points out that both the fine and the probability of detection are low in existing permit programs in Europe and the U.S., while observed compliance is high. This combination is somewhat of a puzzle, given the predictions of the model, but perhaps firms are concerned with public perceptions – the firm's image with customers, host communities, and potential employees. She also looks at the trend over time in the price of actual carbon dioxide permits in Europe, as opposed to the price of credits for reducing emissions elsewhere (offsets). Since the EU-ETS allows one-for-one trades between permits and offsets, we might expect these prices to be similar. Yet the difference in price is sometimes large, indicating that the offsets are not worth as much as permits to European firms. Again those firms may be concerned about the public relations problem of avoiding actual abatement in Europe, or they perceive a greater risk that offsets will be declared non-compliant.

With heterogeneous monitoring and enforcement costs among firms or emissions sources, Sigman notes that government policymakers have a choice about how many of them to include within the emission cap. The government might want to exclude emission sources with very high monitoring and enforcement costs, where a firm might find cheating easier, but Sigman shows that extending the program to include more sources can bring down the price of a permit enough to discourage noncompliance generally. Thus the government might find more compliance with a broader program that includes more sources – even those that might be more difficult to monitor.

In both the economic research and the policy spheres, most discussions have focused on mitigation – addressing climate change by restricting GHG emissions. Chapter 14 by Kerry Smith, by contrast, models adaptation to the warmer temperatures, reduced rainfall, and other changes associated with higher GHG concentrations. This can be a policy issue, as governments face the choice of either doing nothing (essentially waiting to see the degree of climate change before responding), or taking steps now to anticipate climate change and to facilitate adaptation.

Some goods represent "substitutes" for climate. If the climate gets hotter, we could substitute into more electricity for air conditioning. If climate change means reduced rainfall in some areas, one substitute good is increased storage of water in reservoirs. Many margins of substitution are possible, as residents could also substitute into goods that require less water! In any case, Smith's chapter points out that economic incentives can facilitate adaptation. If electricity or water is capacity constrained, for example, then policymakers can help allocate those scarce resources with pricing policies that take into account the scarcity at any particular time and place – perhaps using new metering technologies. Old technologies allow only one price per unit of water or electricity, so past analyses find the best single price and best single capacity that maximize expected social surplus given uncertain supply and demand. New technologies allow time-of-day pricing, however, which allows better allocation of the resource given any total availability within one period. Economic welfare then can greatly exceed the level under current rules, where a drought leads to arbitrary decisions about water allocation (e.g. rules against certain uses of water, regardless of value).

In other words, efficient policy planning for adaptation should not focus only on building the right number or type of power plants, dams, and other infrastructure. The need for that infrastructure depends on how goods like water and electricity will be priced. The bottom line is that policymakers must make decisions about built capacity, pricing policies, and access to resources during times of shortage; these decisions are related to each other, and they all affect economic welfare.

A final design decision considered in this section is the question of whether or not to phase-in the provisions of climate policy, either by raising the carbon tax rate gradually over time or by reducing the number of permits over time. To address this question, Chapter 15 by Roberton Williams builds a simple analytical, dynamic model with one sector that uses two inputs: emissions and one type of capital. Investment in new capital entails adjustment costs, providing a reason not to switch too rapidly away from emissions and into new capital. He then considers several different cases: a flow pollutant or stock pollutant, where marginal damages are either constant or rising with pollution.

For climate change, the relevant case is that of a stock pollutant, because damages depend on the concentration of greenhouse gases in the atmosphere, a stock that depends on accumulated emissions. If damages are proportional to that stock, so that marginal damages are constant, then Williams shows that the optimal price of emissions is constant – no phase-in of a carbon tax. In this same case, however, the optimal emissions each year are falling. Thus the optimal permit policy is phased in, with a falling number of permits issued each year.

If marginal pollution damages increase with the stock of GHG, however, then an optimal policy that reduces the stock of pollution over time will result in marginal damages that also fall over time, and therefore a price of emissions that falls over time. Then the optimal price path for emissions is one that jumps immediately to a level above its long run level. The optimal carbon tax then falls gradually, which is the *opposite* of the usual phase-in with a rising carbon tax.

Finally, Williams analyzes other considerations that may alter this optimal phase-in rule. If policymakers are concerned about the distribution of burdens, for example, then they may phase in a gradually increasing tax rate to limit the cost imposed on current owners of polluting capital. If authorities must take time to build capacity for monitoring or enforcement, then they may need to start with a subset of polluters and gradually expand the program to more firms. In any case, having dug into the topic, Williams concludes that these issues deserve more study.

D. SECTOR-SPECIFIC ISSUES

The remaining four chapters consider climate policy issues that are specific to four important areas: urban policy, plus the agricultural, automotive and buildings sectors.

Much of Matthew Kahn's recent work, summarized in Kahn (2010), considers the interaction between cities and climate change. As temperatures rise, for example, which cities are likely to gain population and which will lose population? Will higher temperatures lead people to move from rural and suburban neighborhoods into center cities? If the answer to the second question is "yes", urban economic theory predicts that center-city residents will use less energy and therefore emit fewer greenhouse gases. This is because land prices are higher in cities, so residents will live in smaller spaces, own fewer cars (which require land to store) and use the ones they do own to drive fewer miles (as urban density makes alternatives like walking or public transportation better substitutes).

Chapter 16 by Matthew Kahn sets out to evaluate this theory empirically. He uses three distinct data sets to evaluate whether central-city residents (a) drive fewer miles, (b) use public transportation more, and (c) use less electricity in their homes. He finds empirical support for the predictions of urban economic theory in all three cases, and the magnitude of the effects he measures is quite large. For instance, he finds households living in census block groups at the 25^{th} percentile of population density drive 25 percent more than households at in the 75^{th} percentile (and this distribution is taken over households that already live within 35 miles of a major city center). It is interesting to consider Kahn's estimates relative to the gasoline price elasticities estimated by Knittel and Sandler (in Chapter 19, discussed below). This comparison suggests that the same change in driving would require a 50 percent increase in gas prices. Kahn's work forces us to consider the fact that urban policies, such as redevelopment or crime prevention programs, also may impact greenhouse gas emissions. As Chris Knittel's comments on the chapter make clear, the article is a first step, but has not fully addressed the possibility that the observed relationships reflect selection. For instance, if households that currently live in the suburbs were forced to relocate to the city center, they might make different choices than households currently choosing to live in dense, urban areas.

Chapter 17 by Michael Roberts and Wolfram Schlenker focuses on the agricultural sector, which is a small share of the U.S. economy (less than 2% of GDP), but which creates large consumer surplus both in the U.S. and abroad. They focus on corn and soybean yields, noting that together with wheat and rice, these crops account for about 75 percent of world caloric consumption. Their estimates, which are consistent with previous work, suggest that U.S. crop yields fall dramatically in response to extreme temperatures. Specifically, yields decrease once average temperatures over the day exceed approximately 30°C, and the effects are predicted to be quite large (yields decrease by five percent for every 24-hour period that the temperature averages 40°C). A natural question to ask is whether technological progress is likely to make crops more resilient to heat in the future. Roberts and Schlenker look to the past as a guide, first noting the tremendous progress over the last seventy to eighty years in efforts to increase yields, particularly for corn. This progress has largely been attributed to advances in new seed engineering and fertilizer use. As they document, however, increased yields have if anything come at the expense of heat resistance, as decade-by-decade estimates suggest that yields may be declining more during periods of extreme heat than they did at the beginning of the sample period. They conclude by discussing the extent to which private companies will have an incentive to invest in research and development on heat-resistant seeds, as well as any possible role for policy.

The buildings sector, which accounts for 40 percent of greenhouse gas emissions in the U.S., has been singled out as a likely source of opportunities to reduce emissions at very low or even negative costs (McKinsey, 2007). The remaining question to economists is why the people who live and work in buildings have not taken advantage of these opportunities already, particularly if they would reduce energy bills by more than they would cost. Chapter 18 by Lucas Davis considers one of the potential explanations for the so-called "energy-efficiency gap." Specifically, he evaluates whether renters are less likely to have energy-efficient appliances than homeowners. This pattern is consistent with a principal-agent problem whereby landlords purchase the inefficient appliances because tenants pay the bills, and tenants cannot observe or do not consider the energy efficiency of the appliances when deciding whether to live in a particular home. Using cross-sectional survey data, Davis finds this to be the case, and his results stand-up to a very careful consideration of alternative explanations and functional forms. In terms of magnitudes, his results suggest that renters are between one and ten percentage points less likely to have energy-efficient appliances, which, relative to baseline penetration rates below fifty percent in all cases, accounts for a reasonable share of the variation between renters and homeowners.

Finally, Chapter 19 by Christopher Knittel and Ryan Sandler considers the automotive sector. Noting that environmental policies to price carbon emissions are likely to lead to higher gas prices, they examine how consumers have responded to recent changes in gas prices as an indication of how they would respond to carbon pricing. As the authors point out, consumers can adjust their behavior along a number of margins when faced by higher gasoline prices – driving less, buying more fuel-efficient new or used vehicles, scrapping fuel-inefficient vehicles, servicing their vehicle more frequently, or not driving too fast on the highway. While much of the previous literature has focused on the car purchase decision, they use a novel data source to consider both retirements (scrapping) and vehicle miles traveled. Specifically, they use information from California smog tests, which monitor every car older than six years at least once every two years.

They find large effects for scrapping decisions – vehicles in general are scrapped less when gas prices are high. This may reflect an income effect, whereby households are less likely to invest in a new vehicle and so keep their old one around longer. The more fuel inefficient cars, however, are more likely to be scrapped. Their results are provocative, yet the importance of the control variables suggests more room for further research. Also, while rich, the authors' data do not perfectly measure scrapping, so they must assume that vehicles that disappear from the data are scrapped. As mentioned above, they also find a large effect on vehicle-miles travelled.

Each chapter of this book makes an initial contribution to the economic analysis of an issue related to the design of U.S. climate change policy. Many of the detailed issues that our authors analyze must be resolved before climate policy can be implemented, so the compilation of initial efforts amounts to a major step forward. We expect that the studies in this book will draw attention to brand new research areas of vital importance to any efforts to reduce future climate change. The work will also contribute to better policy regarding whether and how to mitigate damages from global warming, sea level rise, loss of coastal areas, increased storm severity, loss of biodiversity, and increased frequency and duration of droughts. We look forward to reading follow-on studies and hope that economists will continue to engage in future policy developments.

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