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Lessons Learned from Three Decades of Experience with Cap-and-Trade

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ABSTRACT

This essay provides an overview of the major emissions trading programs of the past thirty years on which significant documentation exists, and draws a number of important lessons for future applications of this environmental policy instrument. References to a larger number of other emissions trading programs that have been implemented or proposed are included.

Key Words: market-based instruments, cap-and-trade, leaded gasoline phasedown, Clean Air Act amendments of 1990, sulfur dioxide, acid rain, carbon dioxide, global climate change, European Union Emissions Trading System

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Richard Schmalensee and Robert N. Stavins[1]

[9,887 words]

INTRODUCTION

Thirty years ago, the notion of a government allocating tradable rights to emit pollution was controversial. Many environmental advocates felt this approach inappropriately legitimized environmental degradation, while others doubted its workability. At that time, virtually all pollution regulations took a more prescriptive, "command-and-control" approach, either specifying the type of pollution-control equipment to be installed or by setting uniform limits on emission levels or rates.

Today, it is broadly acknowledged that because emission reduction costs often vary greatly, aggregate abatement costs under command-and-control approaches can be much higher than they need to be. Instead, by establishing a price on emissions, either directly through taxes or indirectly through a market for tradable emissions rights (called permits or allowances) established under a cap-and-trade policy, market-based approaches tend to equate marginal abatement costs rather than emissions levels or rates across sources, and thereby can – in principle – achieve pollution-control targets at minimum cost.

Most early experience with market-based environmental policies was in the United States, starting with the Federal government's attention to localized air pollution, and subsequently transboundary acid rain. More recently, with increased attention to the threat of global climate change, the locus of policy action using this approach has shifted from national to sub-national policies in the United States, and for national policies from this country to others.

We examine the design and performance of seven of the most prominent emissions trading systems that have been implemented over the past 30 years – systems that are particularly important environmentally and/or economically and the performance of which has been documented. We ask what lessons this experience offers for future applications. We focus on systems that involve trading emissions rights and exclude emission-reduction-credit (offset) systems, which offer credits for emissions reductions from some baseline. It is worth noting, however, that systems of the latter kind have been used in many

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countries, as well as internationally in the form of the Clean Development Mechanism under the Kyoto Protocol.

THIRTY YEARS OF EXPERIENCE

The seven emissions trading systems examined here are: the U.S. Environmental Protection Agency's (EPA's) leaded gasoline phasedown in the 1980s; the sulfur dioxide allowance trading program under the Clean Air Act Amendments of 1990; the Regional Clean Air Incentives Market in southern California; NO_X trading in the Eastern United States; the Regional Greenhouse Gas Initiative in the northeast United States; California's AB-32 cap-and-trade system; and the European Union Emissions Trading System. All but the first of these are textbook cap-and-trade systems. Table 1 provides a brief overview of these systems.

*** Insert Table 1 near here ***

Leaded Gasoline Phasedown

In the 1970s, concern arose regarding the use of lead as an additive in gasoline. Although it was later documented that lead oxide emissions were a serious human health threat, the original concern was that these emissions were fouling catalytic converters, which were required in new U.S. cars starting in 1975 to reduce emissions of carbon monoxide and hydrocarbons. Because of this concern, in the early 1980s, EPA began a phasedown of lead in gasoline to 10 percent of its original level.

A trading program was launched in 1982 that was intended to lessen the financial burden on smaller refineries, which had significantly higher compliance costs. Unlike a textbook cap-and-trade program, there was no explicit allocation of permits, but the system implicitly awarded property rights on the basis of historical levels of gasoline production (Hahn 1989). If a refiner produced gasoline with a lower total lead content than was allowed, it earned lead credits that EPA allowed it to sell. Under banking provisions of the program, lead credits could be saved for later use, providing an incentive for early reductions to help meet the lower limits that existed during the later years of the phasedown. Firms made extensive use of this option.

Performance

Trading resulted in leaded gasoline being removed from the market faster than anticipated. In each year of the program, more than 60 percent of the lead added to gasoline was associated with traded lead credits (Hahn and Hester 1989), until the lead phasedown was completed and the program was terminated at the end of 1987. Overall, the program was successful in meeting its environmental targets, although it may have produced some temporary geographic shifts in use patterns (Anderson, Hofmann, and Rusin 1990; Newell and Rogers 2007). The high level of trading between firms far surpassed levels observed in earlier environmental offset markets. This level of trading activity and the rate at which refiners reduced their production of leaded gasoline suggest that the program was relatively cost-effective (Hahn and Hester 1989; Kerr and Maré 1997; Nichols 1997). EPA estimated savings from the lead trading program of approximately 20 percent compared with alternative approaches that did not provide for trade (U.S. Environmental Protection Agency, Office of Policy Analysis 1985), and the program provided significant incentives for cost-saving technology diffusion (Kerr and Newell 2003).

Lessons

First, as the first environmental program in which trading played a central role, EPA's leaded gasoline phasedown served as a proof of concept, showing that a tradable emission rights system could be environmentally effective and economically cost effective.

Second, the program's implementation demonstrated that transaction costs in such a system could be small enough to permit substantial trade. Specifically, requiring prior government approval of individual trades had raised transactions cost and hampered trade in EPA's Emissions Trading Program in the 1970s (a set of emission-reduction-credit systems), while the lack of such requirements was an important factor in the success of lead trading (Hahn and Hester 1989).

Third, as in other programs to follow, banking played a very important role. By enabling intertemporal substitution, it contributed a significant share of the gains from trade.

Sulfur Dioxide Allowance Trading

During the 1980s, there was growing concern that acid precipitation – due mainly to emissions of sulfur dioxide (SO_2) from coal-fired power plants – was damaging forests and aquatic ecosystems. Because costs of emissions reductions differed dramatically among existing plants, legislative proposals to use one-size-fits-all command-and-control methods to address this problem failed to attract significant support.

In response, Title IV of the Clean Air Act Amendments of 1990 launched the path-breaking SO_2 allowance trading program. Phase I (1995–1999) required emissions reductions from the 263 most polluting coal-fired electric generating units (larger than 100 MW), almost all located east of the Mississippi River. Phase II, which began in 2000, placed an aggregate national emissions cap on approximately 3,200 electric generating units (larger than 25 MW) — nearly the entire fleet of fossil-fueled plants in the continental United States (Ellerman *et al.* 2000). This cap represented a 50 percent reduction from 1980 levels. The allowances were demarcated by vintage, with the total number decreasing for successive years, thereby establishing a declining cap.

The government *gave* power plants permits to emit (called "allowances"), denominated in tons of SO_2 emissions; allocations were based mainly on actual fuel use during the period 1985--1987.[2] If annual emissions at a regulated facility exceeded the allowances allocated to that facility, the owner could buy allowances or reduce emissions, whether by installing pollution controls, changing the mix of fuels used to operate the facility, or scaling back operations. If emissions at a regulated facility were reduced below its allowance allocation, the facility owner could sell the extra allowances or bank them for future use. EPA monitored emissions on a continuous basis and verified allowances submitted for compliance.

The cap-and-trade system created incentives to find ways to reduce SO_2 emissions at the lowest cost. Although government auctioning of allowances would have generated revenue that could have been used – in principle – to reduce distortionary taxes, thereby reducing the program's social cost (Goulder 1995), this efficiency argument was not advanced at the time. Because the entire investor-owned electric utility industry was subject to cost-of-service regulation in 1990, it was assumed that the value of free allowances would be passed on to consumers and would not generate windfall profits for generators. As important, the political value of being able to allocate free allowances to build support by addressing differential economic and other concerns was substantial (Joskow and Schmalensee 1998). Since the equilibrium allocation of pollution permits, after trading has occurred, is independent of the initial allocation (Montgomery 1972) — barring particularly problematic types of transaction costs (Hahn and Stavins 2012) --- the initial allocation of allowances could be designed to maximize political support without compromising the system's environmental performance or raising its cost.

Performance

The program performed exceptionally well along all relevant dimensions. SO_2 emissions from electric power plants decreased 36 percent between 1990 and 2004 (U.S. Environmental Protection Agency 2011), even though electricity generation from coal-fired power plants *increased* 25 percent over the same period (U.S. Energy Information Administration 2012). The program delivered emissions reductions more quickly than expected, as utilities made substantial use of the freedom to bank allowances for future use. With its $2,000/ton statutory fine for any emissions exceeding allowance holdings (and continuous emissions monitoring), compliance was nearly 100 percent.

Some worried that emissions would end up disproportionately concentrated and would produce "hot spots" of unacceptably high SO_2 concentrations in eastern forests. However, the geographic pattern of emissions reductions was broadly consistent with model predictions, and the program did not generate significant hot spots (Ellerman et al. 2000; Swift 2004).

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[2] In addition, the statute required EPA to withhold about 2.8% of all allocated allowances each year, sell them at an annual auction, and return the proceeds in proportion to those from whom allowances had been withheld (Ellerman *et al* 2000). This provision was intended to stimulate the development of private market-trading activity and seems to have done so.

The cost of the program was significantly reduced as rail rates fell after their substantial deregulation in 1980, significantly reducing the cost of burning low-sulfur Western coal in the East (Keohane 2003; Ellerman and Montero 1980; Schmalensee and Stavins 2013). That said, cost savings were at least 15 percent and perhaps as great as 90 percent of the costs of various counterfactual command and control policies (Carlson et al. 2000; Ellerman et al. 2000; Keohane 2003). In addition to static cost effectiveness, there is evidence that the program reduced costs over time by providing incentives for innovation (Ellerman *et al*. 2000; Popp 2003; Bellas and Lange 2011). On the other hand, the program's costs were likely not as low as they could have been, due to a variety of constraints (Schmalensee and Stavins 2013).

In any case, the SO_2 allowance-trading system's actual costs were much lower than would have been incurred under a traditional regulatory approach – if such an approach had been politically feasible. The program's goals were achieved with less litigation (and thus less uncertainty) than is typical for traditional environmental programs, because firms that found it particularly costly to reduce emissions had the option to buy allowances instead, and because firms could not complain about EPA's exercise of administrative discretion, since the law gave it very little discretion. That said, subsequent regulatory actions, court decisions, and regulatory responses led to the virtual elimination of the SO_2 market by 2010 (Schmalensee and Stavins 2013).

The SO_2 reductions achieved benefits that were a substantial multiple of costs (Burtraw, *et al*. 1998; Chestnut and Mills 2005). In contrast to what was expected at the time of the program's enactment, however, the program's benefits were due mainly to the positive human health impacts of decreased local SO_2 and small particulate concentrations, not the ecological impacts of reduced acid deposition (Schmalensee and Stavins 2013), though there were significant ecological benefits as well (Banzhal et al. 2006).

Lessons

Even though the conclusion of trading in the leaded gasoline phasedown preceded by a decade the beginning of the SO_2 allowance trading program, the SO_2 system was and is still today often celebrated as the first important use of this policy instrument. Some of the lessons from the system's design and performance reinforce lessons that emerged from the lead program.

First, to provide some degree of certainty to regulated entities, facilitate their planning, and limit price volatility in early years, it is valuable to put final rules in place well before the beginning of the first compliance period. This was done two years prior with the SO_2 allowance trading program.

Second, as with the lead trading program, the absence of requirements for prior approval of trades reduced uncertainty for utilities and administrative costs for government, and it contributed to low transaction costs and substantial trading (Rico 1995).

Third, as in the lead trading program, banking was extremely important. It accounted for more than half of the program's cost savings (Carlson et al. 2000; Ellerman et al. 2000).

Fourth, a robust allowance market can be fostered through a cap that is significantly below business-as-usual (BAU) emissions, combined with unrestricted trading and banking.

Fifth, allocation of free allowances can be used to build political support, an important reminder for later programs focused on climate change.

Sixth, intra-sector emissions leakage can be minimized, as it was in this program, by including all non-trivial sources within the sector.

Seventh, high levels of compliance can be ensured through accurate emissions monitoring and significant penalties for non-compliance.

Regional Clean Air Incentives Market

The South Coast Air Quality Management District, which is responsible for controlling emissions in a four-county area of southern California, launched its Regional Clean Air Incentives Market (RECLAIM) in 1993 to reduce emissions of nitrogen oxides (NO_x) and in 1994 to reduce SO_2 emissions from 350 affected sources, including power plants and industrial sources in the Los Angeles area that emitted four or more tons per year of either pollutant. RECLAIM replaced command-and-control regulations that were scheduled to bring the region into compliance with national ambient air quality standards (Ellerman, Joskow, and Harrison 2003).

Initial free allocations of NO_x and SO_2 RECLAIM Trading Credits (RTCs) were based on historical peak production levels, and the initial allocations were 40 to 60 percent above actual emissions until the year 2000. The NO_x and SO_2 caps declined annually by 8.3% and 6.8%, respectively, until 2003, when the market reached its overall goal of a 70% emissions reduction (Hansjurgens 2011; Ellerman, Joskow, and Harrison 2003). The compliance period was a single year, and banking was not allowed. A particularly interesting aspect of the trading program's design was its zonal nature: trades were not permitted from downwind to upwind sources.

Performance

Prospective analysis predicted significant cost savings (Johnson and Pekelney 1996; Anderson 1997). By June 1996, 353 program participants had traded more than 100,000 tons of NO_x and SO_2 credits, with a value of over $10 million. Retrospective empirical evidence indicates that emissions at RECLAIM facilities were some 20 percent lower than at facilities that were regulated with parallel, command-and-control regulations, that hotspots did not appear, and that substantial cost savings were achieved (Burtraw and Szambelan 2010; Fowlie, Holland, and Mansur 2012).

In the program's early years, allowance prices remained in the expected range of $500 to $1,000 per ton of NO_X, but California's electricity crisis in 2000-2001 eliminated some sources of electricity and thereby caused electricity demand and production levels at some RECLAIM generating facilities to increase dramatically. This caused emissions to exceed permit allocations at these facilities, thereby bringing about a dramatic spike in allowance prices to more than $60,000/ton (Fowlie, Holland, and Mansur 2012). Part of the problem was the absence of a pool of banked allowances. The program was temporarily suspended for the affected sources, and prices returned to normal levels (below $2,000/ton) by 2002, with all sources rejoining the program by 2007. As of July, 2015, the twelve-month moving average of prices was $3,625/ton (South Coast Air Quality Management District 2015).

Lessons

First, because the RECLAIM system included two zones, with trades allowed in only one direction to account for prevailing winds, the design demonstrated the feasibility of a basic ambient as opposed to an emissions-based cap-and-trade system. Thus, system design can accommodate a non-uniformly mixed pollutant and attendant concerns about hot spots.

Second, a lesson from RECLAIM that later turned out to be important for several CO_2 cap-and-trade systems is that over-allocation of allowances means there is no scarcity created and therefore no functioning spot allowance market, though there were active forward markets throughout.

Third, provisions for emissions banking (and other cost-containment elements) are crucial in order to allow for compliance at reasonable cost in years in which unanticipated circumstances lead to greater than expected emissions.

NO_x Trading in the Eastern United States

Two programs are relevant here. First, under EPA guidance and enabled by the Clean Air Act Amendments of 1990, eleven northeastern states and the District of Columbia developed and implemented the NO_x Budget Program, a regional NO_x cap-and-trade system, in 1999. Reflecting the significant adverse health effects of ground-level ozone (smog) (U.S. Environmental Protection Agency 2004), the goal was to reduce summertime ground-level ozone by more than 50% as compared with 1990 levels. Some 1,000 electric generating and industrial units were required to demonstrate compliance each year from May through September (the summer ozone season).

The region was divided into upwind and downwind zones. Allowances were given to states to distribute to in-state sources, with less generous allowance allocations, measured as percentages of 1990 emissions, given to upwind states. Since interzonal trading was permitted on a one-for-one basis, however, the two zones made similar reductions from baseline emissions levels (Ozone Transport

Commission 2003). Sources could buy, sell, and bank allowances (within limits due to the seasonal nature of the ozone problem).

In 1998, the EPA issued the NO_x SIP Call, which required 21 eastern states to submit plans to reduce their NOx emissions from more than 2,500 sources. The Call included a model rule, which, if adopted by a state, enabled it to meet its obligations by participating in an interstate cap-and-trade program. All affected states adopted the model rule, and the NOx Budget Trading Program went into effect in 2003, replacing the NOx Budget Program. As in the earlier program, states were given allowances to allocate to in-state sources.

In 2009, the NO_X Budget Trading Program was effectively replaced by the Clean Air Interstate Rule (CAIR), and CAIR was replaced in January 2015 by the Cross State Air Pollution Rule (CSAPR).

Performance

Uncertainty existed in the NO_X Budget Program market at the outset because some rules were not in place when trading commenced. The result was a high degree of price volatility in the program's first year, although prices stabilized by the program's second year of operation (Farrell 2000). Overall, NO_x emissions declined from about 1.9 million tons in 1990 to less than 500,000 tons by 2006, with 99% compliance (Butler, *et al.* 2011; Deschenes *et al.* 2012). Abatement cost savings of 40 to 47 percent were estimated for the period 1999-2003, compared with conventional regulation without trading or banking (Farrell 2000).

Lessons

First, to avoid unnecessary price volatility, the design of an emissions trading program should be clear, with all rules in place well before the program takes effect.

Second, a lesson that is potentially important in the future for the Obama administration's Clean Power Plan is that a well-designed multi-state process with federal guidance can be effective in coordinating what are legally state-level goals.

Third, this history provides a precedent and model for expanding the coverage of a cap-and-trade system over time to include additional jurisdictions (such as neighboring states).

Fourth, giving states freedom to allocate allowances among in-state sources can provide valuable flexibility without compromising environmental goals.

The Regional Greenhouse Gas Initiative

Nine northeastern U.S. states participate in the Regional Greenhouse Gas Initiative (RGGI), the first cap-and-trade system in the United States to address carbon dioxide (CO_2) emissions. RGGI is a downstream program limited to the power sector. The program began in 2009 with a goal of limiting emissions from regulated sources to then current levels in the period from 2009 to 2014. The emissions cap was then set to decrease by 2.5 percent each year from 2015, until it reached 10 percent below 2009 emissions in 2019. It was originally anticipated that meeting this goal would require a reduction approximately of 35 percent below business-as-usual emissions (13 percent below 1990 emissions levels).

Because of the economic recession and drastic declines in natural gas prices relative to coal prices, the cap quickly ceased to be binding, and it appeared unlikely to become binding through 2020. In response, the RGGI states agreed in a pre-planned review in 2012 to establish a lower cap in 2014, with 2.5% annual cuts thereafter to 2019. Reflecting these changes, allowance prices fell from approximately \$3/ton of CO_2 at the first auction in 2008, down to the floor price of \$1.86/ton in 2010, and up to \$5.50/ton in 2015.

The program has required participating states to auction at least 25 percent of their allowances and to use the proceeds for energy efficiency, renewable energy, and related improvements.[3] In practice, states have auctioned virtually all allowances. The major rationale for an auction was to avoid the windfall profits that would generally result from free allocation of allowances in deregulated electricity markets (Sijm, Neuhoff, and Chen 2006).

An allowance price ceiling is included in the form of a cost containment reserve, from which some additional allowances are released for sale when auction prices hit specified, escalating levels. A price floor is also included through an auction reserve price. Any unsold allowances are permanently retired after three years, thereby providing an automatic mechanism for tightening the cap in the face of any chronic allowance surplus. This combination provides a price collar, making the program a hybrid – to some degree – of a cap-and-trade system and a carbon tax.

Performance

Because the cap was not binding during the program's first compliance period (though the price floor kept the allowance price positive) and has been barely binding since then, the direct impacts of the RGGI program on power-sector CO_2 emissions have been small. However, the program's auctions have generated more than \$1 billion in revenues for the participating states. Per the program's design, some of this revenue has gone to financing government programs that can reduce energy demand and hence CO_2 emissions and demand for allowances (Hibbard, *et al.* 2011)

Monitoring costs for the program have been very low, because U.S. power plants were already required to report their hourly CO_2 emissions by the federal SO_2 allowance trading program. The penalty for non-compliance is that entities must submit three allowances for each allowance they are short.

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[3] Three states have used some of their auction revenue to help balance their overall state budgets.

Because of the geographically-limited scope of the RGGI system, combined with interconnected electricity markets, emissions leakage has been a significant concern (Burtraw, Kahn, and Palmer 2006). One study found that if the program were fully binding, power imports from Pennsylvania to New York State could result in emissions leakage approximating as much as 50% (Sue Wing and Kolodziej 2008).

Lessons

First, a lesson that has not been lost on policy makers is that a cap-and-trade system that auctions its allowances can generate substantial revenue for government, whether or not the system has much effect on emissions.

Second, the leakage problem is potentially severe for any state or regional program; this is particularly the case for a power-sector program because of the interconnected nature of electricity markets (Burtraw, Kahn, and Palmer 2006).

Third, a changing economy can render a cap non-binding or drive prices to excessive levels. Hence, there is an important role for price collars. In the case of RGGI, an effective floor on the price of allowances was established through the use of a reservation price in allowance auctions, so that allowance prices remain positive. Upside cost-containment has not been tested and may be less effective because of limits on the size of the cost containment reserve.

California's AB-32 Cap-and-Trade System

In 2006, California enacted Assembly Bill 32 (AB-32), which required the California Air Resources Board to establish an ambitious program to cut the state's greenhouse gas (GHG) emissions to their 1990 level by the year 2020. The program includes: energy efficiency standards for vehicles, buildings, and appliances; renewable portfolio standards that increase the share of renewable electricity supply from 20% to 33%; a low carbon fuel standard that requires refineries to reduce the carbon content of motor vehicle fuels; and a cap-and-trade system (California Environmental Protection Agency 2014).

The AB-32 cap-and-trade system began in 2013 with coverage of electricity sold in California (wherever generated[4]) and large-scale manufacturing. It was expanded to include fuels in 2015, thereby covering 85% of the state's emissions. The 2013 cap was set at approximately 98% percent of anticipated 2012 emissions, and annual cuts follow until 1990 emission levels are achieved in 2020. Most allowances were initially distributed via free allocation, with greater use of auctions over time. Banking is allowed, and regulated entities may use approved offsets from emissions reductions from forestry, dairy digestion, and ozone-depleting substances reduction to account for up to 49% of reductions.

[4] Profound leakage risks nonetheless exist in California for the electricity sector due to contract reshuffling (Bushnell, Peterman, and Wolfram 2008).

A ceiling on allowance prices is established by releasing allowances from a reserve when auction prices hit specified levels that escalate over time. A price floor is created through an auction reservation price, with unsold allowances held until the reservation price is exceeded for six consecutive months. This combination produces an effective price collar, making the system a hybrid of cap-and-trade and a carbon tax. In addition, competitiveness concerns in energy-intensive, trade-exposed (EITE) industries are addressed by granting free allowances in proportion to production levels in previous periods.

It is noteworthy that California's system was linked to a very similar system in Quebec in 2014 (Kroft and Drance 2015). Each system recognizes allowances from the other system for compliance purposes, and joint allowance auctions are held on a quarterly basis.

Performance and Lessons

Since the system was only launched in 2013, it is too soon to comment on its performance, other than to note that the auction mechanisms and other features of the program's design have functioned as anticipated. Hence, the lessons we identify from the AB-32 cap-and-trade system are from its design, rather than its performance.

First, the California system has demonstrated that an initial free allowance allocation that fosters political support can be successfully transitioned over time to greater auctioning of allowances.

Second, the California experience is a reminder of the political pressures to use auction revenues for purposes other than reducing distortionary taxes. Through May, 2015, the AB-32 cap-and-trade auctions had generated over $2 billion, an amount that is anticipated to reach nearly $4 billion by the end of 2016 (California Legislative Analyst's Office 2015). As courts have interpreted the state constitution, the funds "are to be used to reduce GHG emissions and, to the extent feasible, achieve co-benefits such as job creation, air quality improvements, and public health benefits."

Third, California's AB-32 system was the first CO_2 (or GHG) cap-and-trade system to be essentially economy-wide, demonstrating the feasibility of this approach, compared with less efficient approaches that treat different sectors differently.

Fourth, the system greatly reduces the risk of unanticipated allowance price changes and price volatility by employing an effective price collar.

Fifth, California has deployed an effective mechanism to address concerns about competitiveness impacts in EITE sectors. Granting free allowances to firms in specific sectors in proportion to their production levels in the previous time period subsidizes production and thus directly affects competitiveness. In contrast, simply giving allowances for free to firms in certain sectors (as in the European Union's Emissions Trading System – see below) has no effect on the receiving firm's competitiveness, because its marginal production costs are unaffected.

Sixth, California's intense interest in linking its cap-and-trade system with those in other sub-national and national jurisdictions – and its implemented linkage with Quebec – reflects the importance of such linkage to reduce abatement costs, reduce price volatility, and restrain market power (Ranson and Stavins 2013).

Seventh, while policies that address other market failures, such as the well-known principal-agent problem associated with energy-efficiency investment decisions by landlords and tenants, can reduce costs, the suite of policies within California's AB-32 provides examples of so-called "complementary policies" that are more likely to increase costs with no effect on emissions.

An important example is the state's Low Carbon Fuel Standard (LCFS), which requires that California refineries produce fuel with, on average, no more than a stated amount of life-cycle carbon content. Since refineries and transportation fuels are already covered by the cap of the cap-and-trade system, this additional regulation cannot reduce emissions in the short run unless it makes the allowance price floor binding. Because the LCFS is a binding constraint on refiners, additional CO_2 emission reductions are achieved in this sector beyond what the cap-and-trade system would accomplish on its own. This produces 100% leakage to other sectors when allowances are sold, however, unless the price floor becomes effective. In any case, marginal abatement costs are not equated across sectors and sources,[5] so aggregate abatement costs are increased. And allowance prices are depressed, causing concern about the ability of the cap-and-trade system to encourage technological change --- except, of course, in the refinery sector. In short, this "complementary policy" mainly serves to increase abatement costs and lower allowance prices (Goulder and Stavins 2011). Many other so-called complementary policies also have these same perverse effects.[6]

The European Union Emissions Trading System

The world's largest carbon pricing regime is the European Union Emission Trading System (EU ETS), a cap-and-trade system of CO_2 allowances (European Commission 2012). Adopted in 2003 with a pilot phase that started in 2005, the EU ETS covers about half of EU CO_2 emissions in 31 countries (Ellerman and Buchner 2007). The 11,500 regulated emitters include electricity generators and large industrial sources. Competitiveness concerns were dealt with by the allocation of free allowances to selected sectors. The program does not cover most sources in the transportation, commercial, or residential sectors, although some aviation sector emissions were brought under the cap in 2012.

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[5] As of August, 2015, LCFS credits were selling for an average of \$57/ton of CO_2 (California Environmental Protection Agency 2015), while the cap-and-trade allowances were selling for about \$13/ton of CO_2 (Climate Policy Initiative 2015).

[6] The requirement that auction revenues from the AB-32 cap-and-trade system be spent to further the purposes of the statute virtually guarantees that this perverse interaction of "complementary policies" and the cap-and-trade system will continue.

The EU ETS was designed to be implemented in phases: a pilot Phase I from 2005 to 2007, a Kyoto Phase II from 2008 to 2012, and a series of subsequent Phases. Penalties for violations increased from €40 per ton of CO_2 in the first phase to €100 in the second phase. Although the first phase allowed trading only in CO_2, the second phase broadened the program to include some other GHGs.

The process for setting caps and allowances in member states was initially decentralized (Kruger, Oates, and Pizer 2007), with each member state responsible for proposing its own national carbon cap, subject to review by the European Commission. This created incentives for individual countries to be generous with their allowances (Convery and Redmond 2007).

Performance

In January, 2005, the allowance price per ton of CO_2 was approximately €8; by early 2006, it exceeded €30. After it became clear that the generous allocation of allowances in 2005 had exceeded emissions by about 4 percent, the price fell by about half in one week of April, 2006, before fluctuating and returning to about €8, en route to a collapse to zero in 2007 (Convery and Redmond 2007). This volatility was attributed to the absence of good emissions data at the beginning of the program, a surplus of allowances, energy price volatility, and the inability to bank allowances from Phase I to Phase II (Market Advisory Committee 2007).

The first and second phases of the EU ETS required member states to distribute almost all of the emissions allowances freely to regulated sources, but beginning in 2013, member states were required to auction larger shares of their allowances. The initial free distribution of allowances led to complaints about electricity generators' "windfall profits" when electricity prices increased significantly in 2005. But higher fuel prices also played a role in the electricity price increases, and some generators' profits reflected their ownership of low-cost nuclear or coal generation in areas where the market electricity price was set by higher-cost natural gas plants (Ellerman and Buchner 2007).

The system's cap was tightened for Phase II, and its scope was expanded to cover new sources in countries that participated in Phase I plus nations that joined the EU in 2007 and 2013. In addition, three non-member states joined the EU ETS in 2008. Allowance prices in Phase II increased to over €20 in 2008, then fell when recession led to decreased demand. Heavy use of offsets under the Clean Development Mechanism also reduced demand. Prices fell to €10 by the fall of 2011 and have remained in the range of €5 to €10 since then.

The EU ETS has been extended through its Phase III, 2013-2020, with a more stringent, centrally determined cap (20% below 1990 emissions), a larger share of allowances to be auctioned, tighter limits on the use of offsets, and unlimited banking of allowances between Phases II and III.

Concern continues in the EU regarding low allowances prices (Löfgren, *et al.* 2015). These prices reflect the slow pace of European economic recovery and the lack of a price floor, as well as the fact that other binding EU policies, particularly renewable generation and energy efficiency standards, reduce emissions under the cap. In the absence of a binding price floor, these other policies raise costs and reduce allowance prices without affecting total emissions.

Lessons

First, good data are potentially important for sound allowance allocation and cap-setting decisions to avoid the type of over-allocation that occurred in the EU ETS's Phase I.

Second, to avoid an artificial price collapse at the end of a compliance period, it is necessary to allow for banking from one period to the next. The European system did not do this in Phase I, and the unsurprising result was that Phase I allowance prices fell to zero as that period came to a close.

Third, more broadly, as with the California system, the EU ETS illustrates the perverse outcomes that are fostered when so-called "complementary policies" are put in place under the cap of a cap-and-trade system, particularly in the absence of a price floor. Unless those policies address sources outside of the cap or other market failures, they relocate emissions, drive up aggregate abatement costs, and depress allowance prices.

Fourth, granting free allowances to selected sectors is a poor way to deal with competitiveness concerns, though it may serve a useful political function. When the allocations are not linked to production, they do not affect marginal costs. Thus, incentives to increase output or to relocate production or investment in other jurisdictions remain unchanged.

Fifth, on the other hand, the history of the EU ETS shows that it can be possible to move over time from a regime of generally free allowances to one in which most are auctioned.

Other Cap-and-Trade Systems

Historically, several countries implemented systems of tradable rights for ozone depleting substances (ODS) during the ODS phasedown from 1991 to 2000 under the 1987 Montreal Protocol (Klaassen 1999; U.S. Environmental Protection Agency 2014). In principle, an international CO_2 cap-and-trade system has also operated since 2008 under the Kyoto Protocol: Annex I countries that have signed and ratified the Kyoto Protocol can sell their emission reductions beyond their compliance obligations to other Annex I parties with compliance obligations. However, because the trading agents are nations, rather than firms, there has been little activity, as anticipated (Hahn and Stavins 1999).

Currently, CO_2 cap-and-trade systems are in various stages of development in a number of countries around the world, including Japan (Sopher and Mansell 2014a), South Korea (Park and Hong 2014), Kazakhstan (Kossoy *et al* 2014), and Switzerland (Sopher and Mansell 2014b). Most importantly, China began municipal and provincial pilot trading systems in 2013 (Kossoy et al 2014), and on September 25, 2015, President Xi Jinping announced that China will launch a national CO_2 cap-and-trade system covering key industries in 2017 (Cunningham 2015).

Cap-and-trade systems have also been proposed in other countries at levels of governance ranging from sub-municipal to national (Kossoy, *et al.* 2014; Organization for Economic Cooperation and Development and World Bank Group 2015). Notably, the government of Ontario has recently announced a CO_2 cap-and-trade system to be linked to Quebec's system and thus to California's (Government of Ontario 2015). In addition, the Clean Power Plan, finalized on August 3, 2015 and aimed at CO_2 emissions from electricity generators, both enables and encourages state-level and multi-state emissions trading (U.S. Environmental Protection Agency 2015). This rule will be subject to serious legal challenges, however (Potts and Zoppo 2015).

KEY LESSONS

While there has been a significant amount of positive experience over the past thirty years with the use of cap-and-trade policies for environmental protection, the design and performance of cap-and-trade systems have varied. That experience has lessons for system design and for identifying future applications, as well as for climate change policy.

Key Lessons for System Design

Most important, cap-and-trade has long since proven to be environmentally effective and economically cost-effective relative to traditional command and control approaches. Less flexible systems would not have led to the technological change that may have been induced by market-based instruments (Keohane 2003; Schmalensee and Stavins 2013), nor the induced process innovations that have resulted (Doucet and Strauss 1994).

Transactions costs can be low enough to permit considerable efficiency-enhancing trade among sophisticated entities, particularly if, in contrast to early U.S. experience with emissions offset systems, prior approval of trades is not required. It is clear from theory and experience that a robust market requires a cap that is significantly below BAU emissions. In addition, it has been shown to be important for final rules (including those for allowance allocation) to be established and accurate data supplied well before commencement of a system's first compliance period to avoid unnecessary price volatility. High levels of compliance in a downstream system can be obtained with accurate emissions monitoring combined with significant penalties for non-compliance.

Provisions for banking of allowances have proven to very important. Such inter-temporal trading represented a large share of the realized gains from trade in the lead phasedown and SO_2 allowance trading. Moreover, the absence of banking provisions can lead to price spikes (RECLAIM) and price collapses (EU ETS).

In addition, of course, a changing economy can render a cap non-binding (RGGI, EU ETS) or drive prices to excessive levels (RECLAIM). Hence, there is a distinct role in cap-and-trade systems for price collars, which reduce the risk of unanticipated allowance price changes and price volatility by combining an auction price floor with an allowance reserve (RGGI, AB-32).

Economy-wide systems have been shown to be feasible (AB-32), although downstream, sectoral programs have been more commonly employed (RGGI, EU ETS). In the context of climate policy, CO_2 emissions trading programs have inevitably been downstream and limited in scope of coverage, in contrast with textbook, upstream trading of rights associated with the carbon content of fossil fuels.

The allocation of allowances is inevitably a major political issue, because of the large distributional impacts that can be involved. Free allowance allocation has proven abler to build political support, although it foregoes the opportunity to cut the program's overall social cost by auctioning allowances and using the proceeds to cut distortionary taxes (SO_2 allowance trading, AB-32). On the other hand, experience has revealed that political pressures exist to use auction revenue not to cut such taxes but to fund new or existing environmental programs or relieve deficits (AB-32, RGGI). Indeed, cap-and-trade allowance auctions can and have generated very significant revenue for governments (RGGI, AB-32).

Another prominent political concern when cap-and-trade systems have been designed has been the possibility of emissions leakage and adverse competitiveness impacts. Of course, virtually any meaningful environmental policy will increase production costs and thereby could raise these concerns, but this issue has been more prominent when cap-and-trade instruments have been considered. In practice, leakage from cap-and-trade systems can range from non-existent (lead phasedown) to potentially quite serious (RGGI). It is most likely to be significant for programs of limited geographic scope,[7] particularly in the power sector because of interconnected electricity markets (RGGI, AB32). Attempts to reduce leakage and competitiveness threats through free allocation of allowances *per se* does not address the problem (EU ETS), but an output-based updating allocation can do so (AB-32).

Carbon pricing (through cap-and-trade or taxes) may be necessary to address climate change, but it is surely not sufficient. Abatement costs can be reduced by complementary policies that address other market failures, such as principal-agent problems associated with energy-efficiency decisions in rental properties. But actual suites of so-called "complementary policies" that have emerged from political

[7] For this and other reasons, linkage between cap-and-trade systems and linkages with other types of policies in other jurisdictions is likely to become increasingly important in the future, because such linkage can reduce abatement costs, leakage, and price volatility, and can restrain market power (AB-32).

processes have instead addressed emissions under the cap, thereby relocating rather than reducing emissions, driving up abatement costs, and suppressing allowance prices (AB-32, EU ETS).

Key Lessons for Identifying New Applications

Cap-and-trade instruments are now considered for a wide range of environmental problems, ranging from endangered species preservation to global climate change. Experience can offer some guidance to the conditions under which such approaches are most likely to work well, and when they may face the greatest difficulties (Stavins 2007).

First, the more the cost of abating pollution differs among sources, the greater the cost savings a market-based system – whether cap-and-trade or tax – is likely to produce, relative to conventional regulations (Newell and Stavins 2003). For example, it was clear early on that SO_2 abatement cost heterogeneity was great, because of differences in ages of plants and their proximity to sources of low-sulfur coal (Carlson *et al.* 2000).

Second, the greater is the degree of mixing of pollutants in the receiving airshed (or watershed), the more attractive will a market-based system be, relative to a conventional uniform standard. Applications of cap-and-trade systems have been based either on the reality of uniformly-mixed pollutants (AB-32, EU ETS, RGGI) or the assumption of uniform mixing (lead phasedown, SO_2 allowance trading). In theory, with a non-uniformly mixed pollutant, a cap-and-trade system could lead to localized hot spots with relatively high levels of ambient concentrations raising distributional issues and potentially also efficiency issues. The problem can be addressed, in theory, through the use of ambient permits (Montgomery 1972), as illustrated by the two-zone trading system under RECLAIM, at the cost of greater complexity.

Third, since the seminal analysis by Weitzman (1974), it is well known that in the presence of cost uncertainty, the efficiency of a quantity-based (cap-and-trade) system relative to a price-based (tax) system depends on the pattern of costs and benefits. Subsequent literature has identified additional relevant considerations favoring one approach or the other (Stavins 1996; Newell and Pizer 2003). But perhaps more important, theory (Roberts and Spence 1976) and experience (RGGI, AB-32) have shown that there are efficiency advantages of hybrid systems that combine price and quantity instruments in the presence of uncertainty.

Fourth, under many circumstances, the equilibrium allowance distribution and hence aggregate abatement costs of a cap-and-trade system are independent of the initial allowance allocation (Montgomery 1972; Hahn and Stavins 2012). Hence, the allowance allocation decision can used to build political support and address equity issues without concern about effects on overall cost-effectiveness.

Implications for Climate Change Policy

Taken together, the lessons from thirty years of experience suggest that cap-and-trade merits serious consideration when regions, nations, or sub-national jurisdictions seek to develop policies to reduce GHG emissions. And, indeed, this has happened. But because any meaningful climate policy will have significant impacts on economic activity in many sectors and regions, it is not surprising that proposals for such policies bring forth significant opposition.

In the United States, political polarization has decimated both moderate Republicans and moderate Democrats (Schmalensee and Stavins 2013). Whereas Congressional debates about environmental and energy policy had long featured regional politics, they have become fully and simply partisan. The failure of cap-and-trade climate policy in the U.S. Senate in 2010 was essentially collateral damage from a much larger political war.

At the same time, as we noted above, political support has emerged around the world for employing cap-and-trade systems to address GHG emissions. In international climate negotiations leading up to the Paris conference in late 2015, many parties endorsed key roles for regional, national, and sub-national carbon markets, and broad recognition emerged of the importance of linkage among these systems.

It remains possible that three decades of high receptivity in the United States, Europe, and other parts of the world to cap-and-trade will turn out to be no more than a relatively brief departure from a long-term trend of reliance on conventional command and control regulation. But in light of the generally positive experience with cap-and-trade, we are inclined to the more optimistic view that the recent tarnishing of cap-and-trade in U.S. political discourse will itself turn out to be a temporary departure from a long-term trend of increasing reliance on market-based environmental policy instruments.

Table 1
Major Cap-and-Trade Experiences

System	Geographic Scope	Coverage & Sectors	Time Period	Allowance Allocation Method	Cost Containment Mechanisms	Environmental and Economic Performance
Leaded Gasoline Phasedown	USA	Gasoline from Refineries	1982-1987	Free	Banking	Phasedown completed successfully, faster than anticipated, with cost savings of $250 million/year
Sulfur Dioxide Allowance Trading	USA	SO_2 from Electric Power	1995-2010	Free	Banking	Cut SO_2 emissions by half, with cost savings of $1 billion/year; but market closed due to regulatory of judicial actions
Regional Clean Air Incentives Market (RECLAIM)	South Coast Air Quality Management District, CA	NO_x & SO_2 from Electric Power & Industrial Sources	1993-present	Free	---	Emissions lower than with parallel regulations; un-quantified cost savings; electricity crisis caused allowance price spike and temporary suspension of market
NOX Trading in the Eastern United States	12-21 U.S. States	NO_x from Electric Power & Industrial Sources	1999-2008	Free	---	Significant price volatility in first year; NO_x emissions declined from 1.9 (1990) to 0.5 million tons (2006); cost savings 40-47 percent
Regional Clean Air Incentives Market (RECLAIM)	South Coast Air Quality Management District, CA	NO_x & SO_2 from Electric Power & Industrial Sources	1993-present	Free	---	Emissions lower than with parallel regulations; un-quantified cost savings; electricity crisis caused allowance price spike and temporary suspension of market
Regional Greenhouse Gas Initiative	Nine northeastern U.S. States	CO_2 from Electric Power	2009-present	Nearly 100% Auction	Banking, Cost Containment Reserve, Auction Reservation Price	Cap non-binding then barely binding due to low natural gas prices; has generated more than $1 billion for participating states
AB-32 Cap-and-Trade	California, USA	CO_2 from Electric Power, Industrial, & Fuels	2013- 2020	Transitions from Free to Auction	Banking, Allowance Price Containment Reserve, Auction Reservation Price	Covers 85% of emissions; reduces competitiveness effects w/output-based updating (OBU) allocation; linked with Quebec cap-and-trade system
European Union Emissions Trading System	27 EU Member States plus Iceland, Lichtenstein, & Norway	CO_2 from Electric Power, Large Industrial, & Aviation	2005-2020	Transitions from Free to Increased Use of Auctions	Limited Banking, previous use of offsets from CDM	Over-allocation by member states in pilot phase; suppressed allowance prices due to "complementary policies," CDM glut, slow economic recovery

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